SECTION III

SUPPRESSION COMPONENTS

CHAPTER 13

CHEMICAL CONTROL

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INTRODUCTION

Historically, production of cotton in southern areas of the United States provided the main source of income for many farm families and was the economic impetus for entire farm communities. Insects occurred as occasional or sporadic pests; however, biological and climatic factors regulated their abundance to a large degree. When the boll weevil, *Anthonomus grandis grandis* Boheman, invaded United States cotton growing areas in 1892, spreading across the Cotton Belt in subsequent years, crop failure and economic disaster followed in its wake (Gaines, 1957).

Devastation of cotton by boll weevil populations provided the impetus for the development and widespread acceptance of chemical control of insect pests of cotton. Producers became heavily dependent on chemical means of control of insect pest outbreaks. As much as 40 percent of the insecticides produced in the United States was used on cotton (Newsom and Brazzel, 1968). Widespread use of insecticides resulted in secondary and occasional pests being elevated to primary pest status as they were released from their natural biotic control (Newsom and Smith, 1949; Reynolds, 1971;

Lincoln and Graves, 1978). In the western areas of the Cotton Belt, plant bug, *Lygus* spp., and spider mite, *Tetranychus* spp., outbreaks provided similar scenarios as did the boll weevil in the eastern areas of the Cotton Belt (Reynolds *et al.*, 1982).

Calcium arsenate was the first in a long line of chemicals that were registered, successfully used, and finally replaced because of diminishing performance. Seven different classes of synthetic insecticides have been developed for use on cotton: (a) inorganics or arsenicals; (b) organochlorines; (c) organophosphates; (d) carbamates; (e) formamidines; (f) pyrethroids; and (g) avermectins. Each class was phenomenally effective upon introduction. After several years of use, some of the products required tank-mixes with other materials to achieve control and finally, with the exception of the arsenicals (which are no longer used), formamidines and avermectins, lost effectiveness due to the build-up of resistance in one or more pest species. Fortunately, new classes of chemicals were developed and approved for use as materials in the former classes were losing effectiveness. This provided only temporary relief, however, as the cycle inevitably would repeat itself. The pyrethroids, one of the latest and most widely used classes to be developed, are now going through the initial stages of resistance development in bollworm, *Helicoverpa zea* (Boddie), and tobacco budworm, *Heliothis virescens* (F.), populations (Plapp and Campanhola, 1986; Leonard *et al.*, 1987, 1988; Luttrell *et al.*,1987). Resistance management strategies have been implemented in an attempt to delay further spread of resistance (Anonymous, 1986; Plapp *et al.*, 1987). There is, however, a desperate need for new chemistry to be developed for cotton insect control.

In addition to the seven classes of insecticides mentioned above, two novel types of insecticides, biologicals and insect growth regulators, also have been registered. The biologicals receiving registration consisted of the delta-endotoxin from the bacterium, *Bacillus thuringiensis*, sold under various trade names, and a nuclear polyhedrosis virus, Elcar®. Use of these materials met with limited success against moderate to high populations of bollworm/tobacco budworm. Commercial production of Elcar® has been discontinued because of lack of use. However, biological insecticides offer a wide area of opportunity as advances in biotechnology and genetic engineering occur.

Diflubenzuron (Dimilin®), an insect growth regulator, has been registered for control of boll weevil populations. It was proven to be effective against low levels of weevils emerging from overwintering sites when scheduled applications were made beginning when cotton initiated fruiting. Commercial success of this product for boll weevil control in cotton has been limited due to a prohibitive price structure and its incompatibility with current insect pest management systems. Most recently, it has been shown to provide good suppression of populations of beet armyworm, *Spodoptera exigua* (Hübner), in cotton (Herzog, unpublished data). Other insect growth regulator materials have been tested during the last few years. Some have shown promise, but none have been registered for use on cotton primarily because of fear of environmental effects on nontarget arthropods. Nevertheless, interest continues in this area of insect control.

Two classes of insecticides with new and unique modes of action are currently under development. They include a class called the pyrroles containing a compound with the proposed name of Pirate® and a class called the nitromethelene guanocycles which includes a material called imidacloprid with the proposed name of Admire®. Pirate® shows promise for control of a broad spectrum of insect pests in cotton, particularly lepidopterous larve. Admire® is a systemic insecticide that is extremely efficacious against a wide range of sucking insect pests.

With the current regulatory climate, increasing environmental awareness, the cost of registration of new chemicals and the high cost of reregistration of existing materials, new products are not being developed as rapidly as in the past. Additionally, during the last decade there has been a trend toward the reduction in the number of agricultural chemical industries that remain in business. This has occurred as a result of corporate mergers or from industries being purchased by other chemical companies. There appears to be a commensurate reduction in the testing and development of new insecticides. Thus, resistance to currently used insecticides poses an even greater threat to the viability of the cotton industry in the United States. Newsom and Brazzel (1968) stated that "there is evidence that populations of *Heliothis* spp. and *Tetranychus* spp. are becoming completely intractable to control by any currently available insecticide". Although new chemicals became available shortly thereafter, that threat still exists perhaps with even more certainty. Chemical control of insect pests in cotton still is the first line of defense against economic damage, but resistance remains the greatest threat to the demise of this highly effective tool. Borlaug (1972) stated that if pesticides were completely banned, crop losses would probably soar to 50 percent and food prices would increase four to five fold. The outlook appears similar if resistance to insecticides by major pests of cotton precludes control.

EVOLUTION OF CHEMICAL CONTROL

SOUTHEASTERN UNITED STATES

The production of cotton in the southeastern United States provided economic stability to the region during a long period of historical development. The establishment of the boll weevil, however, brought crop devastation and economic disaster to most of the cotton growing areas in this region.

Arsenicals — Calcium arsenate was first tested in 1916 and was found to effectively control the boll weevil, but profitability was diminished due to added production costs. As calcium arsenate was more widely used, the disruption of biotic control factors involved in regulation of other insect pests allowed secondary and occasional pests to be elevated to primary pest status. Cotton aphid, *Aphis gossypii* Glover, and bollworm/tobacco budworm outbreaks were common following the use of these inorganic insecticides. Cost of control became prohibitive in much of the area; thus, producers began searching for alternative crops. Alternatives such as peanuts, soybeans, vegetables and livestock increased in popularity thereby dramatically reducing the acreage planted to cotton.

Organochlorines — The introduction of the organochlorine insecticides ushered in a new era of cotton insect control. These broad spectrum materials were effective in controlling virtually all insect pest problems in cotton. These materials created a renewed interest in cotton production; however, it was found that costs for control were too high even in light of the unprecedented yields that were obtained. A major drawback to their use was the increased incidence of spider mite problems. Producers that continued to grow cotton found that, in view of the heavy pest infestation levels and the overlap of populations experienced in much of the southeastern United States, it was expedient to apply controls on a scheduled basis. This approach lead to extensive use of the available chemicals bringing about serious problems with resistance (Tippins and Beckham, 1962; Snow, 1965). By the late 1960s many of the organochlorine compounds were found to be ineffective against boll weevil and bollworm/tobacco budworm populations. A mixture of toxaphene-DDT was still used to some extent until the cancellation of DDT registration by the Environmental Protection Agency in 1972.

Organophosphates — The late 1950s and early 1960s ushered in the era of the extensive use of organophosphate insecticides. These materials provided excellent control of bollworm/tobacco budworm and boll weevil. The systemic nature of several of the organophosphates also afforded excellent control of plant bugs, spider mites and several species of thrips. A wide array of organophosphate products was developed. Many of them had a broad spectrum of activity, while others offered selective control of some pests.

The organophosphate compounds were not unlike their predecessors—resistance began to develop in several pest species to several products (Canerday, 1974; Sparks, 1981). However, the boll weevil appears to be an exception as it is currently as susceptible to methyl parathion (Metaphos®, Penncap-M®), malathion (Cythion®) and azinphosmethyl (Guthion®) as when these compounds were introduced over thirty years ago. The selection pressure being placed on this species by the Boll Weevil Eradication Program in the Southeast should reveal organophosphate resistance mechanisms—barring mutations—if they are present in the population. Nevertheless, after completion of the eradication program in over one million acres of cotton in six southeastern states, no indication of increased resistance or tolerance has been documented or even suspected.

Carbamates — Carbamate insecticides were introduced into the marketplace for cotton insect control beginning in the late 1950s with the registration of carbaryl (Sevin®). It took only about ten years for resistance to this compound to develop in bollworm/tobacco budworm populations (Sparks, 1981). Methomyl (Lannate®, Nudrin®) was introduced in the early 1970s. Although not effective against boll weevil, it provided broad spectrum activity against other cotton insect pests. It was particularly useful in the control of insecticide-tolerant armyworms, *Spodoptera* spp. The major drawback to its use was the reddening of cotton foliage that occurred when high rates or repeated applications were made. Methomyl was also found to be a very effective contact ovicide against bollworm/tobacco budworm eggs when used at low rates (Pitts and Pieters, 1980). Resistance to methomyl (Lannate®, Nudrin®) followed similar patterns to other materials (Sparks, 1981). Thiodicarb (Larvin®) was registered in the mid-1980s for use in cotton insect control. It has proven to be extremely effective against beet armyworm and fall armyworm, *Spodoptera frugiperda* (J. E. Smith), that are tolerant to most other insecticides. It also provides good control of bollworm/ tobacco budworm but is ineffective against the boll weevil. Low rates of thiodicarb have been shown to have contact ovicidal activity against bollworm/ tobacco budworm eggs.

Aldicarb (Temik®), a systemic carbamate insecticide, has been used extensively since the early 1970s as an in-furrow treatment at planting for the control of early season pests of cotton. It is particularly effective against thrips, aphids and spider mites in seedling cotton. It has been shown to control other insects, including boll weevil, when applied at high rates as a side-dress application (Hopkins and Taft, 1965). Resistance has not become a problem with this compound in target species.

Formamidines — A formamidine insecticide, chlordimeform (Fundal®, Galecron®) has been used extensively through the 1970s and 1980s. Its primary activity is as an ovicide against bollworm/tobacco budworm (Dittrich, 1967). It exhibits contact and vapor activity against eggs of this group of pests and has a unique adverse effect on adult moths (Phillips, 1971). It was also demonstrated that there is an adverse effect from chlordimeform residues on larvae infesting treated foliage (Treacy *et al*., 1987).

Plapp (1976) reported that chlordimeform synergized compounds against resistant bollworms/tobacco budworms. In fact, chlordimeform proved to be effective in the field when used against resistant tobacco budworms. Nevertheless, it was voluntarily removed from the market by the manufacturers following the 1989 crop year because of toxicological problems regarding safety to manufacturing employees. Several alternatives have received federal registration as ovicides for control of bollworm/tobacco budworm eggs, including another formamidine, amitraz (Ovasyn®), methomyl (Lannate®, Nudrin®), thiodicarb (Larvin®) and profenofos (Curacron®).

Pyrethroids — Pyrethroids were among the last groups of insecticides to be developed and marketed for control of insect pests of cotton. They were first used commercially in 1978 under FIFRA Section 18 emergency use program and have since gained widespread acceptance as the materials-of-choice for control of bollworm/tobacco budworm populations. Use rates of these materials is roughly one-tenth or less that of organophosphate or carbamate insecticides. One consideration in the use of these products is their propensity to induce secondary pest outbreaks. Outbreaks of spider mites, cotton aphids and western flower thrips, *Frankliniella occidentalis* (Pergande), frequently occur following pyrethroid applications. Pyrethroids have not been reliable materials for control of armyworms, *Spodoptera* spp., particularly larger larvae, in cotton. There appears to be a preadaptive tolerance to the pyrethroids in these species (Herzog, 1988).

The soybean looper, *Pseudoplusia includens* (Walker), has been a sporadic pest of cotton in the southernmost areas of the southeast United States during the 1980s and early 1990s. It was effectively controlled with applications of permethrin (Ambush®, Pounce®) until 1988 when resistance to these pyrethroids began to appear. A 22-fold level of resistance to permethrin was documented in this pest during 1988-1989 (Herzog, 1988) making permethrin virtually useless for control of this pest.

Recently, there has been considerable concern that pyrethroid resistance in tobacco budworm populations already identified in Arkansas, Louisiana, Mississippi and Texas—may be spreading to the Southeast. One cotton growing area of north Alabama reported unexplained difficulty in achieving control of tobacco budworm beginning in late 1987. Adult moth vial tests (Plapp *et al.*, 1987) indicated that some resistant individuals may have been present in that population (Herzog, 1988). Standard laboratory bioassays using topical application on bollworm/tobacco budworm larvae indicate no change in pyrethroid susceptibility in either species in Georgia (Herzog *et al.*, 1987). There have been no reports of unexplained field failures in other areas of the Southeast.

The loss of these valuable compounds to resistance would certainly be a critical setback to cotton production in the Southeast. Cotton acreage in this region has experienced a steady increase over the last several years. This expansion may be attributed, in part, to the dependable control provided by the pyrethroids. Resistance, at least at some level, appears to be inevitable.

The success of the Boll Weevil Eradication Program in elimination of the boll weevil in much of the southeastern United States has provided significant opportunities for the return to a more biologically-based system of insect pest management. There has been a dramatic reduction in the amount of insecticide used in areas where sprays for boll weevils are not required. Natural enemies of pest species are more able to regulate populations to at least some extent reducing the number of insecticide applications appreciably. This reduction in insecticide use may delay pyrethroid resistance, however, the increased acreage of cotton with the accompanying exposure of a greater proportion of the tobacco budworm population to these compounds may portend a more rapid development of pyrethroid resistance.

MID-SOUTH AND SOUTHWEST UNITED STATES

Until the boll weevil entered the United States in 1892, only the cotton leafworm, *Alabama argillacea* (Hübner), cotton aphid and bollworm/tobacco budworm were recognized as occasional pests of cotton in the Mid-South and Southwest United States (Newsom and Brazzel, 1968). The boll weevil became a perennial pest of cotton (Metcalf and Luckmann, 1975) since populations exceeding recognized economic thresholds usually occurred annually due to insufficient natural control from climatic and biotic factors. In 1918, Coad demonstrated for the first time that a chemical, calcium arsenate, could be used to effectively control the boll weevil. The widespread use of calcium arsenate from the 1920s through the mid-1940s resulted in the cotton aphid and bollworm/tobacco budworm becoming severe pests (Lincoln and Graves, 1978).

The advent of DDT and other organochlorines in the mid- to late-1940s revolutionized cotton insect pest control since they exhibited a broad spectrum of activity against practically all arthropod pests. However, most organochlorines induced spider mite outbreaks. Development of insecticide and acaricide resistance in numerous arthropods, resurgence of arthropod pests following pesticide applications, and induced arthropod pest problems resulted in rapid shifts to new pesticide chemistry as it became available.

Use of organophosphates and carbamates became widespread in the late 1950s and continues to the present. However, the pyrethroids, which became available in 1978 are now being used extensively for control of bollworm/tobacco budworm, boll weevils and other insect pests of cotton. Outbreaks of cotton aphids, spider mites and western flower thrips have been associated with the use of pyrethroids. Other classes of insecticides useful in managing arthropod pest populations on cotton are formamidines (chlordimeform [Fundal®, Galecron®]) and insect growth regulators such as diflubenzuron (Dimilin®).

Arsenicals — Prior to Coad's (1918) demonstration that calcium arsenate could be effectively and economically used to manage boll weevil populations, there was no appreciable use of insecticides on cotton in the Mid-South or Southwest United States. During this period producers relied mainly on cultural and biological approaches, but they proved to be unreliable and inadequate.

From the early 1920s until the mid-1940s, calcium arsenate was used extensively for boll weevil control. Early recommendations for its use followed modern concepts of insect pest management. Emphasis was placed on cultural controls with calcium arsenate to be used only after other methods had failed. Dusting was recommended when 10 to 15 percent of the cotton squares were damaged (Hunter and Coad, 1923; Isely and Baerg, 1924); however, the treatment level later was increased to 25 percent in the Mississippi Delta (Gaines, 1944). Isely found that automatic early-season applications of calcium arsenate failed to control boll weevils effectively or increase yields; whereas, scouting and treating as needed proved quite effective (Isely and Baerg, 1924). Isely (1926) also introduced spot-dusting for control of emerging first-generation adults. From the early work of Isely, an insect pest management system was developed, its major components being scouting, spot dusting and early maturity of the cotton crop (Lincoln *et al.*, 1975).

Repeated applications of calcium arsenate, which were necessary in areas of heavy boll weevil pressure, usually induced cotton aphid outbreaks. Folsum (1928), Smith and Fontenot (1942) and Isely (1946) reported that these aphid outbreaks resulted from the detrimental effects of calcium arsenate on the biological control system that ordinarily controlled this insect. Furthermore, disruption of the biological control system plus the abundance of honeydew (from aphids) as a food source for adults of bollworm/tobacco budworm often led to outbreaks of these species (Lincoln and Graves, 1978). Nicotine, a plant product insecticide, was used to control aphids, but control of bollworm/tobacco budworm with available insecticides was virtually impossible. Meanwhile, the widespread use of calcium arsenate greatly reduced the pest status of the cotton leafworm.

Organochlorines — The advent of DDT and other organochlorines beginning in the mid-1940s revolutionized cotton insect pest control. These broad spectrum and relatively long residual insecticides were so effective against boll weevils; bollworms/tobacco budworms; aphids; cotton leafworms; thrips (primarily tobacco thrips, *Frankliniella fusca* [Hinds]); tarnished plant bugs, *Lygus lineolaris* (Palisot de Beauvois); cotton fleahoppers, *Pseudatomoscelis seriatus* (Reuter); and, other occasional pests of cotton that yields resulting from their use approximately doubled that obtained with calcium arsenate and other inorganic insecticides (Newsom and Brazzel, 1968).

DDT was the first truly effective insecticide for control of bollworm/tobacco budworm. DDT was soon followed by BHC, dieldrin, endrin and toxaphene, which were shown to be highly efficacious against boll weevils and most other cotton insect pests (Anonymous, 1947-71). Unfortunately, use of organochlorines released spider mites from their biological control agents and outbreaks became widespread (Anonymous, 1947-71; Boyer and Bell, 1961). Thus, mixtures of insecticides, including sulfur to suppress spider mites, were commonly used to control the insect pest complex attacking cotton, (Lincoln and Graves, 1978).

Because of their effectiveness, many cotton producers began to use the organochlorines on a preventative basis rather than when economic thresholds were exceeded (Lincoln and Graves, 1978). This "automatic" system, which was based on a fixed schedule of applications, was successful in its primary objectives of controlling insect pests and increasing cotton yields. However, subsequent problems of environmental pollution by the long-residual organochlorines and development of resistance to organochlorines by several cotton insect pests dictated a return to cotton insect pest management systems based on scouting, economic thresholds and timing of insecticide applications.

The boll weevil developed resistance to such organochlorines as BHC, toxaphene, endrin and dieldrin in less than a decade after their introduction (Roussel and Clower, 1957). Though first documented in Louisiana (Roussel and Clower, 1957), resistance to organochlorines developed rapidly throughout the range of the boll weevil (Graves and Roussel, 1962; Brazzel and Shipp, 1962; Tippins and Beckham, 1962). Nevertheless, mixtures of toxaphene and DDT still effectively controlled weevils even though weevils were resistant to toxaphene alone or DDT alone. Also, calcium arsenate again was used to effectively control boll weevils.

Other species of cotton insect pests also developed resistance to organochlorines. Resistance to DDT in the tobacco budworm occurred in Texas in 1961 (Brazzel, 1963) and soon was reported from across the Cotton Belt (Graves *et al*., 1964, 1967; Pate and Brazzel, 1964; Snow, 1965; Lingren and Bryan, 1965; Harris, 1970). Graves *et al*. (1963) first reported organochlorine resistance in bollworms from Louisiana. Resistance to DDT and other organochlorines in the bollworm was soon reported from across the Cotton Belt (Graves *et al*., 1963, 1964; Lincoln *et al*., 1967; Brazzel, 1964; Snow, 1965; Lingren and Bryan, 1965). As with the boll weevil, mixtures of toxaphene and DDT remained effective against DDT-resistant bollworms/tobacco budworms. However, the removal of the DDT registration on cotton by the United States

Environmental Protection Agency in 1972 not only ended the use of the toxaphene-DDT mixture, but also signalled an end to the organochlorine era.

Organophosphates — Organophosphate insecticides were first developed in the late 1940s and early 1950s. Parathion was recommended for emergency use on cotton in 1951. Also TEPP (tetraethyl pyrophosphate) was recommended for aphid control in 1951. By the mid-1950s several compounds (malathion [Cythion®], demeton [Systox®, Metasystox®], methyl parathion and EPN) were registered on cotton and exhibited broad spectrum activity against most arthropod pests. Malathion and methyl parathion remain highly effective today on the boll weevil. In 1958, carbophenothion (Trithion®) was registered for control of cotton aphids and spider mites. During 1959, naled (Dibrom®), trichlorfon (Dylox®) and ethyl parathion were used to control several cotton pests. Ethyl parathion was used to control a wide variety of pests including organochlorine resistant bollworm/tobacco budworm populations.

Methyl parathion was recommended for bollworm/tobacco budworm control in the early 1960s. Shortly thereafter methyl parathion was mixed with endrin, carbaryl (Sevin®), strobane (Strobane®) and DDT for bollworm/tobacco budworm control. In 1962, phosphamidon (Swat®) was shown to provide effective control of cotton aphids, tarnished plant bugs and other mirids (small plant bugs that feed mainly on plant juices). Dicrotophos (Bidrin®), recommended in 1963, gave excellent control of cotton fleahoppers, cotton aphids, spider mites and tarnished plant bugs. Azinphosmethyl (Guthion®) was recommended in the mid-1960s for control of boll weevils, aphids, thrips and armyworms. Azinphosmethyl (Guthion®) still remains very effective against boll weevils. In the mid-1960s, dimethoate (Cygon®) and dicrotophos (Bidrin®) were used to control *Lygus* spp., cotton fleahoppers and thrips. Both are still recommended for the control of early season pests of cotton (except for spider mites). Monocrotophos (Azodrin®) was also registered during the mid-1960s for control of: boll weevils; bollworms/tobacco budworms; cabbage loopers, *Trichoplusia ni* (Hübner); cotton aphids; cotton fleahoppers; tarnished plant bugs; thrips; and spider mites. Monocrotophos (Azodrin®) was recommended for control of the majority of these pests but was voluntarily removed from the market by the manufacturer following the 1989 growing season.

In 1969 the bollworm began to develop resistance to methyl parathion in Arkansas and Oklahoma. During the early 1970s bollworm/tobacco budworm populations began to develop resistance to most recommended organophosphates used alone (Lukefahr, 1970). At that time several mixtures of organophosphates were used on populations that were difficult to control. Among these were: EPN + methyl parathion; EPN + methyl parathion + methomyl (Lannate®, Nudrin®); toxaphene + methyl parathion + chlorpyrifos (Lorsban®); and, EPN + methyl parathion + chlorpyrifos (Lorsban®). These mixtures provided effective control for several years.

Acephate (Orthene®) was registered for use in the mid-1970s for control of bollworms/tobacco budworms as well as loopers, cotton aphids, cotton fleahoppers, tarnished plant bugs and the bandedwinged whitefly, *Trialeurodes abutilonea* (Haldeman). Also during the late 1970s and early 1980s, sulprofos (Bolstar®) and profenofos (Curacron®) were registered for control of the bollworm/tobacco budworm and armyworm complexes.

Several organophosphate insecticides including disulfoton (Di-Syston®), phorate (Thimet®) and acephate (Orthene®) are recommended as seed treatments or in-furrow applications at planting for systemic control of thrips in seedling cotton.

The development of resistance in bollworm/tobacco budworm populations to organochlorines (Brazzel, 1963) made it necessary to rely on organophosphate insecticides for control (Adkisson, 1968). However, as early as 1970, Cantu and Wolfenbarger (1970) recommended that insecticides with different modes of chemistry were needed because of resistance to methyl parathion and monocrotophos (Azodrin®) that was found in larvae of the tobacco budworm collected in the Mante-Tampico, Mexico area and at Brownsville, Texas. Also, Whitten and Bull (1970) reported the tobacco budworm to be resistant to organophosphate insecticides. Plapp (1972) recognized that bollworm/tobacco budworm were becoming resistant to methyl parathion and immediately began looking for alternative insecticides. He reported that chlordimeform (Fundal®, Galecron®) worked as a synergist with many insecticides to control resistant populations of tobacco budworm (Plapp, 1976). Watve *et al.* (1977) reported high levels of resistance in bandedwinged whitefly to methyl parathion and monocrotophos (Azodrin®). However, Bottrell *et al.* (1973) reported that the boll weevil had failed to develop resistance to malathion (Cythion®) after several years of exposure.

Carbamates — Carbaryl (Sevin®) was the first of the carbamate insecticides to be recommended for use in the control of insect pests of cotton. By 1958 it was recommended for the control of boll weevils, bollworms/tobacco budworms and plant bugs. About ten years later the bollworm showed signs of resistance to this compound in Texas (Adkisson and Nemec, 1966) and Louisiana (Graves *et al.*, 1964). Methomyl (Lannate®, Nudrin®) was recommended for control of bollworms/tobacco budworms and plant bugs in the early 1970s. Methomyl-resistant bollworm/tobacco budworm larvae were found, however, in Louisiana (Clower, 1980) and Mississippi (Furr, 1978) as early as 1976. Carbofuran (Furadan®) showed promise as an in-furrow treatment for controlling tarnished plant bugs, cotton fleahoppers, bandedwinged whiteflies and thrips. Aldicarb (Temik®), used at high rates, was shown to control overwintering boll weevils (Hopkins and Taft, 1965; Bariola *et al.*, 1971). However, researchers reported that increases in bollworm/tobacco budworm populations occured following use of aldicarb at high rates, one to two pounds of active ingredient per acre (Cowan *et al.*, 1966; Coppedge *et al.*, 1969). Scott *et al.* (1985) reported little effect on total predator populations and no increase of bollworm/ tobacco budworm infestations when aldicarb was used at 0.25-0.5 pounds active ingredient per acre. Aldicarb currently is used widely across the Cotton Belt to control early-season pests in cotton. Oxamyl (Vydate®) was registered on cotton for control of several insect pests in the late 1970s but has not been widely used. Thiodicarb (Larvin®) was registered in the mid-1980s for cotton insect control. It has been especially effective against armyworms *Spodoptera* spp.; it provides good control of bollworm/tobacco budworm eggs and larvae; but, it is ineffective against the boll weevil.

Pyrethroids — Natural pyrethrins and early pyrethroids were recognized as excellent insecticides with a broad spectrum of activity against insects but relatively harmless to mammals (Barthel, 1961; Elliott, 1971). However, they were too unstable and expensive to efficaciously control pests of agricultural crops such as cotton (Elliott, 1976). Once permethrin was synthesized in 1972, pyrethroids which were photostable enough to be used on cotton and other agricultural crops started to become available (Elliott's *et al.*, 1973). Although pyrethroids exhibit a broad spectrum of activity against practically all cotton insects, they are especially toxic to the bollworm and tobacco budworm. For example, permethrin is approximately ten times more toxic to these pests than organophosphates and carbamates.

Pyrethroids became available for field use under a large-scale Section 18 program in 1977-1978. Conditional registration was granted in 1979 and they quickly became the insecticide of choice for controlling cotton insect pests, particularly the tobacco budworm, which had developed high levels of resistance to most organochlorines, organophosphates and carbamates (Clower, 1980). To reduce their usage and thus lessen the possibility of resistance development, pyrethroids usually were recommended only for control of the bollworm/tobacco budworm, although they were quite effective against boll weevil, tarnished plant bugs, cotton fleahoppers, cutworms and most species of thrips. Conversely, pyrethroids generally exacerbate aphid, spider mite and western flower thrips problems.

Pyrethroids became the most widely used insecticides on cotton during the early 1980s and remain so today. However, the development of problem levels of resistance to pyrethroids by the tobacco budworm in some locations in Texas in 1985 and in Texas, Arkansas, Louisiana and Mississippi during 1986 (Leonard *et al.*, 1987, 1988; Plapp *et al.*, 1987; Roush and Luttrell, 1987) threatens their continued usefulness. In response to the pyrethroid resistance problem in tobacco budworm, state and federal research and extension entomologists from Arkansas, Louisiana and Mississippi adopted and recommended a pyrethroid resistance management plan (Anonymous, 1986). This plan was widely accepted by cotton producers in the Mid-South and resistance monitoring data for 1987 indicates that resistant genotypes of tobacco budworm were reduced about 50 percent in Louisiana (Graves *et al.*, 1988a, 1988b).

Pyrethroid resistance problems in tobacco budworm have continued to increase through much of the Mid-South and Southwest United States. A number of field control failures using pyrethroids against tobacco budworm have been reported as a result of this resistance. This has made it necessary for growers to use tank-mixtures with other classes of chemistry or to switch to other classes altogether (Leonard *et al.*, 1993).

WESTERN UNITED STATES

Evolution of insecticidal control of pest insects in cotton grown in the irrigated deserts of the western United States followed a pattern similar to that in the southern and southeastern United States, except that the pest control scheme was dominated by the western lygus bug, *Lygus hesperus* Knight, and the bollworm (Reynolds *et al.*, 1982). More recently insecticide usage in cotton has been dictated by: (a) the pink bollworm, *Pectinophora gossypiella* (Saunders), which completed its spread across Arizona and southern California in 1965 (Noble, 1969); (b) the tobacco budworm beginning in 1972 in Arizona and subsequently into southern California (Watson, 1974); (c) the boll weevil in various parts of Arizona and southern desert valleys of California beginning in 1978 (Bergman *et al*., 1982; Watson *et al*., 1986a); and most recently by (d) the sweetpotato whitefly, *Bemisia tabaci* (Gennadius) (Henneberry, 1993).

Prior to the establishment of the pink bollworm, insecticide treatments were generally initiated for control of lygus bugs and occasionally for control of the bollworm. Since 1966, when control of the pink bollworm required scheduled applications of insecticides, secondary pest outbreaks have occurred including the cotton leafperforator, *Bucculatrix thurberiella* (Busck), sweetpotato whitefly, and spider mites. Little insecticide was used in western cotton prior to the mid-1940s when the organochlorines became available. DDT and other organochlorines dominated the scene for the next two decades, ultimately being replaced by the organophosphates and carbamates beginning in the late 1950s and continuing to the mid-1970s, and then the pyrethroids in the late 1970s.

Organochlorines — DDT was first used experimentally in Arizona in 1943 and 1944; its first commercial use occurred in 1945, primarily against *Lygus* spp. (Ware, 1974). Subsequent outbreaks of other species such as the beet armyworm and saltmarsh caterpillar, *Estigmene acrea* (Drury), were also effectively controlled by DDT and other organochlorines (Ware, 1974). Because of severe insecticide-induced problems with secondary pests, developing in southern California in the late 1950s, the broad spectrum organochlorine insecticides were phased out in favor of a simple system of integrated pest control (Reynolds *et al*., 1982). This system was centered on: (a) conserving the natural enemies of the target insect pest and secondary pest species and (b) using selective dosages of selected organophosphate insecticides.

During the mid-1950s, additional problems with organochlorine insecticides were beginning to surface. DDT was losing its effectiveness against the pests which were of greatest economic importance. Western lygus bugs could no longer be controlled with DDT in the San Joaquin Valley of California (Leigh, 1969). By 1966 the bollworm had become nine-fold more tolerant to DDT in Maricopa County, Arizona, than in the generally untreated area of Cochise County (Fadare, 1967).

In 1968, the United States Food and Drug Administration placed an embargo on 50,000 pounds of butter shipped from Arizona to California because of DDT residues present in amounts over the legal tolerance; in the same year, the University of Arizona Department of Entomology removed DDT from all of its agricultural pest control recommendations with the sole objective of reducing DDT residues in food and feed crops (Ware, 1974). This, of course, did not eliminate the use of DDT but paved the way for a one-year ban placed on its use in 1969 by the Arizona Board of Pesticide Control. This was repeated in 1970, 1971 and 1972. A federal ban on the use of DDT on cotton was declared by the United States Environmental Protection Agency, effective January 1, 1973 (Ware, 1974).

Organophosphates — The organophosphates, especially methyl parathion, were effective against bollworm and tobacco budworm in the western areas of the cotton growing region of the United States up to 1972. However, following the serious outbreak of tobacco budworm in 1972, it was found that these materials were becoming ineffective (Lentz *et al.*, 1974). During the tobacco budworm outbreak years of 1976-78, methyl parathion became virtually useless (Watson *et al.*, 1986b). The organophosphates, particularly methyl parathion and azinphosmethyl (Guthion®) were very effective against the key pest, the pink bollworm. Cotton leafperforators became an increasingly serious problem during this time as they became resistant to organophosphates and problems were in fact exacerbated by their use.

The boll weevil required insecticidal control measures in some areas of Arizona prior to the eradication effort in that area. Several organophosphate insecticides, such as methyl parathion, azinphosmethyl (Guthion®), malathion and encapsulated methyl parathion (Penncap-M®), as well as some of the pyrethroids, still effectively control the boll weevil. However, applications must be made at shorter intervals and for a much longer part of the growing season than for other pests. This results in excessively high control costs and the development of additional secondary pest problems.

Carbamates — During the early 1970s the introduction of the carbamate methomyl (Lannate®, Nudrin®) provided much needed relief for control of the resistant cotton leafperforator, a serious secondary pest caused by the use of organophosphate insecticides. Methomyl was also quite effective against tobacco budworm until the outbreak years of 1976-78 at which time resistance rendered it virtually useless.

Pyrethroids — During the tobacco budworm outbreak years of 1976-78, the pyrethroid insecticides were being developed and by 1979 had gained conditional federal registration. This group of insecticides had broad-spectrum activity and was extremely effective against the pink bollworm and tobacco budworm. Because of the need to conserve these materials for use against the bollworm/tobacco budworm complex, growers were cautioned against using them to control pests for which other effective materials were available. Specifically, they were encouraged to continue using the organophosphates for pink bollworm control.

During the next decade much of the chemical control of cotton pests in the West involved the use of pyrethroids, with the exception of the San Joaquin Valley of California. The result has been the development of higher levels of tolerance in certain localized populations of the pink bollworm (Miller, 1987). Additionally, a laboratory study in Arizona has shown that selective pressure on tobacco budworm at the LD_{80}[1] level will result in high levels of resistance after only twelve generations (Jensen *et al.*, 1984).

Because of increased spider mite populations following the use of pyrethroids, these materials are not recommended in California's San Joaquin Valley. In southern California and Arizona, there also is an association between sweetpotato whitefly outbreaks and the use of pyrethroids. Few effective materials are currently available for spider mite control and no really satisfactory insecticide is currently registered for sweetpotato whitefly control.

[1]LD80 is the dosage level which is lethal to 80 percent of the treated individuals.

In the highly fragile agroecosystem of the San Joaquin Valley, the western lygus bug is the key to the insect pest management program. Insecticide applications for lygus control can trigger outbreaks of bollworm/tobacco budworm, beet armyworm, cabbage looper and spider mites. Careful timing of insecticide applications and utilization of higher economic thresholds help prevent outbreaks of these secondary pests. This results in fewer insecticide applications in the San Joaquin Valley than in the lower desert areas of southern California and Arizona.

The sweetpotato whitefly has become an extremely serious pest problem not only in cotton but in a variety of other crops in the southwestern United States since the B-Strain became the predominant biotype (Henneberry, 1993; Henneberry and Toscano, 1993). Management and insecticidal control of this pest is extremely difficult because of: (a) its tolerance to most pesticides; (b) its wide and diverse host range; and (c) its biotic potential.

Several combinations of insecticides have shown promise for control of the sweetpotato whitefly provided that populations do not reach high levels before control programs are initiated. Fortunately, from the standpoint of insecticide resistance management, several classes of insecticides are included among those that are useful for control of sweetpotato whitefly. The materials that have shown the greatest activity against the whitefly include: (a) the pyrethroids–Capture® and Danitol®; (b) the organochlorine–endosulfan (Thiodan®, Phaser®); (c) the formamidine–amitraz (Ovasyn®); and (d) several organophosphates including Orthene® and Monitor®. Additionally, an insect growth regulator, buprofezin (Applaud®), and a systemic insecticide, imidacloprid, NTN-33893 (Admire® [proposed] have shown promise for sweetpotato whitefly control, however, it may be several years before their use is approved by the Environmental Protection Agency.

RELATIVE EFFICACY

Pesticide efficacy in relation to cotton pest control may be defined as "the ability of a compound, when applied to the crop, to reduce or eliminate the capability of a pest to cause crop damage". For purposes of this discussion, this is interpreted as resulting from pesticide-induced mortality or some other direct effect on the pest population.

There is no universal index of relative efficacy of insecticides. Labelling information required by state and federal agencies may be used to indicate general efficacy of a compound, at least at the time of registration (Table 1). However, because of the dynamic nature of insecticide efficacy in relation to individual pest species, label recommendations may not always reflect reality. Pesticide effectiveness is dependent upon a number of factors including: (a) the susceptibility of the pest species to the compound; (b) the density of insects per unit area; (c) the concentration of resistant genotypes in the population; (d) the type of resistance demonstrated in the population; (e) weather factors; (f) method of application; (g) timing of the pesticide application in relation to life stage of the target pest or time of day; (h) pH of the insecticide spray solution; (i) crop canopy density; (j) age of the plants; (k) plant uptake and transport; (l) pest behavior, and many other factors.

Table 1. Insecticides and acaricides fully registered for control (C) or suppression (S) of cotton arthropod pests as derived from actual labels or labels printed in Crop Protection and Chemicals Reference as of January 1993.

Insecticide/acaricide common name		Class	Cotton leafperforator	European corn borer	Yellowstriped armyworm	Beet armyworm	Fall armyworm	Tobacco budworm	Bollworm	Pink Bollworm	Cutworm	Cabbage looper	Saltmarsh caterpillar	Cotton leafworm	Boll weevil	Thrips*	Cotton aphid	Stink bug	Lygus bugs	Cotton fleahopper	Spider mites	Whiteflies**	Grasshoppers
Bacillus thuringiensis†	I	BIO	C		C	C	C	C	C		C	C											
Aldicarb	Sy	CAR	C												C	C	C		C	C	C	C	
Carbaryl	Ct	CAR	C		C		C		C	C	C			C	C	C	S	C	C	C			
Carbofuran	Ct,Sy	CAR														C							
Methomyl	Ct	CAR	C			C	C	C	C					C		C	C		C	C			
Oxamyl	Ct	CAR	C												C				C	C			
Thiodicarb	Ct,I	CAR	C		C	C	C	C	C	S	C	C		C	S				S	S			
Amitraz	Ct,F	FOR						C	C	C											C	C	
Diflubenzuron	Ct,I	IGR				C	C								C								
Dicofol	Ct	OCL																			C		
Endosulfan	Ct	OCL	C						C			C			C	C	C	C	C				
Acephate	Ct,Sy	OP			C		C	C	C	C	C	C				C	C	C	C	C		C	
Azinphosmethyl	Ct	OP							C	C				C	C	C		C	C	C			
Chlorpyrifos	Ct	OP			C	C	C	C	C	C	C		C		C	C	C		C	C	C		C
Dicrotophos	Ct,Sy	OP	C										C		C	C	C	C	C	C	C		C
Dimethoate	Ct,Sy	OP														C	C		C	C	C		
Disulfoton	Sy	OP														C	C				C		
Phosphamidon	Sy	OP														C	C		C	C			
Malathion	Ct	OP													C	C	C		C	C			C
Oxydemeton-methyl	Sy	OP														C	C		C	C	C		
Methamidophos	Ct,Sy	OP				C						C				C	C	C	C	C	C	C	
Methidathion	Ct	OP							C	C					C				C		C	C	
Methyl parathion	Ct	OP						C	C						C	C			C	C			
Naled	Ct,F	OP	C		C				C			C							C	C	S		
Phorate	Sy	OP									C					C	C				C	C	
Phosmet	Ct	OP													C							C	
Profenofos	Ct	OP	C			C	C	C	C								C		C		C	S	
Sulprofos	Ct	OP				C	C	C	C	C						C		C	C	C	S	S	
Trichlorphon	Ct,Sy	OP	C		C	C							C	C				C	C	C			
Bifenthrin	Ct	PY	C	C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	
Cyfluthrin	Ct	PY	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		S	C
Cypermethrin	Ct	PY	C		C	C	C	C	C	C	C	C	C		C	C	S		C	C		S	
Esfenvalerate	Ct	PY	C			C		C	C	C	C	C	C	C	C	C			C	C		S	C
Lambdacyhalothrin	Ct	PY	C	C		C	C	C	C	C	C	C	C	C	C	C	S	C	C	C	S	S	
Permethrin	Ct	PY	C			C		C	C	C	C	C	C				S		C	C		S	
Tralomethrin	Ct	PY	C			C	C	C	C	C	C	C	C	C	C	C	S	C	C	C	S	S	
Zetacypermethrin	Ct	PY	C	[illegible]	C	C	C	C	C	C	C	C	C			C	S		C	C		S	

Key: BIO - biological, CAR - carbamate, FOR - formamidine, IGR - insect growth regulator, OCL - organochlorine, OP - organophosphate, PY - pyrethroid, Ct - contact, Sy - systemic, I - ingestion, F - fumigant

*Western flower thrips are suppressed by only a few systemic insecticides.

**There is no effective compound for sweetpotato whitefly control in Arizona & California.

†All current commercial products of *Bacillus thuringiensis* used in cotton include vars. Kurstaki, Aizawai, or a combination of the two.

Pesticide efficacy may be affected by previous use or misuse of insecticides which may induce pest resistance to the pesticide of choice (cross resistance). By the 1960s resistance to at least one insecticide was noted for every major cotton insect pest (Brazzel and Wilson, 1967). Insecticide efficacy for a specific compound and pest may vary among geographical areas. Factors that contribute to these variations include weather differences, differences in the pest insect gene pool caused by previous insecticide use, immigration of insects (gene flow) or other reasons. In addition, insecticides may stimulate the development of secondary pest populations by reducing natural control agents. Thus aphid and whitefly populations may increase drastically following repeated pyrethroid applications, and spider mite populations may build following applications of organophosphate or pyrethroid compounds.

Relative efficacy is related to the mode of entry of the insecticide into the insect—by contact, stomach (ingestion) or fumigant action. Insecticides which are taken into the plant's vascular system, and hence by feeding into the insect, are classified as systemic insecticides. In general, insects with a piercing-sucking method of feeding are best controlled by systemic insecticides. This is particularly true of aphids, spider mites, whiteflies and thrips which typically inhabit the abaxial (lower) leaf surface where deposition of insecticide by standard spraying systems is minimal. Usually, lepidopterous larvae which attack cotton fruit are controlled best with contact poisons that are transported through the insect integument (exoskeleton or enveloping layer) either when the spray falls on the insect or the insect contacts chemical residue on the plant's surface during movement. Leaf feeding insects are usually more susceptible to stomach poisons than insects which feed on more protected areas of the plant where there is less insecticide deposited. The fumigant activity of most insecticides is negligible and generally does not contribute much to efficacy of cotton insecticides. A notable exception is chlordimeform (Fundal®, Galecron®) which provides ovicidal activity in the vapor phase (Dittrich, 1967; Phillips, 1971) and affects mating behavior and fecundity (the ability to lay eggs and thus reproduce) of adult moths (Phillips, 1971).

Insecticide efficacy is also related to mode of action. In general, organophosphates and carbamates function as acetyl cholinesterase inhibitors, while pyrethroids function by altering ion permeability of nerve axons in a manner similar to that of early organochlorines. Endosulfan (Thiodan®, Phaser®), an organochlorine currently labelled for control of some cotton insects, blocks inhibitory nerve synapses. Insect growth regulators, pathogens and other biological or pseudobiological compounds used as insecticides function in various ways, many against specific insects or related groups of insects. For a more indepth discussion of mode of action of specific types of insecticides, readers are referred to Chapter 8 of this book.

Pyrethroids and organophosphates are the primary insecticides used on cotton. According to Luttrell and Reed (1986), field tests over a period of ten years indicate that control of larvae of the tobacco budworm and the bollworm collectively was significantly better with pyrethroids than organophosphates, and control of boll weevil, spider mites and aphids was significantly better with the organophosphates than with pyrethroids. Clower *et al.* (1987) reported that, over a period of several years throughout the Cotton Belt, pyrethroids were slightly more efficacious than carbamates or organophosphates for the control of bollworm/tobacco budworm.

The bollworm/tobacco budworm complex aptly demonstrates the difficulty in adequate insecticide efficacy evaluation. The larvae of the two species are so similar that identification in the field is difficult and reports of insecticide efficacy have generally referred to the population as a whole, rather than to populations of separate species. Because of the development of resistance in tobacco budworm larvae, the control of this species with pyrethroids is decreasing in the Arkansas, Louisiana, Mississippi and Texas. This continual decline in efficacy for control of larvae of the bollworm/tobacco budworm complex by two pyrethroids as used in several states from 1980 to 1986 is demonstrated in Figure 1. An increase in tobacco budworm resistance in 1986 (Leonard *et al*., 1987; Luttrell *et al*., 1987; Roush and Luttrell, 1987; Plapp *et al*., 1987) may explain the drastic drop in efficacy of pyrethroids that year, 1986. In Mississippi, the percentage of field-collected bollworm/tobacco budworm eggs which developed into tobacco budworm was low in 1984 and 1985 (Pfrimmer, 1986). In Mississippi and Louisiana, the portion of adult pheromone-trapped male bollworm/tobacco budworm which were tobacco budworm also was low in 1984 and 1985 (Personal communication, E. A. Stadelbacher, retired, Greenville, Mississippi; Leonard, *et al*., 1989) . If this trend was true in the rest of the Mid-South and Southwest United States, the increase in efficacy of the two pyrethroids during those years may be related to higher bollworm populations and lower tobacco budworm numbers. Stadelbacher (1979) ascribes a reversal in species dominance of these insects prior to 1979 to development of higher levels of resistance to insecticides in tobacco budworm than in the bollworm population. He attributes the general increase in tobacco budworm density to increased acreage of wild geranium, *Geranium dissectum* L. Thus, species identification, population densities, wild host availability and prior insecticide use all have played roles in efficacy evaluation for insecticides used to control bollworm/tobacco budworm larvae.

The relative efficacy of compounds used against resistant populations may be augmented or synergized by addition of other compounds. Field tests summarized over a period of several years indicate that pyrethroids, at one-half the recommended rate in combination with chlordimeform (Fundal®, Galecron®) at low rates, performed as well against bollworm/tobacco budworm as pyrethroids alone at full recommended rates (Luttrell and Reed, 1986). In addition to synergistic applications, compound mixtures may allow for concurrent control of secondary pests or as partial insurance against development of resistance.

When insecticide resistance has occurred, changing to a compound with a different mode of action has usually circumvented the problem. Thus control of boll weevil changed from organochlorine compounds to organophosphates in most areas. Similarly, the cotton leafperforator in the western United States developed resistance to organophosphates used for control of pink bollworm and was elevated from a minor pest to a primary pest. Introduction of chlordimeform (Fundal®, Galecron®) proved effective in regaining control of this pest.

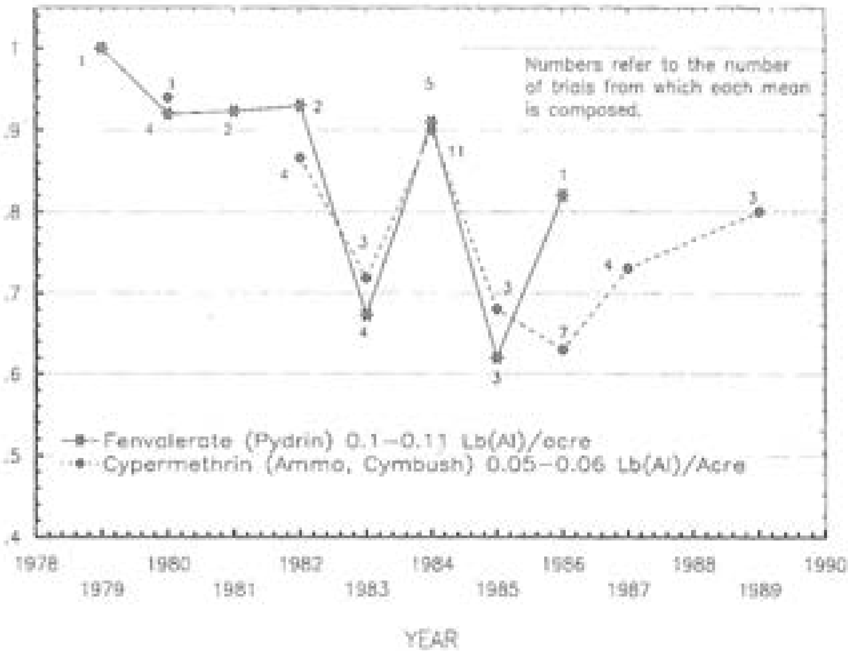

Figure 1. Downward trend of an efficacy index representing control of bollworm/tobacco budworm larvae by cypermethrin (Ammo®, Cymbush®) and fenvalerate (Pydrin®) as calculated from small plot field studies published in *Insecticide and Acaracide Tests* from 1979 to 1989. Data are from Mississippi, Louisiana, Texas and Alabama. The Efficacy Ratio is computed by dividing the larvae reported in treated plots by the number of larvae reported in untreated plots. An Efficacy Ratio of 1.0 indicates the same number of larvae are reported in the treated and the untreated plots. Negative efficacy ratios were not included in the graph.

Following a change in pesticide type, insect resistance to a previously used compound might decrease in time; but with the strong possibility that resistance in the insect population would build very rapidly if the insecticide were brought back into repetitive use.

As new chemistry is developed, there is a trend for compounds to be much more specific for the control of insects and less toxic to vertebrates. Early pyrethroids were used at a rate of approximately one tenth of a pound of active ingredient per acre; rates of three hundredths of a pound per acre or less are common with the newer pyrethroid insecticides. Such specificity is even more apparent in contrast to the organophosphates and organochlorines which were, or are, recommended for use at one pound or more active ingredient per acre. In addition to increased efficacy, there is a tendency for increased specificity, particularly in the case of experimental insect growth regulators and pathogens used as insecticides. These factors, however, have little bearing on the probability that pests may become genetically adapted to a chemical control agent. A major task of researchers and insecticide developers is to maintain an index of pesticide efficacies (insecticide resistance monitoring) in order to evaluate efficacy changes and to institute new procedures or compounds to insure maximum efficacy and longevity of compounds in common use.

INSECTICIDE RECOMMENDATIONS

Prior to the discovery that calcium arsenate could be used to effectively control the boll weevil (Coad, 1918), management of insect pests of cotton relied mainly on cultural and biological means (Lincoln and Graves, 1978). From the 1920s until the appearance of the organochlorines in the mid-1940s, insecticide recommendations were available only from bulletins published by either the USDA or agricultural experiment stations in the various states where cotton was grown. Typical of these early bulletins are: (a) "The Boll-Weevil Problem", a USDA publication by Hunter and Coad (1923), and (b) "The Boll Weevil Problem in Arkansas", an Arkansas Agricultural Experiment Station publication by Isely and Baerg (1924). These bulletins explained how and when to use calcium arsenate in concert with cultural controls to manage boll weevil populations.

The advent of the organochlorines in the 1940s and the organophosphates in the 1950s made available a large number of effective and economical insecticides and acaricides for use against arthropod pests of cotton. The sudden availability of so many pesticides that generally had a broad spectrum of activity was confusing and necessitated a more timely and a more formal approach to insecticide recommendations. The cooperative extension services of the various states producing cotton began publishing annual insecticide recommendations to fit their individual cotton insect pest problems and situations. Similarly, the National Cotton Council of America began publishing the annual Beltwide Conference Reports on Cotton Insect Research and Control starting in 1947 (Anonymous, 1947-1987; see Commemoration, this book).

The current process through which the cooperative extension services of the various cotton-producing states derive their cotton insect control recommendations varies greatly. However, the most common procedure involves an annual meeting of extension and research cotton specialists (primarily entomologists); private agricultural consultants, USDA cotton specialists, state regulatory officials, and cotton producers often are included. They discuss and decide upon additions, deletions and restrictions. To be recommended for a particular use, a pesticide must be registered by the United States Environmental Protection Agency and the state pesticide regulatory agency; it also must effectively control the pest(s) in question. The question of efficacy is answered by considering: (a) data made available by the registrant or manufacturer; (b) data obtained by state and federal scientists in that state; and, (c) data available from state and federal scientists in other states. Usually two to three years of efficacy data are required before new pesticides are added to official state recommendations. The most common reasons for deleting a pesticide from recommendations are: (a) the development of resistance to the pesticide; (b) cancellation of its registration by the Environmental Protection Agency or state regulatory agencies; and, (c) lack of availability.

In Louisiana, eight criteria are used in evaluating an insecticide for inclusion in the recommended list (Reagan, 1981). These are: (a) efficacy; (b) residual activity; (c) effect on important beneficial arthropods; (d) potential to cause buildup of secondary pests; (e) hazard to the applicator; (f) potential mortality to birds, fish, crustaceans and other nontarget animals; (g) potential for development of insecticide resistance; and, (h) ability to use the insecticide within the context of pest management so as to insure its availability for a longer period of time. Other states use most, if not all, of the criteria listed above as well as additional criteria that are pertinent to their cotton insect pest situations.

The most recent conference reports on Cotton Insect Research and Control published by the National Cotton Council of America contain a listing entitled "Changes in State Recommendations for Treatment of Arthropod Pests of Cotton". The list shows changes by states that are applicable to the upcoming season. The rates or rate ranges for each chemical recommended for controlling individual cotton pests are reported in the section titled "Cotton Insects and Spider Mites and Their Control". These annual conference reports serve as a national and international source of information on current cotton arthropod pest control recommendations.

FUTURE AREAS OF RESEARCH

Historically, insecticides have been the primary means of managing arthropod pests of cotton. However, the continued availability of effective and economical chemicals is in question because of: (a) rapid development of resistance by arthropods to chemicals used for control; (b) the increasingly stringent and costly federal and state registration requirements; (c) the relatively short patent life of new chemicals; and (d) the difficulty in discovering new leads for insecticides with novel modes of action. Increased research concerning the best utilization of available chemicals (i.e. mixtures, alternations, rates, timing and resistance management) is required to prolong the use and effectiveness of currently available compounds and insure continuing adequate control of cotton insects and mites.

There is a current research thrust to "focus on the unique aspects of insect-specific physiological processes, thereby increasing the margin of safety for nontarget animals" (Adams, 1986). This biorational approach to insecticide synthesis and screening offers, long term, great promise since it capitalizes on knowledge of insect physiology and biochemistry which emphasizes differences between pests and nontarget organisms (Williams, 1967; Sparks and Hammock, 1983). There is current interest in insect endocrinology, especially juvenile hormones, hormone inhibitors, biologically active peptides (Ross *et al.*, 1986a, 1986b, 1987) and other regulators of insect growth and development. These would include insect specific hormone or pheromone inhibitors such as anti-juvenile hormone agents (Staal, 1986).

Synthetic aggregation and "sex" pheromones or close mimics are commonplace in monitoring programs for boll weevil, bollworm, tobacco budworm and pink bollworm. They have been used for increasing the efficacy of pathogens on other crops, or to increase insecticide efficacy by attracting the pests to insecticide treated areas.

Entomopathogens have been developed and marketed. Nuclear or cytoplasmic polyhedrosis viruses and various strains of *Bacillus thuringiensis* have been utilized with varied success for insect control on cotton or other crops. Further research has resulted in bacterial exotoxins which are pesticidal and show promise of efficacy where resistance has developed to standard pesticides (Roush and Wright, 1986). Added to these are the little exploited entomophagus fungi (Samson, 1981; King and Humber, 1981; Bland *et al*., 1981; Wilding *et al*., 1986) which are active in nature and often reduce populations of aphids and spider mites.

Recently, the entomophagus fungus, *Beauveria bassiana* (Balsamo), has been shown to suppress populations of boll weevil and sweetpotato whitefly as well as other pest arthropods (Wright, 1993; Wright *et al*., 1993). A commercial formulation of this fungus, Naturalis-L®, has been granted an Experimental Use Permit by the Environmental Protection Agency on various crops including cotton. The registration and successful use of this fungus may provide an additional biorational tool for control of several insect pests of cotton.

Allelochemicals are yet another possibility for insecticide research. These compounds occur in nature, originating in individuals of one species but affecting individuals of another species. Terpenes, tannins, gossypol and similar allelochemicals of cotton or other plant species may be found useful in future insecticide-related concepts such as predisposing cotton pests to insecticide susceptibility.

Genetic engineering developments that permit incorporation of foreign genes into bacteria, viruses, plants (Marvel, 1985) and insects (Maeda *et al*., 1985) offer new vistas for imaginative researchers. Toxin producing genes have been transferred from bacteria to plants and shown to produce plants possessing insect tolerance (Fischhoff *et al*., 1987; Vaeck *et al*., 1987). Similarly, Hammock (1985) has proposed that genes for bioactive molecules could be transferred to pest insects through an appropriate viral or bacterial vector. Adaptation of the insect populations to genetically altered monocultures is a possibility, and although this elicits questions concerning longevity of the benefits (Gould, 1988), genetically engineered crops remain a viable hope for future crop protection.

The possibilities of light-activated compounds which are toxic to insects primarily in the presence of light have been explored (Heitz, 1987). Rebeiz (1988) recently researched entomological applications of the light-sensitive porphyric insecticides which cause insect mortality by uncontrolled biosynthesis of a protoporphyrin within the insect. The future of such compounds remains to be decided, but if perfected, they may contribute to the arsenal of insect-specific insecticides.

Abamectin (Zephyr®), which is as toxic to tobacco budworm as permethrin in laboratory tests and field trials on flue-cured tobacco (Wolfenbarger *et al*., 1985), represents a new class of insecticides, avermectins, which are revolutionizing animal health care. Because the avermectins act on the peripheral nervous system rather than the central nervous system, there is no anticipated cross-resistance present from previous use of organochlorines, organophosphates or pyrethroids (Roush and Wright, 1986). The avermectins offer great promise in controlling insect pests of cotton. However, many of those now available are too labile (unstable) to be efficacious under field conditions.

Thus there are many possibilities for future insecticide research, but few promises of functional breakthroughs with an impact comparable to the development of pyrethroids in the 1970s. Research is being slowed by the burdens of increased cost and registration requirements. Although some functional advances in bioengineering and chemistry are expected in the near future, they probably will not be frequent and may be designed for specific pests or related pest groups rather than as broad spectrum insecticides.

SUMMARY

R. L. Metcalf (1980) indicated that the "Age of Pesticides", beginning with the introduction of DDT in 1946, had undergone three distinct phases in the thirty years leading up to 1976. Those phases were: (a) the Era of Optimism, 1946-1962; (b) the Era of Doubt, 1962-1976; and (c) the Era of Integrated Pest Management beginning in 1976. Cotton entomologists and producers have experienced the first two of those cycles on several occasions. Those cycles coincide with the introduction of new classes of insecticides and then their eventual loss due to resistance. First there was the "optimism" that the arsenicals would provide the needed relief from boll weevil invasion. Then came the period of "doubt" when secondary pest infestations became overwhelming problems. With the introduction of the organochlorines came the period of "optimism" that all of their pest problems had been solved. Reality of resurgent pest populations and later resistance brought about the second cycle of "doubt". Organophosphate and carbamate insecticides brought "optimism" that finally control would be achieved without worry, but "doubt" returned when resistance removed many products from recommendations. Finally, "optimism" was high upon the introduction of the pyrethroids. But now "doubt" is beginning to return as secondary pest problems become more significant and reports of resistance in tobacco budworm and pink bollworm populations become more widespread.

Looking back at the history of insecticide use in cotton, it becomes evident that a new class of insecticides has a life expectancy of only about ten years. After that time resistance usually has negated the use of many or most products of this type at least for some important uses. Changes in use patterns of a new class of insecticides also occurs in a predictable manner. First, there is careful and judicious use of the materials in insect pest management systems followed by a period when applications are made on a preventative or scheduled basis. This latter period is inevitably followed by a period of decreasing effectiveness, elevation of secondary pests to primary pest status and often resurging pest populations.

Should another highly effective class of insecticides for use in cotton be discovered and registered, past experiences make it imperative that their use be carefully managed in order to maintain a viable cotton industry throughout the Cotton Belt. Following the basic principles of insect pest management, i.e. monitoring pest populations, utilizing established economic thresholds, and timing necessary applications to achieve maximum long term benefits, is the obvious and logical approach to conserving such a valuable resource as a new class of insecticides. In addition, resistance management systems such as those now being recommended for pyrethroids in the Mid-South United States (Anonymous, 1986) and Texas (Plapp, 1987) must be designed and implemented as part of an overall insect pest management system when new classes of insecticides become available.

CHAPTER 14

CULTURAL CONTROL

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INTRODUCTION

It is likely that at some moment in the last years of the 1890s, a cotton farmer — perhaps several cotton farmers — in the Rio Grande Valley of Texas, sizing up his experience, reached a persuasive conclusion about a matter of importance. He had had by now several years to examine and mull the matter; surely he regarded his judgement as meaningful, and surely he communicated his conclusions to neighbors. Taking account of what he had seen on his and neighbors' farms, he decided that cotton grown on certain soils, and in certain locations, and that certain cultivars of cotton, were especially vulnerable to damage from the newly introduced Mexican cotton boll weevil, *Anthonomus grandis grandis* Boheman. Entering the Valley probably in 1892, the boll weevil was the beginning of the end for a cotton production era that had run a course largely free of infestations of injurious insects. For a 100 years, acreage of the crop had expanded in this country, and it was acreage farmed with considerable license and leeway. Such was the absence of insect threat that cotton could be cultivated across the southern United States, restricted only by the lack of suitable soils or by deficient rainfall. In no instance had an insect dictated where the crop should be grown, or how it should be grown. The bottomlands of the Brazos and the Mississippi, and the upland spaces of the Piedmont and the Blacklands Prairies, and creek bottoms of Alabama and Georgia and sandy fields grubbed out of thickets of east Texas pines — all were chosen for the crop, although, obviously, the more productive lands were preferred. The boll weevil then would violate an old self-evident truth, making at the same time a compelling statement about how the crop would be grown in the future.

In any case, the Rio Grande Valley farmer who had enjoyed this historical production license took measure of the new and unprecedented situation: on sandy, loamy soils where cotton had always fruited slowly, losses to the boll weevil were often severe; and where cotton was planted in proximity to brushy rangeland, losses were substantially elevated. Aware of the varying earliness among the cultivars grown in his community, this grower noted that cottons that proceeded quickly with vigorous fruiting and rapid boll set produced more cotton in the presence of weevils than the slower-fruiting cottons that were commonly planted. Thus was born, though informally, the beginnings of a control strategy. There was a corollary to his observations: If the likelihood of weevil damage was associated with certain farmer decisions and practices, there were clearly adjustments possible to alter or cancel these; there were immediate, practical changes — cultural changes — that could be made in the face of this new reality.

From this imagined but likely beginning, and from the watershed of broad experimentation that followed by entomologists of the public institutions on all cotton insects, emerged a strategy—cultural control. For many years, until the organic insecticide period of post World War II, the cultural strategy represented the major component of the plan for addressing several of cotton's insects. The efficacy of these chemicals then largely eclipsed the cultural elements, but in more recent times with new understandings and an awareness of the difficulties of cotton insect control strategies built on an insecticide foundation only, application of cultural measures has received renewed attention.

The cultural recommendations of the public institutions that answered the intrusion of the boll weevil were promulgated, roughly, from 1895-1912; and these came to be known as the "Government Method" (Helms, 1980); and pioneer protagonist and advocate of agricultural extension education, Seaman Knapp, set about with on-farm demonstrations to promote this scheme of the entomologists (Knapp, 1911). If the program was given to farmers as a package of steps, the hard reality was that but two of the recommendations were the important elements; and only one of these was, or could be, carried out successfully. The first of these was timely stalk destruction, but its practice for boll weevil management was ahead of the times and usually not followed; the second, the securing of earliness in cotton production by way of selection of cultivar, planting date and row spacing, and through judicious fertilizer use, became common practice and had a powerful effect in mitigating boll weevil damage. These were the heart of the Government Method, and in this chapter we will consider them and other aspects of cultural control.

STALK DESTRUCTION, FIELD SANITATION, HARVEST PRACTICES, TILLAGE AND WINTER IRRIGATION

BOLL WEEVIL

In the fall of 1894, L. O. Howard, the new chief of the Division of Entomology (C. V. Riley had just stepped down) of the United States Department of Agriculture in Washington, D.C., contacted an old friend and erstwhile member of the Division, C. H. T. Townsend (Wagner, 1980). Would he, Howard asked, accept a position as temporary agent for the Department in south Texas where a disturbing situation had only recently developed in cotton? Charles Henry Tyler Townsend jumped at Howard's offer, accepting the position with relish. A man of catholic biological interests, a student of natural history, Tyler Townsend sought a research appointment. And so he accepted, moving briskly to south Texas in a few weeks where he began to examine the developing problem, the boll weevil. He kept Howard apprised during the following months with what were surely alarming reports, and the full substance of his investigation was published the next year in Insect Life (Townsend, 1895). The content of the report was an apocalypse. Analysis of the situation in several of the cotton producing communities near Corpus Christi indicated that the weevil had exacted yield reductions of 30 to 90 percent. Extensions of these figures north and east across Texas, and possibly across all of southern United States where cotton was farmed in a one-crop economy, must have been frightening considerations for Howard and all others privy to the possibilities of the matter.

Research on the boll weevil started with Townsend. Perhaps his significant contribution was the recognition of the need for stalk destruction after harvest to reduce winter carry-over of adult boll weevils. Kill the boll weevils in the crop residue in a field he reasoned, by plowing or burning, and you will have fewer boll weevils to endure the following season. Because the weevil was known to attack only cotton, this tactic was all the more persuasive. Townsend clearly thought that overwintering was restricted to the immediate infested cotton field, unaware that the adults fly throughout cotton growing communities as they seek quarters in many places, especially in the leaf litter of well-drained wooded sites (Isley, 1929). Townsend called for other cultural adjustments, these well beyond the practice of the individual farmer. No shrinking violet, he boldly implored for laws that would interdict cotton farming across a broad fifty mile swath of southern Texas to stop the weevils' northern, and eastern, progress. Politically charged, involving the livelihood of hundreds of farmers, this recommendation had no chance for implementation. Later, as the weevil ranged eastward, states attempted, to little effect, to apply quarantines (Hunter, 1905). The proposed Townsend interdiction, had the Texas Legislature acted or had there been Federal imposition, might have bought, at best, a few years for northern and eastern production — before the cotton free zone was breached by dispersing weevils.

USDA investigations of the boll weevil problem in Texas continued into 1898 — the year the Texas Legislature appropriated money to fund a State Entomologist position at the Agricultural and Mechanical College; the year the insect was well into east Texas. The Division of Entomology withdrew from Texas in 1898, and Frederick William Mally was engaged in the state position (Little, 1960). Without delay, Professor Mally was about this problem of the boll weevil. Launching a triad of effort — research, extension and education — Mally, as he toured south central and eastern Texas cotton growing districts, speaking before farmer groups, arguing and exhorting, extolling early-maturing cottons, grimly demanding prompt stalk destruction after harvest, acquainted farmers and the public with the term "entomology" (Wagner, 1980; Anonymous, 1901). As Townsend, he recognized the value of stalk destruction before frost because this was the "vulnerable period" in the weevil's yearly history. Mally recognized that even in the absence of the practice of early stalk destruction, relatively few adult weevils survived the winter; obviously the additional tier of mortality resulting from early stalk destruction would further reduce numbers (Mally, 1902). He made a judgement about the weevils that survive the winter, and this conclusion, because it apparently was based on Mally's imagination rather than on the facts of experimentation, is rather more remarkable. He sensed that there was some special quality of the weevils that reached the adult stage during the fall, and it was only these insects that could successfully overwinter.

It is credited to Brazzel and Newsome (1959) the discovery of diapause (a physiological reordering that permits survival in a harsh period) in the boll weevil. They demonstrated that boll weevils that are to survive the winter originate primarily from eggs deposited in the late summer-early fall and that these adults are, in several ways, different from the reproducing weevils of summer; they noted also that a feeding period of some days is required by adult weevils for the attainment of diapause, further emphasizing then the need for timely stalk destruction. Later, research (Brazzel and Hightower, 1960; Lloyd *et al.*, 1967; Tingle and Lloyd, 1969; Carter and Phillips, 1973) would measure the pattern of diapause incidence in the insect in the late summer-fall period and the factors that influence its occurrence. Mally, not knowing the term "diapause," and in the absence of the understanding of the phenomenon we presently enjoy, seemed to recognize this difference in the two kinds of weevils that Brazzel and Newsome described. In his 1902 report to the President of the Agriculture and Mechanical College, Mally wrote of the weevils belonging to the "summer brood" and to the "hibernating brood" (Mally, 1902):

> "It is safe to state that a large percent of those which had laid a considerable portion of their eggs before going into winter quarters will either have died during the winter, or perish very early in spring after having deposited a few more eggs. The weevils coming from hibernation quarters in spring and which have laid no eggs the previous fall are the ones which live longest in spring and lay the principal portion of eggs for the first generation of larvae."

He suggests here that diapausing boll weevils lay no eggs prior to entering winter quarters, that these weevils have an entirely different purpose—A conjecture later confirmed (Walker, 1967). As Townsend, Mally was convinced that elimination of boll weevils in crop residue in the immediate cotton field or very nearby, by plowing, burning or grazing, would reduce overwintering. Neither man had appreciated the dispersing quality of late summer-fall boll weevils, that these insects seek out overwintering quarters throughout a farming community, often distances away from cotton fields.

Frederick Mally as Townsend was not a man burdened by reticence. In his report to President D. F. Houston of the College, together with a number of practices that the individual grower should follow to diminish weevil losses, Mally included his critical thoughts on those farmers who had not warmed to his recommendations on prompt stalk destruction after harvest; and he demanded, posthaste, enactment of laws requiring this practice in the fall and the summary means to deal with those recalcitrants who do not see fit to comply. His passion notwithstanding, laws were not passed; increasingly the professor came under fire from a dissatisfied clientele, and in 1902 he resigned (Wagner, 1980). Mally had not given the easy control answers invoked by growers, but both he and Townsend had made the case for stalk destruction. Both had thought erroneously that the total benefit of the practice came from the immediate destruction of weevils that happened to be present when a cotton field is destroyed. The fact that they did not understand that it is the removal of growing cotton that ends the food source necessary for the attainment of diapause that curtails overwintering does not form as a great error however.

Uncomfortable with the progress of the entomologists of the public institutions and feeling the continuing political heat, the Texas Legislature with prodding from the Governor responded again, posting in 1903 a reward of $50,000 for solving the boll weevil problem. This staggering amount (a fortune in 1903 dollars) was to be given to anyone coming forward with a solution (Cohn, 1956). Fiscally chary lawmakers of those times who were knowledgeable in matters of the boll weevil probably lost little sleep over the prospects of awarding the money. As they had half-imagined, the $50,000 was never collected. Apparently the Legislature felt that the partial cultural solution to the weevil soon to derive from the organized research programs of the USDA and state entomologists did not qualify. In the end, none of the numerous (about three hundred) and sometimes harebrained schemes and devices that were submitted as solutions measured up under examination. Each though had been dutifully scrutinized by USDA entomologists who had returned to Texas in 1901, and their findings were made known to a legislature appointed committee, the Boll Weevil Commission. One secret remedy was fuzzily described in a letter from France, from a Dr. L'heureux. A pesticide apparently, the product was "very simple, infallible and little expensive..." and did no injury to plants. And there was more. Applied to human skin, this boll weevil remedy, Dr. L'heureux noted, behaved as a mosquito repellant (Wagner, 1980).

Mally's entomological program had been supported by an initial state appropriation of $5000. Out of that came his salary, $2800, and $2200 remained for research and travel. It was a level of funding that, given the scale and complexity of the weevil problem and the political discomfort that grew from the insect's pillage, may not have been a token appropriation but it wasn't a great deal more. Examined against the well-funded, well-staffed research program of the USDA, research of Texas' first State Entomologist moved along on a shoestring (Wagner, 1980). The Division of Entomology built a laboratory at Victoria in 1902, moving the facility to Dallas in 1905; and as research leader for Texas, chief L. O. Howard chose, in 1901, young Walter David Hunter. The selection was a masterstroke: Hunter, age 26, would move with grace and control through the political thickets created by the boll weevil, establishing credibility in the eyes of growers as Frederick Mally had not; and the considerable progress in the understanding of the "natural history" of the pest that would arise from USDA research. The application of that understanding to cultural strategies, became a testament to Hunter's leadership.

With the eastward advance of the weevil, a USDA research facility was established at Tallulah, Louisiana in 1909. A cotton entomology research program was launched in the state a few years earlier. It was sponsored by the Louisiana State Pest Crop

Commission and under the direction of Wilmon Newell (Little and Martin, 1942; Parencia, 1978). It was during the ten years or so after Mally's departure that the Government Method, in part, was implemented by farmers. The extreme yield losses that Townsend had measured in south Texas in the first years of weevil infestation did not last (Hunter, 1909a); cultural adjustments, largely in the form of early-maturing cottons, had partially deflected the brunt of weevil attack; and reductions in cotton yields because of the boll weevil fell to ten percent or less. Although weevil losses were greater as the pest moved into the higher rain zones of the eastern United States, they were not as severe as that foreshadowed in the Townsend report (Brown and Ware, 1958a). The fast-fruiting cottons had made the difference. But, if farmers had willingly and successfully changed one practice, from slow-fruiting cultivars to early-maturing ones, they could not bring themselves to assiduously practice prompt stalk destruction. There were, as we shall see, reasons for this.

Considerable evidence accrued during the early 1900s, expanding the understandings of boll weevils and hibernation, making an ever stronger case for the cultural operation of stalk destruction. However, entomologists still did not understand that potential overwintering weevils in the late summer-fall season disperse in all directions and for some distance from old cotton fields as they seek all manner of places to protect themselves from winter climes (Hunter, 1904a). Destroying weevils in or very near to cotton fields before frost was thought to lessen overwintering. USDA entomologist W. D. Hunter repeated the earlier advice of plowing out cotton (to the roots), wind rowing and burning, adding a description too of a stalk cutter that could be pulled by either horse or mule — "a wheeled cylinder provided with oblique knives." Experiments reported by Hunter (1907) made even a stronger case for early stalk removal, showing that weevils removed on different fall dates from cotton and caged on hibernation media survived in greater numbers as they were caged later in the season. It logically followed that if stalks were cut and destroyed at dates corresponding to those of the hibernation cage tests, similar hardship would be placed on weevils seeking to overwinter. By 1909, the strong dispersing ability of the hibernating weevil seems to have been recognized. "They fly from cotton in the fall in all directions," Hunter wrote (Hunter, 1909b), adding that the insect could fly forty miles. Hunter and Pierce (1912), taking a backward glance, assessed the weevil and the success of research to combat it, contrasting the extreme losses to the pest in its first years in Texas with contemporary and improved yields. They noted again the persuasion of the hibernation cage study data that, over a period of years, had argued for early stalk destruction — the earlier weevils were removed from cotton in the fall, the greater the winter mortality. For example, about 0.3 percent of the September weevils survived against a 10 percent survival of weevils caged in December, a pattern of survival not adequately explained until the research of Brazzel and Newsome. September survival was low because the incidence of diapause was low, that of December greater because of the higher incidence of diapause. The writers referred to a stalk cutter newly invented by the State Crop Pest Commission of Louisiana, and the USDA entomologists obviously had pinned hopes on the device. Unlike the "wheeled cylinder..." previously mentioned, the contrivance was a "V" shaped sled, each side of the V armed with a sharpened blade. An implement of some bulk, the rig was to be pulled, instructed its inventors, by two horses, hitched, not side by side, but in tandem. Plans that might be used for on-farm construction of the V cutter appeared in a circular of the Commission (Newell and Dougherty, 1909).

Certain field experiments and observations averred the findings of the hibernation cage work. Hunter wrote of the experience in Calhoun county of Texas in 1906 where 400 acres of isolated, weevil infested cotton were plowed up and burned in the first ten days of October. The following year a series of examinations on cotton planted there established a much reduced weevil infestation and high production. A check field was infested early, incurring considerable lint loss to the pest (Hunter, 1912). Observations were made by Wilmon Newell in Louisiana on the effects of an early killing frost, November 13, 1907, on weevil infestation in cotton of the area during the following year: It was considerably reduced, compared with infestations in cotton in south Louisiana (Newell, 1909a). By 1912, it seems, experience and a body of data had made a case for the removal of cotton stalks by early October. Hunter put it well, this need for stalk destruction, in the title of a circular of the Bureau of Entomology: "The most important step in the cultural system of controlling the boll weevil" (Hunter, 1904a).

As important as the tactic seemed to cotton entomologists, the truth of the matter was that farmers found every reason not to follow the recommendation. As Helms (1980) wrote: "Farmers shunned most the aspect of the cultural system that entomologists claimed brought the highest degree of control." In the first place, hand-harvesting of cotton was a protracted affair, often extending late in the fall and past the time of early October when stalk destruction was called for. Too, the economics of the crop compellingly demanded that every last harvestable boll be harvested; and the lure of that occasional event, a "top crop," as infrequently as that occurred, served to counter the earliness theme itself. An official of the Texas Agricultural Experiment Station of those early years estimated that less than one percent of Texas farmers practiced the recommendation (Helms, 1980).

Stalk cutters were available, but their costs were prohibitive to many farmers; and in the event that a farmer owned one, he found it an inadequate tool for cutting tough, resilient, green cotton stalks in October (Wilkes *et al.*, 1962). On the other hand, should he wait into the late fall or early winter after a freeze had killed the stalks, dried them, made them brittle, stalk destruction was a far easier chore. But, of course, by then it was too late; weevils had already prepared for hibernation and left the field. In those instances when a grower did destroy stalks with some sort of a cutting implement, it did not follow that the plants' roots could always be immediately plowed out — a practice needed to prevent regrowth. Perhaps dry, hard soils would prevent the plowing operation after stalks were cut; and when plowing could be started, the slow mule drawn operation naturally worked against a quick removal. And, perhaps, a human element, the propensity to rein up and take one's ease after a job is seen to be over — and indeed the harvest of that last lock of cotton on one's farm had a ring of finality to it — was factored into the southern cotton farmer's unwillingness to assiduously tend to stalk destruction. For years, following harvest, growers had plowed out their cotton stalks, at their own pace, at a time of their choosing. Now they were being asked to do something else.

The early stalk cutters were inadequate to deal with green cotton especially in those regions where stalks were large; and even the first modern rolling stalk cutter (Brown and Ware, 1958b), an implement introduced in 1925 that could be used behind animals or, in rare instances, tractors, lacked the engineering capability for cutting green cotton stalks over a range of conditions. There must have been hopes though for improved stalk cutting where the implements were tractor drawn; in any event, the Ford Motor Company, in the 1920s, saw cotton stalk removal as a sales opportunity for their newly introduced Fordson tractor — they even made a movie about it with the title: " Where the Fordson Shines: Beginnings of the Systematic Extermination of the Enemy of the South: Boll Weevil" (Helms, 1980). Ford figured to carry out this systematic extermination using the Fordson to pull a cutter.

If the cultural practice of stalk destruction was in the main ignored, there were a few examples where concerted efforts brought stalk clean-up in areas of some scale. Little and Martin (1942) noted that the strategy was more ordinarily observed on the coast (presumably the Texas Gulf coast) because early planting and earlier harvest happened to accommodate its practice. Also, Gaines and Johnston (1949) described the organized stalk destruction program that took place in Williamson county of Texas in the late '40s and the positive reductions in weevils the next year. Included was an account of various levels of farmer compliance in stalk destruction in the Rio Grande Valley and the resulting effects on boll weevil infestations the following seasons. War, patriotism and propaganda even have had a place in cotton stalk destruction: Concerned not so much with boll weevils as pink bollworms, *Pectinophora gossypiella* (Saunders), cotton interests of the Rio Grande Valley during World War II years and a high pitch of propaganda in local newspapers placed farmers who were not attentive to stalk destruction and the unpatriotic on the same shelf (Walker, 1984). Everything Americans did or did not do in those years had something to do with winning the war, and that included cotton farmers.

In another instance, stalk destruction and allied practice achieved such a concert of appliance that, if it resulted in a victory over overwintered weevils, it was literally a Pyrrhic one. During the 1920s, growers of Greene county Georgia took the early burning recommendation to heart, extending its application not only to cotton fields but to woods, hedgerows and terraces. Weary of claims for burned down houses and farm buildings, insurance companies in the mid-'20s refused to write rural policies for the county (Helms, 1980).

For all of the preceding, yearly, effective, areawide practice of stalk destruction, as W. D. Hunter had imagined it, did not come about until well after World War II. If there was a single reason, we believe it rested with the lack of a specific farm implement: a stalk cutter of appropriate design, and power, to cut green cotton stalks efficiently over a range of stalk sizes. The old rolling stalk cutter, whether powered by mules or early tractors, operated largely as a consequence of the weight of the implement or the sharpness of its cutting blades (Wilkes *et al.*, 1962). Its efficiency arose, obviously, apart from any external power source other than the speed at which it was drawn. An effective stalk cutter awaited mechanization in cotton; and during the '30s, through the first years after World War II, mechanization became, indeed, fact (Brown and Ware, 1958b). Stalk cutters were developed that functioned not just because they were equipped with a set of stalk cutting blades — they cut stalks efficiently because power could be transmitted from the engine of the tractor to the cutter. The first of these machines was powered by way of a chain or belt drive (Smith and Jones, 1948), but the rapid development and standardization of power take-offs on tractors after World War II permitted new and efficient design in stalk cutters: the horizontal rotary blade cutter (Smith, 1964). Further improvements arrived with the flail cutter, a machine that chops the entire plant into small pieces. The rotary cutter, a simpler machine, however, is the more common choice today. By the late '50s, rotary cutters were common implements for farmers: For the first time, stalk removal in cotton fields, whether in Texas or Mississippi, could be addressed with ease. Rotary horizontal stalk cutters as they came to be used in increasing numbers had to have decreased numbers of boll weevils overwintering; but they received little formal credit. They were being used now because cutters had become part of a well-managed farming operation. Farmers were cutting stalks out, not so much because of boll weevils, but because it was the first step in a series that would lead to seed bed preparation for next year's crop.

Another practice, mechanical harvest, came soon after World War II that would accomplish some of the goals of stalk destruction but before the act of stalk destruction. Stripper and spindle harvest, and the harvest-aid chemicals that are required for their operation, necessarily has levied another level of mortality on boll weevils that are to overwinter (Cleveland and Smith, 1964; Summy *et al.*, 1986); and today the machines are used to gather the entire United States crop. Mechanical harvest with spindle pickers has eliminated the protracted hand harvest period that had once left standing cotton in the field late in the season, and stalks can be destroyed earlier. But even before stalk destruction, the required use of defoliants, applied before harvest, will have caused leaves and small fruits to shed. In effect, preparation for harvest, the picking operation itself and finally stalk destruction are an interruption of considerable magnitude in the usual seasonal order of boll weevil diapause. One or two harvests are made where spindle pickers are used. In the March planted cotton in the Rio Grande Valley of Texas, good managers can destroy stalks in August, an operation early enough to reduce sharply numbers of overwintered weevils. Recent improvements in earliness of new cotton varieties of the eastern United States (a topic discussed in a later section) should allow harvest and stalk termination in October in many instances, a time early enough to affect weevil overwintering.

Practiced in large parts of Oklahoma and Texas, stripper harvest can exact a heavy toll on boll weevils that might otherwise seek to overwinter. The desiccant arsenic acid is applied to cotton before stripper harvest in the Blacklands and Lower Gulf Coast of Texas; and the chemical kills all leaves, drying squares and small bolls, swiftly eliminating food for weevils that might overwinter. A single harvest gathers the entire crop.

Shredding is often accomplished in late July in Texas coast cotton, in early September in the southern Blacklands of Texas. Removing cotton stalks early in these regions, and that effect on overwintering weevils, is an important determinant of the reduced insecticide usage there (Anonymous, 1981).

Certain new harvest-aid chemicals, ethephon (Prep®) and thidiazuron (Dropp®) hasten the opening of mature bolls and cause small, immature green bolls to shed from the plant, allowing still earlier harvest. In addition, the chemicals reduced the number of weevils emerging from collected squares and bolls (Bariola *et al*., 1986). Thus, these products are an additive to the cultural management of the pest that present harvest procedures bring. Modern harvest technology followed by stalk destruction then, unimagined in its present detail by Frederick Mally or Walter Hunter, has effected, variously, the tactic these entomologists roughed out more than 80 years ago.

The powerful force of stalk destruction followed by stubble plow-out in suppressing boll weevils in the cotton system can be witnessed in the current yields and insecticidal use patterns of farmers participating in the integrated pest management program of Williamson county, Texas. Under the auspices of the Texas Agricultural Extension Service, a county agent-pest management professional supervises insect management for a number of farms in this Blacklands' location where the crop is grown dryland. Cotton is stripper-harvested in early September, and stalk destruction and plowing follow. Historical yields, 1928-1939, for Williamson county averaged 162 pounds of lint per acre. The average yield over the seven years 1983-1989 was 513 pounds of lint. Essentially all growers apply early season applications for thrips, *Frankliniella* spp., overwintered boll weevils and cotton fleahoppers, *Pseudatomoscelis seriatus* (Reuter). C. G. Sansone, Extension county agent-pest management, compiled the following information on late-season insecticide use by participating growers for boll weevils, bollworms, *Helicoverpa zea* Boddie, and tobacco budworms, *Heliothis* virescens (F.):

	Number of late-season treatments						
	1981	1982	1983	1984	1985	1986	1987
Bollworms-budworms	0.9	0.8	0.4	2.2	1.0	1.5	1.6
Boll weevils	1.2	1.4	0.6	0.2	0	0	1.0

Obviously, late-season infestations of weevils are a small matter for Williamson county growers. Assiduous attention to stalk destruction and plow up are accountable in large part.

We have considered in this discussion cultural actions that are performed to reduce numbers of overwintering boll weevils, of diapausing adult weevils. These actions deny food sources to the special adult weevils that are to diapause. But boll weevils can overwinter as immature and unfed adults enclosed in late cotton bolls (Bottger *et al*., 1964; Bergman *et al*., 1983), and a small percent can live to infest squares the following years. That is, these adults that emerge in the spring have not fed, and will not feed, until the squares appear in the new crop. This problem has occurred in Arizona stub cotton fields, (cotton not plowed out at the end of a growing season but cotton allowed to remain in the field for next year's crop). Stub cotton provides a source for infestation in not only the stub fields but also in adjacent cotton farmed under normal culture. Practiced off and on in Arizona for years, contributing to the pink bollworm problem, stubbing of cotton is now prohibited in Arizona (Moore, 1985). Unfortunately, weevils also overwinter in Arizona as typical diapausing adults; and these establish, in cotton, as they do in the East, beginning infestations in the spring. Stalk destruction, which is not required of growers until mid-winter in Arizona, could not be expected to levy the degree of population management that a September shredding brings in Texas.

As in Arizona, weevils survive during the winter in bolls on undestroyed stalks in scattered cotton fields in the Rio Grande Valley of Texas. Moreover, the mild winter here, the lack of freezing temperatures in some years, sometimes allows cotton in these unattended fields to fruit through the winter; and weevils springing from such locations become a serious threat (Norman *et al*., 1984; Summy *et al*., 1988). A few unshredded fields or fields that have regrown after shredding become a source of inoculation for considerable acreage in the following growing season. Although there are September stalk cutting and plow down laws for pink bollworm management in the Valley for years(Allen *et al*., 1985), scattered fields have remained unattended every year, these influencing nearby acreage. Recently, a new stalk destruction law (The Boll Weevil Control Act) was passed by the Texas Legislature. Under this law, stalk destruction by September 1 is now required for the Valley.

PINK BOLLWORM

In 1916, the chilling experience of the boll weevil fresh in everyone's memory, the United States Department of Agriculture considered the ominous development that only recently had occurred in Mexico. The pink bollworm, an insect pest of cotton in different world regions, had entered the country in 1911 and by 1916 was bringing damage to the Mexican crop. In view of the measures that were soon to follow in the United States, it is apparent that the insect was regarded in 1916 as a manifest threat to cotton — all cotton grown in this country. Taking no chances and prepared to act, the Department by now had the authority to deal with such a threat by way of newly passed quarantine legislation; and the Federal Horticultural Board could execute this authority (Hunter, 1926). Certainly, contingency plans had already been drafted by 1917; and the quick events that reeled off in succession in the autumn of that year justified all of the concern, all of the attention.

Infestations of pink bollworm appeared in a field of cotton near Hearne, Texas in the fall of 1917, a location receiving about 40 inches of rain per year; not many weeks later, additional infestations were noted in southeast Texas where annual rainfall averaged about 50 inches. Typical of United States rainbelt cotton, these production areas with their pink bollworm infestations now, represented the gravest of portents. Analysis of the situation incriminated infested cottonseed imported from Mexico (Hunter, 1926). Armed to deal with such a situation, the United States Department of Agriculture and the Texas Department of Agriculture, in full cry, worked to eradicate these infestations; and they did. The operation was a large, labor intense effort. A force of 500 was organized, its activities directed toward destroying all cotton plant products in the localities: seeds, fallen lint, burs, stalks, bolls, cotton refuse about gins — anything that remained after harvest and that was related to the cotton plant. Sixteen hundred acres of cotton at Hearne and over 7000 in southeast Texas were subjected to this effort in the fall of 1917; and the following year and for additional seasons, no cotton was permitted to be grown in the locales of the infestations. For example, an area six miles in diameter was denied the crop at the Hearne site following the clean-up. And that prohibition was to continue for several years. The eradication clearly was as successful as a political achievement as it was as a biological success. Shortly, other rainbelt infestations were detected in Louisiana, and eradicated (Noble, 1969). Underlining the vulnerability of the insect during fall, these several eradications made, in time, a positive statement on the cultural management of the pink bollworm with, at least, some of the eradication tactics — should it ever become permanently established. In not many years it had.

As with the boll weevil, the diapausing stage (last larval instar) of the pink bollworm represented a weak link; as with the weevil, stalk destruction (and field sanitation) could be used, and even more effectively, to manipulate downward numbers of the pest overwintering. The special realm of the overwintering larvae necessarily makes them vulnerable to cultural measures, limited as these diapausing individuals are to the immediate cotton fields, to implements transporting cotton products and to cotton gin residues. They cannot, as the boll weevil, disperse by flight to overwinter in scattered sites remote from man's actions. Pink bollworm larvae overwinter where cultural procedures can be applied. Unlike the weevil, there are a number of hosts other than cotton; but with the exception of cultivated acreage of okra, it is cotton that provides the important matrix for winter survival (Little and Martin, 1942). The success of the rainbelt eradications, notwithstanding, there is considerable doubt in our minds that the insect would have ever achieved and maintained pest status in the colder, wetter rainbelt production areas of the United States where the eradications had been so effective. But, of course, at a time when public figures were still reeling from the experience of the boll weevil, and when there was less known about the pink bollworm, it is understandable that these eradication programs were conducted. Since those times, infestations have briefly appeared in rainbelt cotton and northwestern cotton of Texas only, in the absence of Draconian quarantine measures, to disappear (Noble, 1969). But for cotton of the southern and warm tip of Texas, and for western desert production, it has been another matter.

The pink bollworm in the years after the Hearne eradication did establish in the near tropical Rio Grande Valley of Texas and, with the exclusion of the San Joaquin Valley of California, the western United States. But, despite the relative nearness of infested cultivated cotton in Mexico, it required years for this to happen. Various quarantine measures slowed its advance. Although the pink bollworm was first detected in Arizona in 1926, for example, much of the production region was held free of injurious infestations; and it wasn't until the early 1950s that the entire state was placed under quarantine (Noble, 1969). The series: Annual Reports of the University of

Arizona, College of Agriculture and Agricultural Experiment Station, 1936-1950, gives the insect little attention. Texas' Rio Grande Valley remained as a fastness from the pink bollworm until 1936, and not until the early 1960s did the southern valleys of California become infested. Quarantine procedures and clean-ups were instrumental in delaying the insect.

The success of the early quarantine and eradication programs had made the case for cultural management of the pink bollworm at the farmer level, and with the 1930s came the beginnings of definitive research on the biology of the insect, and the new understandings that followed together with new technology would make even a more robust argument for the application of cultural measures for the management of this insect.

In 1927, the United States Department of Agriculture established its first laboratory in the United States for pink bollworm research , locating the facility at El Paso. (Earlier investigations, beginning in 1918, had taken place in Mexico.) Experiments in cooperation with the Texas Agricultural Experiment Station were carried out near Castolon, a location on the Rio Grande in the Big Bend country of Texas; and in 1927 a laboratory was opened at Presidio, a remote Texas town on the Rio Grande. Sub-laboratories were put in operation by USDA at other sites as infestation warranted, and one of these, at Brownsville, was elevated to headquarter laboratory status in 1941. Responding to sudden increases in infestation levels in Texas in the early '50s, programs were expanded in 1952; and these were once again a joint effort of USDA and the Texas Agricultural Experiment Station (Noble, 1969). The record of understandings of the pink bollworm derived from the research programs of these agencies across the years is indeed laudable, and much of the progress directed the formation of cultural management strategies. Diapause, the understanding of it, is a case in point.

The appearance of overwintering or diapausing pink bollworm larvae, individuals known as "long cycle" larvae by the entomologists of the 1930s, was first thought to occur because of the influence of the moderating temperatures of late summer-fall (Busk, 1917). They were called long cycle because the insects would remain in the last larval instar in cotton bolls, usually in the seeds of the bolls, through the winter until spring when they would pupate with adult moths later emerging. It became apparent to researchers that the appearance of the long cycle or diapause condition could first be seen in September: About 50 percent of the larvae in open cotton bolls was noted to be in diapause then (Owen and Calhoun, 1932). Although temperatures of early September in Texas often differ little from those of August, temperatures were still commonly thought to be the effectors of this September diapause. Establishing that diapause seemed to be initiated in September eventually became the opening argument for the seasonal timing of regional stalk destruction programs. The reduction of overwintering by pink bollworm larvae ideally would be achieved if cotton stalks could be removed before diapause was prompted in the pest, and it was this rationale that specified September as the month for stalk destruction in the Rio Grande Valley (Curl, 1949).

Understandings broadened as data accreted during the course of research. Chapman and Cavitt (1937) established that earliness of fruit removal from cotton stalks influenced negatively the numbers of larvae in soil beneath the plants; where plants were denuded of fruit on October 1, fewer larvae were recorded than when the stripping process was delayed until November. Other investigations showed that the large majority of the long cycle larvae survived in cotton bolls, although some did exit bolls to burrow in soils, later to form hibernacula (for protection in the winter) (Fenton and Owen, 1931). Studies of Fife *et al.* (1947) that measured the survival of the pest in cotton bolls collected on different dates showed that winter survival of the insect for August bolls was 0.4 percent, in October bolls it was 25 percent.

Other experiments assessed the influence of winter moisture on the time of spring emergence of adults. Moisture hastened pupation and early moth emergence (Chapman and Cavitt, 1934). Other studies measured the effects of tillage and irrigation, winter irrigation and deep plowing reduced survival (Isler and Fenton, 1931). From the foregoing, and from other research, stalk destruction, field sanitation, tillage and winter irrigation (gin sanitation too) were framed into cultural programs for the pink bollworm; and, evidently, for many years these were successful for the management of the pest in the infested areas. For much of the early period of pink bollworm infestations to the 1950s, it should be remembered that growers lacked efficient stalk cutters. Although another agency of control, the organic insecticides of post World War II, was given wide currency in the first years of the 1950s for all cotton insects, an outbreak of pink bollworms throughout much of central and north Texas happened then, this despite the new chemicals. Expanded research programs were quick to follow (Noble, 1969), and they brought a larger comprehension of diapause and the pink bollworm mortality factors that man could impose.

The imperfect understanding of the pink bollworm seasonal diapause was soon given clarity. Lukefahr (1961) tied the appearance of the condition to photoperiod, the length of daylight hours; and Adkisson *et al.* (1966) demonstrated the precision with which the insect cleverly reads the decreasing hours of daylight in the days of late summer and into the fall, in increments of fifteen minutes even, translating these messages purposefully into a higher incidence of diapause as each few days pass. This line of investigation revealed that the first diapause actually arose in larvae that originated from eggs deposited in the last week of August; and from eggs laid at September's end, a cohort of larvae would follow containing 70 percent diapausing individuals.

The effects of harvest-aid chemicals on overwintering in the pink bollworm were researched. When defoliants and desiccants were used at the propitious (favorable) time, the occurrence of larvae in the overwintered state could be greatly reduced. Applied August 22, these chemicals reduced diapausing larvae in cottonseeds about 85 percent over counts in check plots; that is, there were about 12,000 larvae per acre in diapause in the defoliant-desiccant treatments, about 97,000 in the control. Delaying application until October 5 allowed for an enormous increase in diapausing individuals, and near 132,000 per acre were recorded. The chemicals at this later date still effected about a 26 percent reduction over numbers in the controls (Adkisson, 1962).

Decreasing day lengths of late summer-early fall, unlike the inconsistent temperatures of the same period, form as unvarying signals: constants at the same time every year for late infestations of pink bollworms as the message to diapause is comprehended by the insect. Understanding the precision with which day length times diapause in the insect removed all uncertainty and argument about when the crop should be brought to end by the harvesting process — harvest aid chemicals, harvest, stalk destruction and plow up. If these measures are brought to bear in mid-September, wintertime survival will be curtailed in a significant way — primarily because the cotton food source is destroyed before a high proportion of the insects are in diapause. Delay the harvest process until November, and one has guaranteed diapause to the insect.

So destroying cotton stalks before the pink bollworm receives the short day cue to diapause exploits a vulnerable place in the life history of the insect; but even when this practice has been delayed and the condition in the larvae already triggered, research showed that modern stalk cutters, rotary and flail, destroy not only cotton plant parts but also larvae in cotton bolls, reducing consequently the overwintering diapausing population (Wilkes *et al*., 1962). The flail machines in this regard are superior. Also following the stalk cutting-shredding, moldboard-turning of the soil to a depth of 6 inches, followed by listing, destroys many overwintering individuals (Noble *et al*., 1962). And, if these practices are followed in desert regions by winter irrigation, even greater reductions accrue. The earlier these tillage operations, the greater the effect; an October practice reduces overwintering more than one of January (Watson *et al*., 1974). Adding to the mortalities has been the contribution of the harvest-aid chemicals ethephon (Prep®) and thidiazuron (Dropp®). Bringing rapid boll opening and the shedding of immature bolls, applications of these compounds also reduce numbers of diapausing larvae. Obviously, the stubbing of cotton that was once allowed in Arizona provided wintering pink bollworms largesse: The cotton stubs were a refuge for late bolls carrying the pest, and these insects escaped the mortalities induced by plowing and listing (Bergman *et al*., 1981).

Estimates of certain mortalities and their accumulation that man, through cultural procedures, can levy on the pink bollworm have been calculated (Graham *et al*., 1962). In this example, stalk destruction is carried out during mid-September when 30 percent of the insects have taken the day length signal to diapause:

Mortality factor	Percent survival after mortality factor
Diapause	30
Harvest	30
Shredding	40
Bolls are left on soil surface until April 15 (squaring date)	1.18

Combined survival is 0.04 percent of the September population. That is, from a larval population of 4,000 larvae in September, less than two are calculated to survive to the adult stage to oviposit in cotton the following April.

Planting and stalk cutting dates for pink bollworm management long have been under the authority of the state departments of agriculture. For example, the Texas counterpart presently sets stalk cutting and plow up by September 25 for the Rio

Grande Valley, a date, if observed by growers, certainly early enough to harshly restrict overwintering (as we noted, a new stalk destruction law recently has been passed in Texas for management of the boll weevil and earlier stalk destruction, September 1, is now required for the Valley). Cotton of the El Paso Valley is allowed to stand until February, long past the time of major pink bollworm diapause (Allen *et al.*, 1985). However, unlike the warm Rio Grande Valley, low winter temperatures often occur at El Paso, bringing greater winter mortality to pink bollworm larvae. Benefiting from a long production season, Arizona has been reluctant to impose stalk destruction dates that are contrary to the opportunities for high cotton yields that are seen by growers to go hand in hand with the long season. Hence, a mid-winter stalk destruction prevails. For another western area, the Imperial Valley of California, there has been a recent change of heart. Accommodated by a warm and long production season, and known for its high yields, the Valley in recent years has lost acreage to the companion difficulties of insecticide resistant major cotton insects, secondary insects and mites, and the onerous expense of the insecticides required to answer the pest challenge. During the last ten years cotton farming has declined 120,000 acres (Anonymous, 1988). The mid-winter stalk destruction time established for the Imperial Valley has allowed abounding overwintering of the pink bollworm, and insecticides for the control of the pest have commonly triggered infestation of bollworm and tobacco budworm and other secondary pests. Until recently, growers have not been agreeable to crop termination procedures that would meaningfully go to the center of the problem; a September harvest practice (which would bring reductions in pink bollworms) has been viewed as unrealistic for their yield priorities. That, as late, has changed; a grower referendum has approved the requirement for the application, by September 1, of a preharvest defoliant, this to be followed by prompt harvest and stalk destruction and plow up by November 1. Such a program, if followed through, could ease the expense and difficulties of insect control in the cotton in the Valley. Though stalks would not be destroyed here in early September, the harvest-aid chemicals and the subsequent harvest (and the stalk destruction to follow) will certainly reduce numbers of diapausing pink bollworm.

ESTABLISHING EARLINESS

GENETIC EARLINESS

Although prompt stalk destruction for weevil management was commonly viewed with disdain because of the impracticality of a mule powered operation, early-producing cultivars that had arisen out of the genetic variability of the planted cottons of the 1800s quickly were seized upon as a means to cut losses to the pest. Within four years after the entry of the weevil, Howard (1896) recommended that farmers plant early-maturing cultivars, and the wisdom of this recommendation was confirmed shortly by other agricultural scientists (Bennett, 1904, 1908; Mally, 1902; Newell and Rosenfeld, 1909). To appreciate the genetic variability that provided cotton producers with this timely means of limiting losses to the boll weevil, one should consider the types and origins of upland cotton being grown in 1892; remember also that scientific development of cultivars of any crop awaited, in the early 1900s, the rediscovery of Mendel's laws. Yet, in the absence of these laws, progress in cotton "breeding" was already being made.

Over the time span covered herein, we will use the term "cultivar" to denote a commercially grown genotype of cotton, realizing that the term "variety" was in vogue until about 1970. The reader should be aware that most cultivars, if not all, from colonial days until probably 1915 or so were not pure lines but rather mixtures of several genotypes, and probably still segregating for others.

In the late 1700s, only two types of cotton were grown on the upland or interior portion of the United States. These were Georgia Green Seed, a cotton introduced to the coastal states from the West Indies by botanist Philip Miller, and Creole Black Seed, which was grown in the lower Mississippi River Valley. The French had brought in the latter about 1730 (Moore, 1956). Lacking a range of useful genetic variability, these cottons likely would not have furnished the kind of germplasm needed in developing the more productive and adapted cultivars that shortly were to be demanded as cotton began its spread from the uplands near the Atlantic coast on to the west. Fortunately, another source of germplasm was soon to appear; and its entry was a new turn for the crop. At no time was that turn more significant than it was in the first years of boll weevil infestation.

Walter Burling, a Mississippi planter from Natchez, traveled to Mexico in 1806 officially to mediate a boundary disagreement between the Spanish territory of Mexico and the Louisiana Territory, a dispute that had kept both sides uneasy throughout the year. To this end, Burling sought and was granted an audience with the Viceroy of Mexico, Jose De Iturrigaray. Following discussions on the dispute, Burling, on a matter of personal importance, opportunistically requested seed of a certain cotton that he had heard of that was grown by Indians of the Central Mexican Plateau. Viceroy De Iturrigaray denied the request. One can only surmise that official Spanish policy was not to part with national resources such as crop plants; at least not to allow their exportation to a territory that had been owned by their traditional rival, France, only three years prior. However, Burling was invited to dine with the Viceroy that evening. After a hardy meal and probably several glasses of wine, the Viceroy became quite cordial, insisting that Burling return to his home in Mississippi with a personal gift "Mexican dolls." The gift was presented in such a manner that Burling could not mistake its meaning; and so he returned to Natchez with dolls, the exact number being unknown, filled with contraband cottonseed (Weiler, 1976). The effects of those seeds were immediate and continuing. If the benefits of Burling's surreptitiously carried germplasm began at once to influence the course of cultivar development, it was the benefits of that same germplasm compounded by selection and outcrossing for the next eighty years that would lead the cotton industry from the weevil disaster.

The following year Burling gave the seed to a friend, William Dunbar, who apparently had received, or shortly would receive, favorable reports on the Mexican fiber from textile experts in England. Between 1807 and 1810, Dunbar increased the contraband seeds to over 3,000 pounds of ginned cottonseed. By 1820, this Mexican introduction had outcrossed with both Georgia Green Seed and Creole Black Seed. Apparently the 1806 introduction was known as Mexican Hybrid, Mexican Highland Stock, and probably by several other names. History suggests that other introductions of the Mexican cottons were made in the early 1800s; however, definite proof is sometimes lacking. The appearance of the Mexican phenotype in Georgia and the Carolinas for instance, about 1825, could have originated from seed of the 1806 introduction. Aside from seed brought by returning United States soldiers from the Mexican War of 1847-48, the historical record notes one other introduction of the stock, this by the Wyche brothers about 1857 (Ware, 1951). When the brothers emigrated from Germany in 1853, one went to Algeria and the other settled in Georgia. In 1857, the brother in Algeria sent a package of cottonseed, apparently of Mexican descent, to the brother in Georgia.

The act of nature in the intermixing of Georgia Green Seed, Creole Black Seed, and the Mexican introduction(s) brought a wellspring of variability that in time yielded extraordinary breeding opportunities; and with the help of Dr. Rush Nutt of Rodney, Mississippi and Mr. Henry W. Vick, son of the founder of Vicksburg, Mississippi, each using different selection techniques, two original cultivars arose — Petit Gulf, developed by Nutt, and One Hundred Seed, developed by Vick. As one would expect, these two cultivars were dispersed across the lower Mississippi Valley and the southeastern United States and renamed many times. Without organized plant breeding efforts and in the absence of widespread use of isolation or selfing techniques to maintain purity, outcrossing, in effect, had resulted in many local or native cultivars. The growth in the number of supposed cultivars was such that during the 1840s, Martin W. Phillips, a seed producer in southern Mississippi attempting to bring order to the trade and move beyond salesmanship and claims, conducted cultivar trials and made the results available to surrounding farmers. These trials may have furnished the first unbiased data of this kind in cotton. According to Brown (1938a), fifty-eight cotton cultivars were grown by 1880, 118 by 1895, and almost 400 by 1907. Tyler (1910), however, identified over 600 cultivars in 1907. It is evident then that a large amount of natural crossing between Georgia Green Seed, Mexican Stock, and Creole Black Seed had resulted in astonishing variability in the cotton being planted at the time of the boll weevil; and it was that diversity that had already permitted, through earlier selection efforts, the development of faster-maturing cottons. By 1900, early maturing cottons had been bred specifically for cultivation in the northern extremes of the Cotton Belt.

The immediate acceptance of the recommendation that farmers grow early-maturing cultivars allowed farmers to survive the onslaught of the pest from Mexico, although there were still yield losses. It is logical that many south Texas farmers, from their own experience, had already observed that cotton fields that fruited quickly, or the earliest-fruiting cottons, or even areas within fields that fruited early, produced more cotton. Surely, Professor Mally made the same observations in growers' fields or had visited with farmers who had had this experience. Perhaps it was this obvious advantage that had prompted him to conduct field evaluations of several cultivars that varied in the earliness quality, and the selection of an early-maturing cotton was high on Mally's list of recommendations to growers (Mally, 1902). The first published recommendation that farmers plant earlier-maturing cultivars was made by L. O. Howard (1896). Howard may have been aware of the early cultivar Dickson, which was being planted in eastern Texas by 1896. This cultivar had been developed in Georgia as an early-maturing cotton to escape the effects of caterpillars (Ware, 1951), probably cabbage loopers, *Trichoplusia ni* (Hübner). Although such things as the removal by hand of flared squares and weevils from cotton plants and the gathering of egg-infested squares beneath cotton plants became part of the Government Method (Mally, 1902; Hunter, 1904b; Newell, 1908; Knapp, 1911), planting early-maturing cultivars was the one component that growers could promptly accept since, obviously, these cottons did not disrupt normal farming operations; and because their benefits were so obvious — even to the most casual observer.

During the 86 years that intervened between the introduction of the Mexican Highland seed stocks by Burling and the first reported case of boll weevil infestation, the number of cultivars of cotton increased from two to 118. And between 1899 and 1904, the boll weevil caused an estimated reduction of 2,000,000 bales of cotton in Texas, a loss of $100,000,000 (Sanderson, 1905). When one considers the magnitude of the weevil problem during those times and the increase in apparently unique cultivars between 1806 and 1892, then the significance of Burling's trip to Mexico must be seen to rank with the development of the cotton gin by Eli Whitney. Perhaps cotton culture would not have survived without the unique genetic stock smuggled out of Mexico in 1806.

Because shorter-season cotton appeared to be the only practical way to survive the boll weevil, producers in Texas who had already experienced the destruction, and those east and north who realized that it was only a matter of time before the weevil migrated into their area, began to import in considerable quantities seeds of cultivars grown in the northern and northeastern ranges of the Cotton Belt. These cottons had been selected by necessity to be early maturing since they were grown in short-season environments. But the acceptance of these from northern areas to reduce losses to the boll weevil became a bittersweet remedy because of the cottons' poor fiber quality, a deficiency either not recognized or appreciated or honestly considered as these early-maturing cottons were brought into Texas with enthusiasm and some fanfare. There were some areas of Texas in 1892 that produced cotton of some renown, being listed as a standard on the Liverpool, England market: "Texas one and one-eighth." Typically though, the majority of the Texas cottons of 1892 had a shorter staple. The exact locales within the state are not identified, but Ware (1951) suggests that most of the cotton grown in Texas in 1892 averaged 15/16 to 1 1/32 inches in staple. And there was a strong market for these cottons. With the introduction of cultivars from the north, however, staple length shortened; and as early as 1904, Liverpool buyers had become skeptical about purchasing cotton on the San Antonio market because of the prevalence of 5/8 inch cotton; and whereas cotton buyers once readily accepted cotton produced from Bryan to Dallas, they soon began to be very selective in their purchases

(Helms, 1980). Hailed as a means to reduce losses to the Mexican boll weevil, these short-season cultivars ironically cost the Texas cotton producer markets, a turn adding to his economic plight. If the Texas grower was caught in this quality-quantity squeeze, then it surely affected producers in the Mississippi River Valley and further east who grew cottons such as Peelers, a type developed in 1864, and Allen, developed in 1879, cottons that enjoyed premium lint lengths of 1 1/2 inches (Ware, 1951). Spinners in the New England states were the primary buyers of these valuable long-staple upland types (Ware, 1951), and although the effects of the boll weevil on these cultivars can not be directly documented, it would seem that their production was halted completely in the early years of this century, presumably because of the boll weevil and the slow rate of maturity of these cottons.

In addition to deficiency in fiber quality, the imported northern cottons had other shortcomings. The Texas big-boll cotton cultivars that had been grown before the boll weevil exhibited a meaningful degree of "stormproofness" or the degree of lint retention in the carpel walls after boll opening — a feature lacking in the imported northern types. Much of the cotton producing area of Texas experienced winds sufficient to require some degree of protection against shattering. Too, producers in Texas and other parts of the southern portion of the Cotton Belt did not care for the small bolls of the introduced northern cultivars; small-bolled cottons slowed harvest. Although inferior fiber and small bolls and loose lint dogged the northern cottons, their superior yield performance under weevil attack became an object lesson demonstrating that there was resolution to the boll weevil — especially if cultivars could be bred for both the early quality and appropriate fiber length. Rather quickly, that would happen.

In the recognition of the need for a different kind of cotton for the southern parts of the Cotton Belt, procedures for the unbiased evaluation of the performances of available cotton cultivars became established. Newell and Rosenfeld (1909) reported on cultivar trials from 1906-1908. These tests were conducted in farmer fields across a range of soil types and native fertility. In 1906, Mebane Triumph, King, and "Southern Missouri" were compared with "native" seed at two sites in Louisiana; on the farm of D. J. Bland, "hill land," and on the farm of J. E. Byram, "alluvial Mississippi Valley soil." In 1908, near Marksville, Louisiana, Toole's Prolific, Mebane Triumph, native, and "Northern Oklahoma" were compared. The results of these and other evaluations enabled growers to make intelligent choices in selecting cultivars.

As farmers and seed dealers brought in large amounts of the seeds of the northern grown cultivars with the inferior fiber properties in their attempts to "outrun" the boll weevil, certain assumptions prevailed about early-maturing cottons:

1. The large-bolled cotton such as native Texas cottons could not be grown early enough to escape the weevil;
2. The northern types by their fast developing nature could not possess good staple ("staple cotton" was a common term for cotton which pulled 1 1/8 inches);
3. Early-maturing cultivars obtained from the north and northeast parts of the Cotton Belt would "adapt" to the longer season in the southern portion of the belt and thereby become late-maturing cotton.

However, R. L. Bennett (1904), who began cotton breeding investigations under the first United States Congressional appropriations for boll weevil work, realized the errancy of the above suppositions. After only one year, Bennett concluded:

1. Texas growers need not import early cotton to escape weevils;
2. Early cottons of superior quality could be obtained from native, big- boll, good staple, Texas cotton cultivars on any grower's farm. This could be accomplished by selecting plants with the desired characteristics.

Bennett noted from studies of many plants of all standard cultivars, and from studies of many nameless cottons, that the earliest-maturing plants "sent out the first fruit limbs at the joint nearest the seed leaf." Plants that fruit more rapidly than average, he found, had short internodes on the main stem and fruiting limbs. For productivity, Bennett urged producers to select the largest plants within the above guidelines. In the years since Bennett's observations, several scientists (McNamara *et al.*, 1940; Ray and Richmond, 1966; Smith, 1984) have quantified his observations. Many later reports on the nature of earliness in cotton have supported Bennett's view that faster-fruiting plants tend to have sympodia at lower main stem nodes, shorter square and boll maturation periods, and reduced vertical and horizontal fruiting intervals.

Leaving an impressive scientific record before entering the commercial cotton seed business, Bennett conducted experiments demonstrating that farmers could select for earliness or lateness, productivity or non-productivity, big leaves or small leaves, natural defoliation or leaf retention at maturity, for boll size ranging from 40 bolls per pound of seedcotton to 90 bolls per pound of seedcotton, as well as for stormproofness. Bennett (1908) secured seed of a common Texas cotton, name and history unknown, from Dr. J. H. Wilson of Quanah, Texas, and demonstrated the benefits of plant selection: Plants chosen in 1904 gave rise to progeny rows planted in 1905 yielding 1854 pounds of seedcotton per acre while the unselected parent yielded only 1630 pounds per acre.

In 1904, Dr. D. N. Shoemaker developed Express, an early cultivar not well accepted because it had small bolls and was not stormproof. However, it did have an improved staple length of 1 3/16 inches. Lone Star, released by D. A. Saunders of Smithville, Texas in 1905, was a big-boll, stormproof type with lint length of 1 1/8 inches (Brown, 1938a). These are but two examples of the rapid development of cultivars of cotton with sufficient early-maturity to be grown in boll weevil zones in the early 1900s, yet with satisfactory staple length. Both cottons supported Bennett's 1904 proposals.

So, earliness in cotton initially came by way of the short fiber "northern" types and later from cultivars specifically bred for earliness after the weevil's arrival. However, two cottons with sufficient earliness to escape weevil damage had already been developed before the hour of the boll weevil, and these were being planted in Texas. Though both had adequate fiber length, these cottons seem to have been overlooked in the first confused years of the weevil's tenure. Perhaps the most widely grown was Triumph, a cotton selected by A. D. Mebane of Lockhart, Texas, using the plant to row method. An unusual man, a man venerated in later years by cotton interests, Mr. Mebane was both farmer and plant breeder (but without portfolio). Mebane Triumph became a kind of standard by which to judge new cultivars grown under boll weevil infestation, and the cotton was widely planted for many years (Ware, 1951). It seems then that, had there been interest, many cultivars with earliness and quality fiber could have been developed before the weevil's entry. But in the absence of the pest, it is evident breeders of the southern parts of the Cotton Belt attached little value to earliness.

Cotton breeding had been practiced in the United States through selection of seed and plant characteristics from 1807 until the early twentieth century. Some hybridizations were made along the way but scientific cotton breeding began with Dr. H. J. Webber, a USDA scientist hired in 1898 to develop improved cultivars of upland cotton. Although some cotton breeding had already taken place at several state experiment stations, including Alabama, Georgia, South Carolina and Tennessee, the programs had been of little permanent value (Brown, 1938b). By 1914 a new force was beginning to exert influence on the United States cotton farming scene. Men of vision realized the commercial application of the new-found science of plant breeding. Initial hybridizations and selections for commercial sale of cultivars had begun at Hartsville, South Carolina by D. R. Coker, and at Stoneville, Mississippi by H. B. Brown and E. C. Ewing (Ware, 1951) — the days when each farmer selected and saved planting seed were coming to an end. The commercial cotton breeder, armed by the new and rapidly expanding knowledge of genetics, supported by germplasm enhancement by USDA and experiment station breeders and geneticists, would work a modern miracle, albeit slow, over the next 50 plus years.

DATE OF PLANTING

With the coming of the weevil, the term "earliness" took on a much different meaning. Prior to the 1890s and early 1900s, a cultivar or crop was early if it matured a reasonable number of bolls prior to frost. But during the early weevil years, farmers and agricultural scientists began to think of an early cultivar and early production in terms of the production that occurred before the late season buildup of boll weevil populations. Early planting as well as fast maturing cottons was recommended to achieve this goal. The entreaty (Howard, 1896; Mally, 1902; Bennett, 1904; Brown, 1938c) to plant as early as possible in order to make an early crop probably told farmers what they already knew. Producers would have seen from experience that early planting resulted in an early crop and less weevil damage or would have learned the same thing from word-of-mouth advice of other farmers.

Although the apparent way to live with the boll weevil was through early-maturing cultivars, early planting and cultural practices to promote earliness (Howard, 1896; Mally, 1902; Knapp, 1911; and Newell and Rosenfeld, 1909), the idea of late planting as a tactic to starve the emerging overwintering weevils in the spring periodically surfaced. The rationale of late planting was that it delayed the appearance of the first cotton squares so that food was denied to weevils recently emerged from winter quarters. As sound as that may have appeared, it rarely, if ever, worked. Having built to great numbers on early-planted cotton, weevils would disperse and flock to late-planted cotton, overwhelming it before an adequate crop could be made. Newell and Rosenfeld (1909) dryly made the following succinct comments about late planting:

1. Weevils emerge in Louisiana from March 22 through June 28. Over 30 percent of the weevils remain in winter quarters until May 15;
2. Cotton planted early is squaring rapidly by July 1 when weevils are reproducing rapidly and it therefore has a chance of producing squares faster than the weevils can destroy them;
3. Cotton planted late is squaring very slowly by July 1 while weevils are reproducing very rapidly; and,
4. If late planting was useful then surely some of the "thousands" of Texas farmers would have discovered that fact by accident by 1908.

Later in this chapter we will describe how purposefully delayed planting in a region of Texas has reduced weevil losses.

ROW WIDTH AND DRILL SPACING

While it is true that the search to find ways to live with the boll weevil stimulated interest and spurred investigations into optimum row widths and plant densities for earliness, these types of scientific inquiry were underway before the weevil affected production and, in some instances, before the boll weevil was ever heard of. The earliest report was by the North Carolina Agricultural Experiment Station in 1888 (Reynolds, 1926). Similar studies were reported from South Carolina, Georgia, Alabama, Mississippi, Louisiana, and Texas before 1907, with many of these conducted obviously before the impact of the boll weevil had been felt (Barrow, 1894; Duggar, 1897, 1898, 1899a; Ferris, 1904; Fox, 1907; Lee, 1889, 1891, 1892, 1893, 1894; McBryde, 1891; Newman, 1890; Newman and Clayton, 1891a, 1891b; Pittuck, 1897; Pittuck and McHenry, 1899; Redding and Kimbrough, 1906; Newell, 1909b).

Typical conclusions were those of Redding and Kimbrough (1906): "The experiments that have been made indicate unmistakably that the cotton plants should be thinned to one in a place; and that the rows should be narrow and the plants wider so as to be more nearly equidistant. Of course on very thin land requiring a very thick stand, the rows can not be economically, with reference to expense of planting and cultivating, closer than 30-36 inches and plants may then be not farther apart than 10 to 12 inches...land capable of a yield of 3/4 to 1 1/2 bales per acre the rows should be 3 1/2 to 4 feet wide and the plants 12 to 18 inches apart in the drills, the narrower rows and the closer spacing for less productive soils." However, Newell (1909b) reported on plant spacing studies conducted in Louisiana in 1907 and 1908, comparing wide (rows 6 to 7 feet apart and plants 18 to 24 inches apart), medium (rows 4 1/2 feet apart and plants spaced 12 to 15 inches), and narrow (rows 3 to 3 1/2 feet apart with plants spaced 12 inches within drills) rows. Of four such experiments, the narrow rows outyielded both wide and medium row widths.

Brown (1923) concluded from 64 spacing experiments conducted across the Southeast and Mid-South that the superior and most consistent yields, in the absence or near absence of the weevil, were from plants spaced 12 inches apart in 3 1/2 to 4-foot wide rows. On less fertile land, closer spacing gave better yields. Under slight to heavy weevil infestation, Brown concluded that it was not practical to leave plants close enough in the drill for maximum yields. Grass and weeds had to be removed with hoes that measured 7 to 8 inches wide, and therefore the producer, at best, could obtain only two to three plants per hill spaced approximately 12 inches, since a chopper rarely "came within an inch of what she was looking at," and sometimes, "was not looking at the row at all." Brown suggested that producers try to obtain four plants per hill on poorer soils. Brown noted that, "with heavy weevil infestation the fruit must be set in a very short period of time, say a month or less." This time period, thirty days or less, is similar to that proposed by Walker and Niles (1971) for the short-season production system that has found favor with producers in parts of Texas, as we shall cover in a later section.

For a brief period following the weevil's entrance from Mexico, the strategy was to plant very wide rows since immature weevils in fallen squares often perished from hot, dry weather when squares fell into clean, dust-mulched middles where abundant sunshine could reach (Mally, 1902). In fields with rank stalks, such as that found in the fertile alluvial soils of river bottoms, little sunshine reached fallen squares and survival was much favored. Mally advised growers to plant in wide rows, cultivate often to create a dust mulch and cultivate in such a manner as to create a slope towards the middle of the furrow such that shed squares would be blown by spring winds toward the open and sunny middle. In addition, growers should plant rows in a direction that allowed the greatest penetration of sunlight; plant such that prevailing winds would blow the fallen squares into the cultivated furrow and away from the natural shade of the plants. Mally's wide rows did not endure, and in time standard row widths of about 36-40 inches came to be accepted.

Soon scientists recognized that closer spaced rows or closer within-drill spacing of plants suppressed the development of vegetative limbs and hastened maturity, encouraging the development of more uniformly small plants (Cook, 1913; Martin *et al.*, 1923). Reducing plant size was desirable under boll weevil conditions, for it created a microclimate conducive to weevil mortality, the same reasons expounded by Mally in defense of wider rows. Hunter and Pierce (1912) reported 23.8 percent mortality of immature weevils from heat and dryness in cotton middles where sunlight could penetrate. Smith (1921) reported up to 91.3 percent mortality under Florida conditions, and McNamara (1927) suggested that it could be even higher in the dryer areas of Texas.

By the 1930s, it was well established that where the boll weevil was a recurring pest, a population of 50,000 plants per acre would result in higher yields and earlier maturity than would result from a stand of 10,000 plants, which was often recommended in non-weevil areas (Reynolds, 1926; Ware, 1930; Cotton and Brown, 1934). It was recognized that thicker stands resulted in fewer blooms per plant but more blooms per acre during the early blooming period; and that translated into a yield increase in the first harvest, although not necessarily in an increase in total yield. But the increase in earliness was often the major objective in combating the weevil; in later years, the pink bollworm, bollworm, and tobacco budworm. Common to all spacing and planting density work from 1888 to the present has been the goal to discover the optimum row configuration and plant density that will result in highest cotton yields.

Although production technology and cultivars have changed dramatically since the introduction of the boll weevil, the desirability of developing earlier-maturing cultivars and technologies to achieve earlier crop maturity remains. Vital to early maturity in modern production is the control of certain insects that delay crop maturity: *Lygus* spp., thrips and cotton fleahoppers; and establishing earliness by eliminating their damage often translates to reduced problems with weevils, bollworms, and tobacco budworms. In recent years, earlier-maturing cultivar development, the Texas short-season production technology and very narrow-row/high plant population production technology have received much attention relative to earlier crop maturity (Davis *et al.*, 1978; Niles, 1970; Taylor, 1971; Ray, 1970; Walhood and Yamada, 1972; Bridge *et al.*, 1975; Bridge, 1986; Sappenfield, 1985; Bird *et al.*, 1986; Smith, 1988).

FERTILITY

A considerable amount of on-farm experience had occurred by 1912 with organic and inorganic fertilizers, along with some scientific experimentation that documented the amount of nutrients removed from the soil by cotton (White, 1896; McBryde, 1891; Duggar, 1899b). But, as with the development of early-maturing cultivars and recommendations on row widths and plant densities, the boll weevil was the new impetus to investigations into the nutrition of cotton (Newell and Rosenfeld, 1909; Hunter and Coad, 1923). Bennett (1904) noted that nitrogen had been known for some time to hasten growth but also to delay the onset of fruiting; that potash would delay maturity; and that phosphorus would hasten fruiting and early boll set. Later, of course, it was recognized that proper nutrient balance only brought optimum growing conditions and that the apparent delay or improvement in earliness were only artifacts. The following are data of Bennett (1904) from experiments conducted in 1903:

Fertility treatments	Plant height	Squares/stalk @ 65 days	First harvest	Total yield
Acid P	18	8-16	683	1003
N	6-9	0-4	195	570
K	6-9	0-4	320	684
O	6-9	0-4	343	740
Complete	—	—	720	1105

- Plant height in inches; harvest in pounds seedcotton per acre -

Such results led early scientists to conclude that phosphorus, in some way, caused cotton plants to fruit faster and yield more in the presence of the boll weevil, again an artifact. The obvious benefits of adding nutrients to soils were seen in crop earliness and yields and were especially striking on the southeastern soils that had been cropped for many years with little attempt made to replace depleted nutrients or to provide nonexistent nutrients.

Scientists would soon determine the role of phosphorus in the energy system of plants, learning that it is stored in relatively large supply in seeds for the energy process. But in 1903 too little phosphorus meant poor plant health, fewer seeds and thus less fiber. By 1923, and in the years since, agricultural scientists were urging producers not to use excessive fertilizer, especially nitrogen, because the abundant vegetation that followed caused problems of late maturity and hindered insect control (Hunter and Coad, 1923; Brown, 1938d; Nelson and Ware, 1932; Murphy and Sanborn, 1929; Tucker and Tucker, 1968; Mistric, 1968; Beckham, 1970; Maples and Keogh, 1971).

CHEMICALS THAT HASTEN MATURITY; IRRIGATION AND NITROGEN MANAGEMENT

In more recent times, scientists (Kittock *et al.*, 1973; Bariola *et al.*, 1976; 1986; Bariola and Henneberry, 1987; Ehlig *et al.*, 1983; Hopkins and Moore, 1980; Kittock *et al.*, 1979) explored the possibilities of reducing the number of days required to produce and harvest cotton by terminating the growth of the crop by certain chemicals. This line of work showed that use of ethylene producing compounds late in the season will cause squares and small bolls to shed, thereby eliminating food supply and reducing the population of diapausing pink bollworms and boll weevils.

In the desert areas of New Mexico, Arizona, and California, where rainfall rarely interferes with irrigation scheduling, producers can reduce or eliminate late irrigations and decrease nitrogen fertilization such that the crop will "cut-out" earlier (Kerby *et al.*, 1984). This production strategy allows for earlier stalk destruction and reduces populations of diapausing pink bollworms and boll weevils.

REDISCOVERING EARLINESS

The groundswell for earlier-maturing cultivars diminished by the 1920s as the "Promised Land" of complete chemical control of insects arrived in the form of an insecticide, calcium arsenate, a product that growers never enthusiastically accepted. If breeding for earliness lost momentum with the appearance of this chemical in 1916 (Coad, 1918), then it came to an almost complete stop with the development of the organic insecticides after World War II. These later compounds were far superior to the arsenical, and the need for earliness as an escape mechanism was no longer so persuasive. This hiatus of sorts, especially after World War II, away from the major push to develop earlier genotypes, gave the fledgling cultivar development industry an opportunity to concentrate on yield potential. Breeding efforts in the rainbelt and irrigated West were directed almost entirely to yield potential of full season types, to take advantage of the botanical indeterminacy of cotton. Yields have steadily increased in the Mid-South, averaging 21 pounds (9.46 kg) of seedcotton gain per acre per year from 1910 to 1979 (Bridge and Meredith, 1983). Surely similar results could be claimed for the remainder of the United States Cotton Belt.

Calcium arsenate had provided a means of significantly reducing losses to the boll weevil, but its use was often linked with outbreaks of secondary pests (Ballou, 1919;

Sherman, 1930). However, the shortcomings of this chemical were forgotten with the synthetic chlorinated hydrocarbon insecticides, and the exodus away from early-maturing cultivars became complete (Walker, 1984). However, by the mid-1950s, the constant selection pressure on the boll weevil population effected a shift in the creature's gene pool to one that contained a large percentage of individuals resistant to the chlorinated hydrocarbons (Brazzel, 1961; Roussel and Clower, 1955). The agricultural chemical industry responded with the organophosphate methyl parathion; and it gave almost complete control of weevils; and chlorinated hydrocarbons, such as DDT, were added to control bollworm and tobacco budworm. The American cotton producer was mesmerized, for the moment, into thinking that all insect problems could be corrected with the right chemical(s). However, within a few years increased dosages of the chlorinated hydrocarbon compounds were often required to control bollworm and tobacco budworm; and by 1965 these chemicals were deemed ineffective in certain areas of the Cotton Belt (Adkisson, 1964; Adkisson and Nemec, 1966; Brazzel, 1964; Harris *et al.*, 1972; Nemec and Adkisson, 1969). For a brief period, bollworm and tobacco budworm were controlled with high rates of methyl parathion; but resistance was soon detected in the tobacco budworm (Brazzel, 1963). With this development, researchers began turning their attention toward the advice of Mally and Bennett sixty years before. New interest in developing earlier-maturing cultivars began in the 1950s, accelerating in the '60s and '70s. Producers and entomologists began to look again for earlier maturity as the cornerstone of cotton insect management. Shortening the growing season reduced exposure time to insects, thereby reducing the number of insecticide applications. Less insecticide was lauded by all, for it placed less selection pressure on insect populations, was cheaper and environmentally desirable. Where bollworm and tobacco budworm outbreaks were attendant with late season insecticide applications for control of weevils, earliness became the structure around which schemes were designed to manage the boll weevil, schemes with less dependence on insecticides. With the rediscovery of earliness and cultural control in general, equipped now with new knowledge of the biology of weevils and other pests, integrated pest management (IPM), systems approach, short-season concept, and communitywide approach became the slogans of the day; and early-maturing, more agronomically determinate cultivars were once again the cornerstone. Walker and Niles (1971), working to understand economic thresholds of the weevil, found that fast-fruiting genotypes could set an acceptable crop of bolls that could escape first generation weevil damage if fields were infested with twenty or fewer overwintered females per acre. But if 60 or more females were found, then the first generation population of weevils would be of sufficient numbers to cause economic loss. This work led to the conclusion that it was important to have thirty days of blooming before weevils built to damaging levels. Thirty days of blooming would result in a sufficient number of bolls, of sufficient age, to escape major damage (Walker and Niles, 1971). Therefore, genotypes setting the greatest number of bolls in the first thirty days of blooming would have a production advantage under reduced insecticide production schemes.

This understanding of overwintering weevils and population dynamics was refined by Parker *et al.* (1980) who reported that 5000 or more punctured squares per acre before bloom meant that a destructive population would build by the twentieth day of bloom, while 1500 or fewer punctures indicated that damaging levels would not occur until the thirtieth day of blooming, or later.

From 1970 through 1973, Sterling and Haney (1973) directed the systems approach to insect management on the farms of the Texas Department of Corrections, increasing yields and decreasing insecticide use. Other researchers reported on the economic advantage of integrated pest management (Carruth and Moore, 1973; Frisbie *et al.*, 1976; Larson *et al.*, 1975; Collins, *et al.*, 1979).

Another event has recently sparked interest in short-season cultivars. The energy crises of the 1970s and the resulting inflation hammered home a startling point: Chemicals were no longer cheap and irrigation water would become more expensive (Schaunak *et al.*, 1982); and in this new reality, short-season cultivars broadened their appeal.

We now digress to the mid-1950s to document one of the first renewed efforts to move toward earlier-maturing cultivars for rainbelt production. Carl Moosberg, USDA cotton breeder headquartered at Marianna, Arkansas released, in 1957, the cultivar Rex; and it was a cotton meaningfully faster fruiting than the then currently available cultivars (Waddle, 1957). Developed for mechanical picking and rainbelt production, Rex was 10 to 14 days earlier than other commercially available cultivars in Arkansas; and in one comparison at Marianna, Rex produced 1112 pounds of seedcotton at first harvest while a "popular cultivar" produced only 409 pounds. Rex outyielded the check cultivar by approximately 350 pounds of seedcotton (Moosberg and Waddle, 1958). With the development of Rex, Moosberg, as had Bennett (1904), demonstrated that earliness could be obtained without sacrifice of yield or quality in picker-type cottons. Ironically, Rex's phenotype was similar to that advocated by Bennett (1904); it had short sympodial internodes and, for 1957, much shortened vertical and horizontal fruiting intervals.

With the cumulative problems of resistance in populations of weevils and tobacco budworms; with harvest problems of late-maturing cultivars, especially in years when the effective growing season was reduced by the early onset of low temperatures; with harvest problems that arose with excessive rates of fertilizer, especially nitrogen; and with the possible delays in maturity associated with certain organophosphate insecticides, breeders began to follow Moosberg's lead, giving consideration to earlier-maturing genotypes. The move to earlier-maturing picker types gathered steam with the release of the DES cultivars in Mississippi in the early 1970s, quickly to be followed by privately developed early-maturing cultivars; and today all cultivars grown in the Mid-South are considered early-maturing. In fact, Bridge and McDonald (1987) found that 34 fewer days were required from planting to final harvest of the Mississippi Cotton Cultivar Trials at Sumner and Stoneville in 1986 than were required in 1968.

As breeders in the Southeast, Mid-South, and Far West proceeded cautiously toward short-season cultivars, attempting at the same time to maintain agronomic indeterminacy, breeders in Texas moved quickly to determinate, ultra short-season (for their day) cultivars. The work of Walker and Niles (1971) had demonstrated the wisdom of planting these types, and L. S. Bird and others put the concepts into practice. Tamcot SP21, SP23, and SP37 were released in 1973; and they fit the requirements for determinacy and productivity (Adkisson, *et al*., 1982; Bird, 1975). These cultivars were especially useful for production in the Coastal Bend area of Texas. The expense and difficulty of insect control had almost driven cotton production out of this five county area near Corpus Christi, with only 50,000 acres remaining by the early 1970s. Acreage planted to cotton in this region increased dramatically during the years following the release of the determinate Tamcot germplasm, and by 1979 near 300,000 acres were grown. Adoption of the Tamcot cultivars and the attendant cultural control of the boll weevil through early harvest and stalk destruction have resulted in an estimated increase of $11,000,000 in producer profits in 1979 (Lacewell and Taylor, 1980; Masud *et al*., 1980).

In higher rainfall production areas, short-season technology, as that used in the Coastal Bend of Texas, could not be transferred. Normal rain patterns and amounts, less than 40 inches, supported the use of determinate types in the drier Coastal Bend area of Texas. But in areas that receive 50 inches of rain per year or more, the new determinate Texas cultivars were found to be poorly adapted. Rainfall amounts and distribution in those areas dictate a less determinate and larger plant type for optimum economic yields. In the irrigated areas of New Mexico, Arizona, and California, agronomically determinate types are presently not acceptable because of the availability of irrigation water and an accommodating long production season that encourage the use of agronomically indeterminate cultivars for maximum yields of superior quality lint. However, all producers in the United States recognize the value of earlier cotton production; they recognize the dollar savings associated with the reduced inputs and are more comfortable with the lower risks that earliness carries.

SEEKING PLANTING LOCATIONS OF LESS RISK

Among the cultural recommendations to emerge from entomological research in Texas in the first years of boll weevil infestation was the cautious suggestion that cotton might be planted at locations where there was less risk from the pest; by 1912 some growers had found the merit of the advice. Hunter and Pierce (1912) showed with maps the decreasing intensity of weevil attack in Texas as cotton had moved west, especially where the crop was planted west of Austin. They added that the percentage of Texas bales produced in this area was increasing yearly. By the late 1920s, near five million acres of cotton were being planted in the Rolling and High Plains as dryland cotton (Bonnen and Gabbard, 1947); and this was acreage free from the weevil. The lower rainfall here, 18 to 25 inches, the low humidity and the harsh winters, all seemed to wall off this space of the state from the weevil; and the classical maps published each year by the USDA that charted the weevil's advance in the United States dramatized how western Texas formed as a redoubt, country free from the insect (Metcalf and Flint, 1939).

The High Plains had little of the forest habitat so important to overwintering of the weevil in the east; and if patches of hardwood cover could be found in the Rolling Plains, the pest had great difficulty in establishing in threatening numbers. If the weevil overwintered here in those years preceding the late 1950s, it was only in seasons of extraordinary description; and even then it was in scatterings of meager numbers. These lines held until the 1960s. Then boll weevils, likely through the genetic selection of a biotype, began to overwinter, and in large numbers, in the Rolling Plains. A recent cultural strategy for this new turn will follow in the next section.

The appeal of growing cotton where boll weevils were presumed absent was persuasive; and that, together with irrigation technology, prompted the crop movement west, to California, Arizona and New Mexico (Turner, 1981). Grown fitfully in California, experimentally and commercially, before and after the Civil War, cotton by the late years of the nineteenth century had been abandoned in the state. Then, in attendance with the development of western irrigation projects after the turn of the century, cotton acreage started back and grew to include production in Arizona and New Mexico.

The series, CENSUS OF AGRICULTURE, published by the United States Department of Commerce, provides the following data on the extraordinary growth of western production:

State	Year	Acres of cotton
California	1889	0
Arizona	1889	0
New Mexico	1889	0
California	1909	324
Arizona	1909	19
New Mexico	1909	790
California	1919	87,308
Arizona	1919	106,283
New Mexico	1919	10,666
California	1929	300,058
Arizona	1929	211,178
New Mexico	1929	136,700

For the moment, this new production in the western states, for all purposes, had left the boll weevil behind; but, as we wrote, another insect, the pink bollworm, would soon take its place. Adding to that problem has been the recent elevation of the pest status of the boll weevil in Arizona (Moore, 1985). But for years the western strategy had worked; and even today the largest production area, the San Joaquin Valley, remains free of the weevil and the pink bollworm. [In 1912, a form of the boll weevil was unexpectedly recorded in Arizona on a wild mallow, the thurberia plant (Pierce, 1913); and a few years later the insect was noted as a pest of Arizona cotton. But infestations for years were sporadic and commonly of little consequence, though severe damage was measured occasionally. For a number of years, the biology of this Arizona insect seems to have been different enough from the biology of the boll weevil of eastern cotton that the Arizona weevil was less a threat to cultivated cotton. That status gradually changed, and today the boll weevil of Arizona cotton possesses the same imperious qualities that characterized the highly destructive boll weevil of southern Texas in 1894.]

If cotton could be grown almost free from the weevil for a long period in the arid western states, it also could escape much of the damage of the pest by moving north in rainbelt country. The crop of northern Arkansas no doubt benefitted; but the "northern tactic" is probably better illustrated by acreage growth in Missouri, especially in the Bootheel of this state (Lewis and Richmond, 1968). The CENSUS OF AGRICULTURE gives these data:

Year	Acres of cotton, Missouri
1899	57,260
1909	96,527
1919	110,027
1929	352,899

Cold winters, perhaps a paucity of overwintering habitat, contributed to a reduced weevil problem; and growers took advantage of it.

In short, about six million acres of cotton were being grown in the late '20s in country chosen in part because it was recognized that the boll weevil either was not a threat or, at worst, only a small matter for concern. Growers had exercised an option to plant acreage at locations purposefully selected to avoid the insect, a cultural option.

Within the traditional country of rainbelt cotton production, growers probably selected certain planting sites because they regarded the weevil as less a threat there. Certainly, any field distant from extensive spaces of trees and leaf litter where the insect could overwinter in great numbers owned an advantage; and Rummel and Adkisson (1970) described, in some detail, the likelihood of weevil infestations in cotton fields located at various distances from wooded habitat in the Texas Rolling Plains. Again, exercising a cultural option, growers here could select planting fields based on the calculations of risk presented in that study.

COMMUNITYWIDE DELAYED PLANTING

Time and time again, entomological writers of the first twenty years of this century, as they considered the course of action to be taken against the boll weevil, entreated farmers to plant cotton early. The Government Method considered early planting as a major tenet, ranking in importance, probably, just beneath the selection of a cotton variety that produced quickly. For most of the cotton of the United States, early planting still forms as a requisite for a judicious cotton farming operation. There is, however, an exception.

Secure from damaging infestations of the weevil until the early 1960s, the Rolling Plains of Texas, a region of low inputs, frugal budgeting and low yields, could not add the extra expense of a series of insecticidal treatments for weevil control to its tightly defined economic situation and survive as a viable cotton producing region. Because Rolling Plains cotton is not harvested until November or later, early stalk destruction could not be used as it is in south Texas to manage weevils. An alternative was needed and one was developed. Out of indepth ecological investigations of weevils in the Rolling Plains came understandings, and these led to a major cultural adjustment by cotton growers. Investigating the overwintering weevil habitat and cotton of the Rolling Plains, Rummel and Adkisson (1970) remarked the obvious effect of phenological age of cotton and the disposition to weevil attack. Intensity of infestation was clearly more severe in early planted fields, and these entomologists conjectured that cotton purposefully planted late might serve as a management strategy. In controlled studies in the region, Slosser (1978) verified this.

White and Rummel (1978) added understandings of overwintered weevil infestation, describing the pattern of entry into early-planted and late-planted cotton. Far more weevils entered cotton of both planting times after the first squares appeared — though sharply fewer infested the late-planted. Other Rolling Plains' studies examined the longevity of overwintered weevils infesting cotton at different phenological ages of cotton; in the absence of fruit, mortality came swiftly. On the other hand where squares were present, 67 percent of the individuals lived more than twenty days (Rummel and Carol, 1985). Early emergence and establishment in cotton before squaring, then, carries high mortality risks.

Studying the population dynamics of the weevil in Rolling Plains cotton, Slosser *et al*. (1989) measured the build-up of the first generation from eggs oviposited by overwintered weevils. Expressing essentially no growth, first generation numbers were contained by the typically harsh, dry environment and represented no threat to yields of cotton of the study. The rate of the drying process in larval infested squares has been shown to be critical to survival to the adult stage (Curry *et al*., 1982); should the process hasten, as it clearly does in dry environments, it hazards the life of the developing weevils. That is, as heat increases with the progression of summer; and when humidities are low, the risk of death of immature weevils in infested squares heightens. Delayed squaring in cotton can represent danger to immature boll weevils in the Rolling Plains.

These several findings were the substance and logic for areawide, delayed planting of cotton, a practice that delays square production until late June-early July. Taking advantage of a high level of suicidal emergence of overwintered weevils that occurs when there is an absence of squares, the system also enjoys the benefits that accrue from pushing the early squaring period later into the summer, to a time of hotter weather when square drying is more critical for immature stages. This program has been adopted by Rolling Plains growers because it works, and because it fits the requirements of the budgets of the low input Rolling Plains production. It costs nothing to delay planting. Economic analysis has measured the benefits of the practice (Masud *et al*., 1984). Planting dates, varying of course from north to south in the Rolling Plains, are set for the different communities. The program encourages growers within a community to complete planting in as short a period as possible so that square production in all cotton initiates about the same time, a result that tends to even overwintered boll weevil numbers among cotton fields. Recommended planting dates are about two weeks later than those previously used.

HABITAT MODIFICATION OR REMOVAL

The possibility of direct action against woodland habitat known to harbor diapausing boll weevils has long piqued the interests of cotton entomologists. Hunter (1909a) wrote of procedures to counter survival of the pest during the winter, and Isely (1930) described how 600 acres of cotton fields were freed of the immediate risk of infestation by clearing brush and undergrowth from about 50 acres of land interspersed among the 600. As an ongoing process, the clearing of large tracts of land to row crop cotton and other crops certainly has brought the same benefits noted by Isely.

Recently, the possibilities of addressing overwintering of the insect in localized, man-constructed habitats — habitats that grew out of the experience of Dust Bowl times — have been examined. During the period 1936-1942, the Prairie States Forestry Program planted belts of several species of trees in sections of the Rolling Plains. Called "shelterbelts," often 100 feet in width, these strips interposed the cropland, serving to reduce wind-caused soil erosion. In time, the accumulation of leaf litter began to satisfy the requirements of overwintering weevils. By the 1960s, weevils were spreading to these opportunities for overwintering; and where the belts were located near cotton they became a source for weevil establishment. Slosser and Boring (1980), on this account, initiated studies on certain cultural practices for management of overwintered weevils in the shelterbelts. Describing the reduction in weevils recorded in leaf litter following fire, these entomologists concluded that the fewer numbers did not justify the damage to trees; and, moreover, secondary sprouting followed, with fresh litter swiftly accumulating. With another approach, they measured the positive benefits of pruning certain species of trees in the strips: Pruning brought highly variable temperatures to the leaf litter, and Slosser and Boring regarded this as responsible for the greater winter mortalities of weevils recorded. Writing to the future, they advise caution for expanded shelterbelt programs, recommending the selection of only those trees whose leaf litter is known to be inferior as weevil overwintering material (Bottrell *et al.* 1972). For regions free from the boll weevil because of a lack of overwintering habitat, the High Plains of Texas for example, that would consider the planting of shelterbelts, Slosser and Boring advise careful scrutiny and planning of the activity. Apparently the wide shelterbelts of the Rolling Plains, which accumulated substantial areas of litter, are not needed to stop wind erosion. Narrow belts of one to three rows of trees would fulfill the need. Nevertheless, it seems to us that the introduction of a network of windbreak belts to the millions of acres of the Texas High Plains would transform a habitat largely barren of weevil overwintering quarters to one that would permit winter survival. The scale of that survival would become known only after the fact.

IRRIGATION TIMING

Slosser (1980) explored the effects of irrigation on bollworm infestations in cotton of the Texas Rolling Plains in experimentation of three years. Using the computer forecasting model, MOTHZV-2 (Hartstack *et al.*, 1976), he was able to predict (and anticipate) peak periods of oviposition (egg laying) in cotton, verifying these by sampling.

The model proving accurate, Slosser showed that irrigation applied during peak moth activity abetted the pest in two ways: (a) In cotton that was water-stressed at the time of irrigation, more eggs were deposited than in water-stressed cotton not irrigated; (b) and, in cotton not suffering from water stress, irrigation applied at peak ovipositional activity smartly increased larval survival over the non-stressed, non-irrigated control plots.

Because the computer model established accurately, within a few days, the time of peak oviposition, Slosser concluded that the predictions could be used, by design, to advance or delay an application of water purposefully to the detriment of the bollworm.

PLANT BUG MANAGEMENT IN ALFALFA AND COTTON

Cotton culture of the San Joaquin Valley of California enjoys an enviable status among the production regions of the United States: Neither the pink bollworm nor the boll weevil occurs here, and consequently insecticide and miticide use is insignificant. Secondary attacks, bollworms and tobacco budworms for example, that so commonly break out in other regions following treatments for the weevil or pink bollworm are not a factor in the Valley today. But this has not always been the case. University of California entomologists remember a period thirty years ago when insecticide use for the plant bug complex, principally *Lygus hesperus* Knight, was followed by multi-treatments for a complex of other pests; sometimes as many as eight were required (personal communication, V. M. Stern). Research began to explore this problem. Alfalfa, investigators noted, served as one of the main reservoirs of the bugs, and the cultural management of alfalfa had much to do with infestations of these pests in cotton (Stern *et al.* 1964; Stern *et al.* 1969). Preferring lush alfalfa, plant bugs primarily would remain in strips of the hay crop interplanted in cotton if these strips were maintained lush by irrigation. When marked bugs were released, most found their way to the alfalfa, not cotton. The hay obviously was a superior host for the bugs.

Harvesting practice of alfalfa was directly incriminated as influencing the spread of the bugs to cotton. If complete harvest of an alfalfa field caused massive migration of plant bugs to cotton, entomologists found that cutting the hay in strips and leaving strips of uncut hay held the bugs in the uncut strips. Again, it was necessary to maintain the alfalfa in a lush condition. Growing from this has been a conceptual understanding of California growers: that it is their management of alfalfa that determines whether plant bugs become a pest of nearby cotton. Providing clarity to a once perplexing cotton problem, research has guided farmers into alfalfa production schemes that influence the course of plant bug infestation in cotton.

OTHER CULTURAL APPROACHES

The possibilities of small plantings of cotton, trap crops, as a piece of the overall boll weevil strategy have occupied the interests of entomologists since the days of Townsend. A leitmotif (leading motive), this approach through the years has waxed and waned only to flourish again as researchers were persuaded and discouraged before what appeared to be its transcending argument (Niles *et al.*, 1978). Transcending as it might seem, trap crop plantings have not found their way into practice. There are good reasons for this.

In its simplest form, the trap effect of early planted (and early fruited) cotton is its attraction to what are obviously disproportionately large numbers of overwintered weevils. This was surely noted by Texas farmers during the first seasons of the boll weevil, and it was formally recorded in the writings of Townsend and Mally. Extending from such observations was the recommendation of Mally (1902): plant, and at an earlier time, small plots of an early-fruiting cotton alongside fields that would be planted later to the main crop. The exaggerated numbers of overwintered weevils that gathered there were presumed to occur at the expense of the weevil infestation of the main crop: Overwintered weevils were being lured from the main and commercial planting by the early-fruited trap crops. Then as now, that was the appeal of this scheme.

Researched, trap crop planting seems to have lost a measure of practicality. It has been difficult to be able to sow the plots early enough in the season to fix a strong differential in fruiting between the plots and the main crop. And even when differentials in squaring rates have been effected, the reports of efficacy in managing the pest in the commercial cotton near the traps have been mixed (Niles *et al.*, 1978). Trap cropping for boll weevil management is not used today by farmers.

There are several once-recommended cultural practices that are largely forgotten today — from the use of a chain implement to drag fallen weevil infested squares to the middles of cotton rows, to the Florida Method (Little and Martin, 1942).

Evidently the Florida Method appealed to farmers of certain regions of the eastern United States and was practiced. Interesting because it seems to have been built on ecological understandings, the Florida Method entailed the removal, by hand, of the first squares punctured by overwintered weevils; these squares, and any weevils collected, were destroyed. Then, the cotton plants were either dusted with a single application of calcium arsenate or their terminals were mopped with syrup-calcium arsenate mixture. Based on weevil hibernation cage data that suggested that major colonization of overwintered weevils had occurred by the time of first squares, this approach was used by Florida growers farming the crop on lower yielding soils (Little and Martin, 1942; Smith, 1922, 1924). As an effective control, it seemed more appropriate for cotton grown in areas where weevil overwintering habitat was restricted. Although there is colonization of weevils after the first appearance of squares (Walker and Bottrell, 1970), more, certainly, than was likely indicated by Florida hibernation cage experimentation, the Florida Method evidently reduced oviposition by overwintered weevils sufficiently that it importantly decreased the size of the first summer generation (Walker and Niles, 1971). The modern strategy of boll weevil management by way of insecticide applications applied at first one third grown cotton squares is obviously an extension of the Florida Method of the 1920s.

LOOKING BEYOND

Elements of the cultural strategy formed in the ideas of cotton entomologists as they dealt with the turn of the century invasion of the boll weevil and, thirty years later, with the newly introduced pink bollworm. One tactic for the boll weevil, scientists argued, was an early-maturing crop. Row widths of about 40 inches, P and K fertilizers, early planting and early-maturing cultivars, they said, would bring earliness and reduce yield losses; and farmers bought almost immediately this program and saw the benefits. On the other hand, another tactic, that of prompt stalk destruction after harvest, though heralded far and wide, in print and harangue and oration, as the most meaningful practice available to growers, rarely was carried out in the early years of weevil infestation.

Much of the weevil strategy applied to the later infesting pink bollworm. Practices to secure earliness seem to have been accepted, and unlike the failed attempts to convince growers to cut stalks after harvest to control boll weevils, recommendations for stalk and field clean-up for the pink bollworm were followed. Cultural elements for the pink bollworm in those years to the 1950s showcased the cultural strategy. So, in one instance the cultural strategy seems to have been rather adequately used, in the other, only a piece of the approach was carried out. Through 1945 this was the way, this cultural approach, that two important cotton insects were managed in United States cotton; and it worked well enough that yields of cotton held up to historical comparison. In fact, starting in 1937 and in the years thereafter, but before the introduction of the synthetic organic insecticides, yields moved upward about 40 percent compared with the average yield of the ten years prior. As meager as it would seem today, production had advanced beyond 250 pounds of lint per acre as World War II concluded. The cultural strategy had demonstrated its value; the vitality of the cotton industry remained, despite the unbidden introductions of two injurious insects. Yet, few close to the crop imagined that yields might increase further without the addition of something more. There was to be something more.

The synthetic organic insecticides that appeared in those quick, enthusiastic and heroic years after World War II found their way into agriculture, and for cotton the benefits were astounding. Yields moved upward as insect and mite damage was powerfully reduced. A permanent shield from arthropod attack, safe and economical, seemed at hand; and the importance of the cultural aspect diminished in the eyes of the industry or at least was hardly thought of.

Earliness no longer received the attention it once had, and new cottons were bred for maximum yields, even if those cottons were slow in maturity. Nitrogen fertilizer, liberally used now to take advantage of the yield capability of the new cottons, further increased production. And if irrigation was available, it could be applied to lengthen the growing season and ensure even higher yields. Arizona growers, losing all fear of the pink bollworm and forgetting the years of cultural management, extended production late into the growing season. Effective insecticides used in multi-applications had brought this, and these products had few detractors. As one cultural practice dimmed, so another tactic, which had rarely been practiced with enthusiasm and timeliness in rainbelt cotton, was given wide currency. New tractor powered stalk-cutters were being used to destroy cotton stalks, though farmers saw this as less a practice for boll weevil management than a necessity for seed bed preparation for next year's crop. Nevertheless, for whatever reason, stalks began getting cut early enough to influence weevil overwintering. It was a first step. Such was the background and outlook in the early 1960s.

But changes were ahead. The recognition, for many reasons, of the value of earliness in cotton production and growing problems with resistance of pests to the new organic insecticides and, in the distance, a building clamor of environmental concern — all would clear the way for a production system less exposed to arthropod pests. Earliness was rediscovered, and much earlier-maturing cultivars were bred; fertilizer and irrigation practice was modified to capture the advantage of this earliness; and new maturity hastening chemicals reinforced the earliness goal. After Wilmon Newell demonstrated in the first decade of this century that more cotton was produced under boll weevil infestation with very narrow rows (36-42 inches), 38-40 inches row width became standard practice. But now, modern research showed that there was a maturity advantage of cotton grown in row widths less than 38 inches. Farmers began to try this rediscovery. The return to earliness and the adoption of stalk destruction for rainbelt cotton have led to superior insect management and have brought marked reductions in insecticides in some cases.

Perhaps all of this is not "coming full circle" but it does tell of the irregular course of the cultural strategy. The approach has operated in spurts and withdrawals with rediscoveries being made along the way as priorities have formed and reformed. Perhaps the meander of the cultural strategy through the years has obscured its value in modern cotton agriculture, but it is, nevertheless, a functioning part of pest management today. The goal for the future would be to make the strategy even more meaningful in managing cotton pests. Presently, much of the United States production hangs together only because there are effective insecticides to be used in multi-treatments. It is a fragile system.

The experience gleaned from over forty years of insecticide use on cotton has not been altogether comforting. Multi-application programs are expensive propositions, and the numerous treatments, no doubt, shorten the productive life of the chemicals themselves by promoting the development of insect resistance. Then another chemical is turned to — if one is available, and largely there has been one available. At some point before us, there might not be that available option.

Hence, it seems incumbent that the industry do those things that would further lower insecticide use on the crop. The cultural elements — earliness and prompt stalk destruction — seem to be the one realistic practice that could influence insecticide use in the immediacy. It seems foolish that we should wait until the efficacy of all insecticides has been exhausted by resistance before there is modification in the cropping system of cotton. And there is another compelling reason to reduce insecticide dependency.

The insecticides of the post World War II years and for a number of years following were given to farmers as tools to be used at their discretion, convenient products for agriculture in a laissez-faire setting. That is not entirely the case today; more, the prevailing political and social temper suggests that agricultural chemicals in general are to be increasingly examined, sometimes restricted. For example, it is not far afield to imagine that the total amounts of an insecticide permitted to be used on a crop, for a given season, may some day be set by law or edict. Such a prospect thirty years ago would have seemed unthinkable. Today it is but one of the several possibilities concerning insecticide use in agriculture.

Cotton then, often a high insecticide use crop, needs to move prudently toward a system less vulnerable to insects and mites, to a system where insecticides are a smaller component. Further shortening the production period and increasing earliness and vigorous, organized attention to stalk destruction would serve this end. Western desert production could accommodate these adjustments. And although such changes would seem more difficult for rainbelt cotton, we note the advances in earliness that have come about in the last twenty years in the new rainbelt cultivars, and we remember too that twenty five years ago there was, in some quarters, little support for developing such early-maturing cottons. But, in the end, it was done.

SUMMARY

The cultural approach for managing insect pests of cotton of the United States began in the years following the entrance of the boll weevil into south Texas in 1892. Recommendations of entomologists of the public institutions then contained two elements that are today as vital to judicious farming as they were in the first years of this century: crop earliness and prompt stalk destruction. Earliness has been achieved with a combination of practices: planting date, row width and planting density, fertilizer application and cultivar — but, perhaps it is the selection of the appropriate early-maturing genotype that has been most influential. The weevil problem of the early years was partially solved by planting faster-maturing cottons, and in recent times progress has continued in breeding plants that produce in a shorter period. Historically, genetic earliness for these cottons came from a distinct region in Mexico, the Mexican Highlands. Providing escape from large late-season infestations, fast cottons also allow the crop to be harvested earlier and the cotton stalks destroyed early enough to reduce overwintering in certain pests.

During the first years of boll weevil infestation, very wide row widths were recommended, but in time this concept was rejected; centers of about 40 inches are commonly used today, although experimentation in certain areas has shown that more rapid maturity can be achieved by planting on rows considerably narrower than 40 inches. On deficient soils, a balance of nitrogen, phosphorus and potash fertilizers has allowed early fruiting in cotton.

Destroying cotton stalks in the fall, a difficult task in the first years of the weevil, is now possible with modern machinery. Prior to stalk cutting, harvest practices (harvest-aid chemicals and mechanical harvest), have already reduced the overwintering numbers of certain insects. The winter survival of the pink bollworm is strongly influenced by tillage practices during the fall and winter, and by winter irrigation.

Required stalk cutting dates and plow downs have been promulgated in the laws of the states' Department of Agriculture for pink bollworm and boll weevil management.

Although early planting has stood for years as a tenet of insect management, recently the application, of delayed planting on a communitywide basis, has reduced weevil damage in the Texas Rolling Plains.

Farmers often in the past planted the crop where insect threat was less. The expansion of cotton to northwest Texas, to the Bootheel of Missouri, and to the western United States was prompted in part by the understanding that this was country free from major cotton insects or, at least, these were areas of diminished risk from insects. The wealth of that production still enjoys that advantage.

The timing of irrigation has been shown to influence infestations of bollworm in cotton of the Texas Rolling Plains, and other studies in this region have dealt with the management of overwintered boll weevils through the modification of the shelterbelts that are planted there to reduce wind erosion of soils.

Plant bug infestations in California cotton fields have been shown to relate to farming practice in nearby alfalfa, and modification of that practice can result in lower infestations in cotton.

CHAPTER 15

BIOLOGICAL CONTROL

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INTRODUCTION

Over 100 species of insects and mites are pests of cotton in the United States (see Chapter 2, this book). From 1980 to 1987, the aggregate damage attributed to these cotton insect and mite pests was about 7 to 14 percent despite the best control efforts (see Chapter 24, this book). In 1993, arthropod pests reduced cotton yields in the United States by about 6.9 percent resulting in a loss of 890 thousand bales from potential yield and $331 million in revenue (Hardee and Herzog, 1994). Moreover, $586 million were spent for pesticides to control these pests. So, the total direct cost of arthropod pests to United States cotton production was $917 million in 1993. Indirect costs not included are the value of the lost lint as it would have moved through the market place and the cost of environmental degradation caused by the application of about 1.6 pounds (active ingredient) of synthetic chemical insecticides and miticides applied per acre over 10 to 14 million acres of cotton in the United States each year (Chapter 24, this book).

Obviously, the cost to United States cotton growers, consumers, and the environment for arthropod pest control in cotton is unacceptably high, and there is an urgent need to develop less expensive pest management techniques. Perhaps even more importantly, United States cotton producers will be forced to consider non-chemical control measures more strongly because of public concern about synthetic chemical pesticides (see Chapter 28, this book; King *et al*., 1988a). For example, concern in California about the need for safe drinking water resulted in Proposition 65, the "Safe Drinking Water and Toxic Enforcement Act of 1986," empowering the governor of that state to declare any chemical to be a health hazard if it is a carcinogen or reproductive toxicant. Moreover, where pesticides may be used, and therefore where cotton may be economically grown, is impacted by The Endangered Species Act of 1973, requiring the United States Environmental Protection Agency (EPA) to protect endangered and threatened species under the Federal Insecticide, Fungicide, and Rodenticide

Act. Finally, the number of effective pesticides for cotton insect and mite pests is decreasing. This decrease is related to obsolescence resulting from resistance (see Chapters 8, 9, and 13, this book), high cost of research and development (estimated over $50 million to acquire the first label for registered use of one single pesticide), and the requirement that all pesticide uses registered prior to November 1984 must be re-registered under EPA requirements because of putative chronic health effects and ground water leaching.

INTEGRATED PEST MANAGEMENT

The integrated pest management (IPM) concept fully emerged in the 1960s (Newsom and Brazzel, 1968) and became the dominant approach to arthropod pest control in cotton as well as other crops during the 1970s and early 1980s (Frisbie and Adkisson, 1985). Its development was in response to the control failures of insecticides and miticides (due to the development of resistant populations) as well as public concerns relative to the impact of these synthetic pesticides on non-target animal populations.

IPM has been defined as a system in which all available techniques are evaluated and consolidated into a unified program for managing pest populations to avoid economic damage and minimize adverse side effects on the environment (National Academy of Sciences, 1969). The evolution of this concept in cotton beginning in the early 1900s to date is reviewed in Chapter 1, this book.

BIOLOGICAL CONTROL STRATEGIES

Biological control is an integral component of cotton IPM strategy in the United States. It involves managing natural enemies (predators, parasites and pathogens) to reduce pest populations and their effects. Other non-chemical control strategies, such as genetic or autocidal control and host plant resistance or cultural control, are discussed in other chapters of this book.

Three strategies are often identified for encouraging and using natural enemies (Figure 1). First, exotic species may be introduced and established on pest species potentially reducing the pest population permanently to a lower level — this is classical biological control. Second, means may be developed to protect and spare natural enemies — conservation. Finally, efforts to increase the number of natural enemies, or their effectiveness, within a defined area may be undertaken—this is augmentation.

Importation — Some of the most important pests of cotton originated in other countries, including the boll weevil, *Anthonomus grandis grandis* Boheman, the pink bollworm, *Pectinophora gossypiella* (Saunders), and the sweetpotato whitefly, *Bemisia tabaci* (Gennadius). Consequently, these pests are not associated in the United States with co-evolved, selective natural enemies. Attempts to import and establish co-evolved natural enemies from the site of origin for these pest have not been success-

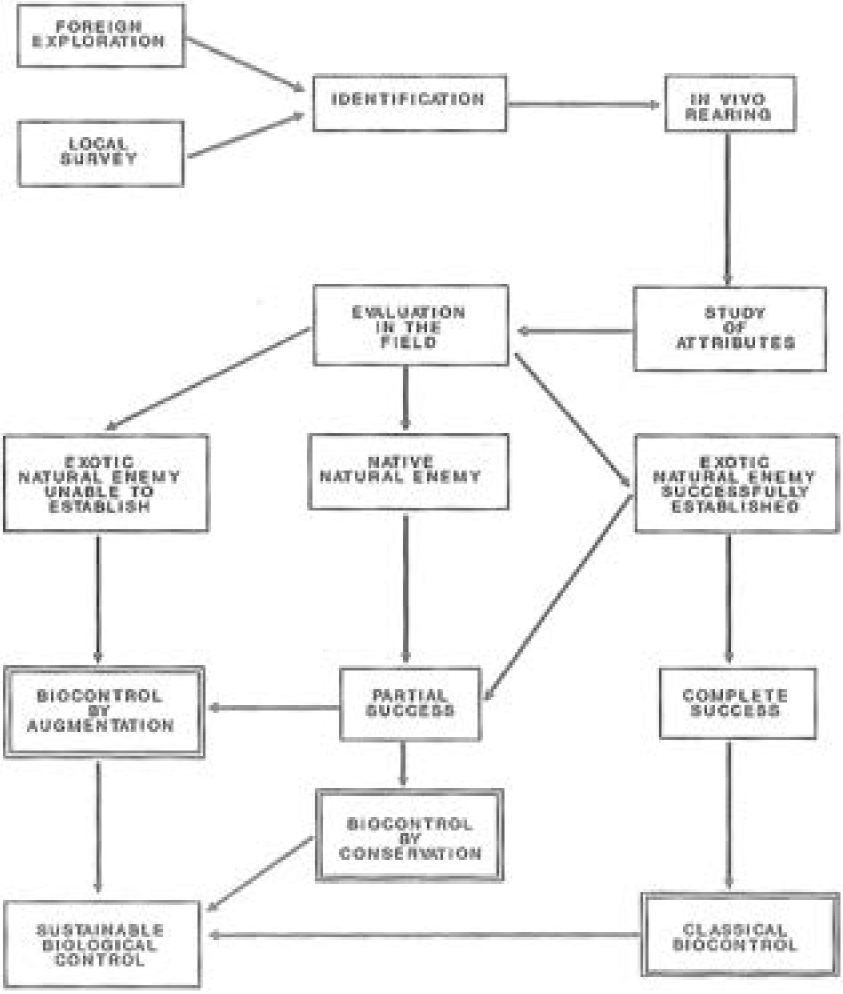

Figure 1. Biological control strategies for using entomophagous arthropods to reduce insect/mite populations and their effects.

ful. This biological control strategy is discussed in more detail on a pest-by-pest basis later in this chapter.

Conservation — Current cotton IPM strategy emphasizes minimizing insecticide and miticide usage to spare natural enemies and maximize their pest suppression action (King, 1986). Avoidance of pesticide usage has often been cited as precluding the buildup of pest populations, such as the bollworm, *Helicoverpa zea* (Boddie), and tobacco budworm (*Heliothis virescens* (F.)), aphids, whiteflies and mites because of pesticide-related mortality to the natural enemies (Bottrell and Adkisson, 1977).

Literally hundreds of species of arthropod predators, parasites and pathogens are associated with cotton arthropod pests (van den Bosch and Hagen, 1966; Whitcomb and Bell, 1964; Falcon, 1971; also see Chapters 3 and 5, this book). Perhaps the best evidence of the importance of these natural enemies in suppressing pest populations is the resurgence of treated pest populations to levels equal to or greater than pretreatment levels, and outbreaks of pests other than those against which the insecticides were directed resulting from insecticide overuse (Newsom and Brazzel, 1968). For example, the cotton aphid, *Aphis gossypii* Glover, became a serious pest of cotton as a consequence of using calcium arsenate for control of the boll weevil (Folsom, 1928). Indications are that this phenomenon occurred because of destruction of predators. Likewise, there is good evidence that the emergence of spider mites, as pests in the West and Southwest regions of the Cotton Belt is related to destruction of effective predators by pesticides used to control other pest species. Lingren *et al.* (1968) correlated a reduction of about 50 percent in predator populations after foliar applications of several organophosphate insecticides for control of the cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter), and a subsequent buildup of damaging bollworm and tobacco budworm populations.

Augmentation — There are two basic approaches to augmentation: periodic release and environmental manipulation. The most direct approach is through propagation and release or application of the natural enemy. These augmentations are classified as inoculative or inundative releases. Excellent reviews of this technology for crops in general may be found in Ridgway and Vinson (1977), Rabb *et al.* (1976), Stinner (1977), and King (1993). King and Powell (1992) reviewed the state of technology for mass propagating and augmentatively releasing predators and parasites for control of insect and mite pests of cotton. Additionally, parasites and predators have been augmented by environmental manipulation, including the provision of supplemental resources such as food or semiochemicals (naturally occurring, behavior-modifying substances that mediate interactions between organisms). For example, Hagen *et al.* (1971) reported that a dairy product composed of the yeast *Saccharomyces fragilis* and its whey substrate sprayed on cotton increased the effectiveness of the common green lacewing, *Chrysoperla carnea* Stephens, against bollworm eggs and larvae. Nordlund *et al.* (1985) provide some evidence for and suggest that semiochemicals from plants and/or hosts or prey may be applied to crop fields for retention and concentration of predator and parasite populations. (See Chapter 11, this book, for a comprehensive review of the use of semiochemicals to manage pest and natural enemy populations).

BIOLOGICAL CONTROL WITH PREDATORS AND PARASITES

This review of biological control of cotton arthropod pests will be largely restricted to those pests normally enumerated in the annual report on "Cotton Losses to Insects" (e.g., Hardee and Herzog, 1994). About one-half of the cotton insect losses in 1993 were attributed to three pest species: the boll weevil, the bollworm and the tobacco budworm. The remainder of the loss is attributed largely to plant bugs (*Lygus* spp. and the cotton fleahopper), spider mites, thrips, the sweetpotato whitefly and armyworms. The loss attributed to the pink bollworm is relatively low in most areas, but may be substantial in California and Arizona. The pink bollworm is included in this review because of its historical importance as a key pest.

BOLLWORM/TOBACCO BUDWORM

Biological control of the bollworm and tobacco budworm, as well as other *Helicoverpa/Heliothis* species has been extensively reviewed for cotton and other crops, worldwide. King and Jackson (1989) organized a symposium resulting in a comprehensive publication on the systematics, distribution and biological control of *Helicoverpa/Heliothis*. Symposium information was updated and summarized in King and Coleman (1989). Johnson *et al*. (1986) comprehensively reviewed cultural and biological control of *Helicoverpa/Heliothis* across crops. Perhaps the most comprehensive review of *Helicoverpa/Heliothis* to date is the "Proceedings of the International Workshop on *Heliothis* Management" (International Crops Research Institute for Semi-Arid Tropics, 1982).

Importation — Hundreds of predators and parasites attack *Helicoverpa/ Heliothis*. Some of the world's most important parasites attacking *Helicoverpa/Heliothis* have been imported, propagated and released for establishment. Three species of predators have been imported. This subject was most recently reviewed by Powell (1989) for the United States and by King and Jackson (1989), worldwide. To date, no exotic parasites or predators have been established on the bollworm/tobacco budworm in the United States. Nevertheless, attempts to establish effective species continue because of the potentially high return that may be gained by reducing the pest status level of the bollworm/tobacco budworm. In fact, the braconid *Cotesia kazak* (Telenga), imported from Europe and released in New Zealand in 1977, was established. It now has altered the number of *Helicoverpa armigera* (Hübner) attaining damaging levels in New Zealand (Cameron and Valentine, 1989).

Cotesia kazak was imported and released in the United States, and recovered from field collected larvae. However, long term establishment has not been documented. Some other important parasites imported and released in the United States include *Campoletis chloridae* Uchida from India, *Microplitis demolitor* Wilkinson from Australia, *Microplitis rufiventris* Kok from Egypt, *Hyposoter didymator* (Thunb.) from Europe and *Palexorista laxa* (Curran) from Kenya (Powell, 1989).

Conservation — Kogan *et al*. (1989), using a database of 7,717 documents, said that for bollworm and tobacco budworm in North, Central and South America, there were reported to be: (a) 60 species of hymenopterous parasites in six families; (b) 61 species of dipterous parasites in four families; and (c) 142 species of predators from eight insect and two Arachnid orders.

In the United States, the most common egg parasites were *Trichogramma* spp. and the most common larval parasites were *Cardiochiles nigriceps* Viereck, *Microplitis croceipes* (Cresson), *Cotesia marginiventris* (Cresson) and several species of *Campoletis* and *Hyposotor*. Common tachinid parasites included *Eucelatoria bryani* Sabrosky and *Archytas marmoratus* (Townsend). Predominant predators included members of the: (a) Coleoptera order (especially the convergent lady beetle, *Hippodamia convergens* Guérin-Méneville, *Collops* spp., the spotted lady beetle, *Coleomegilla maculata* DeGeer, and *Scymnus* spp.); (b) Hemiptera order (especially bigeyed bugs, *Geocoris* spp.; pirate bugs, *Orius* spp.; damsel bugs, *Nabis* spp.; and soldier bugs, *Podisus* spp.); (c) Neuroptera order (primarily lacewings, *Chrysoperla* spp.); and (d) the spiders.

Most of the predators and parasites cited above have been recorded from cotton fields. Whitcomb and Bell (1964) recorded over 600 predators in Arkansas cotton fields and van den Bosch and Hagen (1966) estimated about 350 different predators and parasites in California. Other data citing the diversity of predators and parasites of bollworm/tobacco budworm and other pests in cotton are given in Chapter 3, this book.

In large measure the emergence of IPM in cotton was caused by the failure of insecticides to control the bollworm/tobacco budworm, particularly the tobacco budworm, and other cotton arthropod pests (Bottrell and Adkisson, 1977). The conservation and maximum use of naturally occurring biological control agents is a key component of the IPM strategy. The potential effect of naturally occurring predators and parasites is generally recognized in cotton insect control guides (King, 1986; see Chapters 20, 21, 22, and 23, this book). On the other hand, explicit instructions for incorporating predators and parasites into decision-making regarding action versus nonaction are generally lacking.

Most state cotton insect control guides provide a listing of the predators that may be encountered while surveying insect pest infestations. Parasitic insects are usually mentioned but not by name. Some guides provide picture sheets to illustrate key natural enemies and some discuss techniques for quantifying predators. Rarely do the guides provide instructions for deciding on treatment versus no treatment based on abundance of natural enemies (King and Coleman, 1989).

The complexity of sampling for predators and parasites, and interpreting what these numbers mean relative to the vast array of biotic and abiotic factors affecting bollworm/tobacco budworm populations make the development of computer based decision-making technology imperative. Wagner *et al*. (see Chapter 6, this book) review the various models that have been developed in an attempt to describe the interaction between bollworm/tobacco budworm populations, their natural enemies and other components of their biotic and abiotic environment. One computer model, MOTHZV, predicted survival of late-instar bollworm/tobacco budworm larvae based on the effects of different densities of total predators (Hartstack and Witz, 1983). Ables *et al*. (1983) describe in detail the concepts underlying the use of predator-prey ratios to make decisions regarding IPM on a field-by-field basis but admit the inability to correlate increase or decrease of predator populations with varying densities of bollworm/tobacco budworm populations. Regardless, articles were cited and data presented demonstrating the efficacy of predators on bollworm/tobacco budworm life stages.

Direct evidence of predator efficacy consists of observations (Fletcher and Thomas, 1943; Whitcomb, 1967a, 1967b) and cage experiments (Lopez *et al*., 1976; van den Bosch *et al*., 1969; Tejada, 1971). Indirect evidence of predator efficacy is persuasive and has emerged as a consequence of first eliminating natural enemies followed by bollworm/tobacco budworm population outbreaks (Lingren *et al*., 1968, van den Bosch *et al*., 1971; and van Steenwyk *et al*., 1976).

MOTHZV has been incorporated into the highly useful management model, TEXCIM (described in detail in Chapter 7, this book). In brief, "TEXCIM is a multipest, multitrophic, multicomponent computer model that uses field counts of cotton fleahopper, bollworm, tobacco budworm and boll weevil, ten groups of predators, insecticides, cotton fruit and local weather to forecast the expected benefits of control."

Other models also contain natural enemy components, e.g., HELSIM (Stinner *et al*., 1977) and CIM-HEL (Brown *et al*., 1979; McClendon and Brown, 1983). The decision making model, DEMHELIC, proposed by Hopper and Stark (1987) made explicit use of natural enemy populations. This model has structures for bollworm/tobacco budworm feeding, the impact of natural enemies on bollworm/tobacco budworm feeding and survival, cotton plant growth, mortality of bollworm/tobacco budworm and predators and parasites from insecticides and the economics of insecticide inputs and returns.

Augmentation: Parasites — The principal parasites that contribute to mortality of bollworm and tobacco budworm eggs and larvae are *Trichogramma* spp., *Microplitis croceipes*, *Cardiochiles nigriceps* (tobacco budworm only) and *Cotesia marginiventris*. Of these parasites, primary attention has been given to augmentation of *Trichogramma* populations. Recently, major emphasis has been placed on the development of augmentation technology for the larval endoparasite *Microplitis croceipes*. Other efforts have been placed on the development of rearing and augmentative release technology for the tachinid *Archytas marmoratus*.

Egg Parasites. Biological control of bollworm/tobacco budworm in cotton by releases of egg parasites like *Trichogramma*, particularly *Trichogramma pretiosum* Riley, in the United States is comprehensively reviewed in King *et al*. (1985a). All aspects are reviewed including: (a) rearing (Morrison, 1985a, 1985b); (b) transport, storage and parasite release technology (Bouse and Morrison, 1985); (c) behavioral manipulation (Lewis *et al*., 1985); (d) parasite movement (Keller and Lewis, 1985); efficacy (King *et al*., 1985b; Lopez and Morrison, 1985); (e) pesticide effects (Bull and Coleman, 1985); and (f) modeling (Goodenough and Witz, 1985). A recent popularized review of the state-of-the-art technology for identifying, propagating and augmenting *Trichogramma* populations is given by Olkowski and Zhang (1990).

Olkowski and Zhang (1990) list seven commercial producers of *Trichogramma* in the United States. These parasites are released over a total of about 200,000 acres. The parasite most commonly reared and released in cotton is *Trichogramma pretiosum*. The Angoumois grain moth, *Sitotroga cerealella* (Olivier), is the host generally used in the mass rearing/production system for this parasite. The technical feasibility of suppressing bollworm/tobacco budworm populations in cotton by inundative releases of *Trichogramma* has been repeatedly demonstrated in the United States. Aerial releases of 49,980 to 99,960 adult *Trichogramma* per acre resulted in an average 51 percent parasitism of bollworm/tobacco budworm eggs on five Texas cotton farms (Ridgway *et al*., 1977). Stinner *et al*. (1974) evaluated the technical feasibility of reducing bollworm/tobacco budworm larval populations in cotton by releasing *Trichogramma pretiosum*. Parasite release rates were high (up to 387,293 per acre), but bollworm/tobacco budworm larval populations were suppressed. King *et al*. (1985b) reported three years of data following releases of *Trichogramma pretiosum* in cotton. In each year egg parasitism was increased as a consequence of the released parasites, but these parasitism rates could not be correlated with larval suppression. Regardless, in the third year, yields in release fields were significantly higher than in non-release, untreated control fields; though this amounted to 77 percent as much lint as in the insecticide-treated plots.

Larval Parasites. Larval parasites are an important part of the environmental resistance to increase of *Helicoverpa/Heliothis* populations. Unique complexes of hymenopterous and tachinid parasites have been recorded in the various regions of the world (King and Jackson, 1989). Cumulative rates of larval parasitism are often high but the predominant species vary between region of the country in the United States as well as crop (King *et al*., 1982). One of the most important parasites of bollworm/tobacco budworm larvae in cotton and wild host plants in the United States is *Microplitis croceipes* (King and Powell, 1989).

The potential for releases of larval parasites has been indicated in small-scale tests. Lingren (1969) reported that *Cotesia marginiventris* had considerable potential for use in augmentation programs. Also, *Campoletis sonorensis* (Cameron) released at the rate of 680/day for 10 consecutive days in a 0.08 acre cage (13,760 wasps per acre equivalent) infested with tobacco budworm larvae resulted in 85 percent parasitization for nine consecutive weeks (Lingren, 1977). Jackson *et al*. (1970) reported that if the tachinids *Eucelatoria bryani* and *Palexorista laxa* were released at the rate of 2,500 female flies per acre on cotton containing 5,000 bollworm/tobacco budworm larvae per acre, about 50 percent parasitization should occur in two days.

Research on *Microplitis croceipes* has been extensive (Powell *et al*., 1989). Basic biology including host relationship physiology was recently reviewed by Powell and Elzen (1989) and Vinson and Dahlman (1989). Behavioral aspects relating to habitat and host location, mate finding and mating were reviewed by Nordlund *et al*. (1989), Elzen and Powell (1989) and Jones (1989). Other research vital to development of the augmentation technology for *Microplitis croceipes* is effect of insecticides on the parasite (Bull *et al*., 1989), genetic characterization and genetic improvement (Steiner and Teig, 1989), and the possibility of developing an *in vitro* rearing system for the parasite (Greany *et al*., 1989).

Hopper (1989) surmised that augmentation of *Microplitis croceipes* for control of bollwom/tobacco budworm is technically feasible. Of the principal parasites of bollworm/tobacco budworm, across host plants, *Microplitis croceipes* has emerged as one of the most important (King *et al*., 1985c; King and Powell, 1989). King *et al*. (1985c) hypothesized—based on dramatically higher rates of bollworm/tobacco budworm larval parasitism—that *Microplitis croceipes* was highly tolerant of many commonly used insecticides, particularly the pyrethroids. In general, the parasites are more tolerant of certain pyrethroids (e.g., esfenvalerate [Asana®] and cypermethrin [Ammo®, Cymbush®]) and carbamates (e.g., thiodicarb [Larvin®] and oxamyl [Vydate®]) and least tolerant of certain organophosphates (e.g., acephate [Orthene®] and profenofos [Curacron®]) (Powell and Scott, 1991). *Microplitis croceipes* prefers to parasitize third instar larvae, (Hopper and King, 1984a), but all parasitized instars move and feed less on the cotton plant (Hopper and King, 1984b). Consequently, less damage is caused by parasitized larvae. Hopper *et al*. (1991) report that releasing 809 female *Microplitis croceipes* per acre of cotton yielded 75 percent parasitized bollworm/tobacco budworm larvae after six days, with an estimated 38 percent reduction in damage. Hopper (1989) suggested that releases over large areas, particularly during the time that bollworm/tobacco budworm are restricted on wild host plants (valid in the United States only for the Mid-South) might be an effective population suppressant tactic.

Augmentation: Predators — No predators are currently being released for controlling bollworm/tobacco budworm in the United States. Most management models do include predator-caused mortality, indirectly if not directly.

Releases of several hemipteran predators indicate that it might be feasible to augment their populations if economical procedures for mass producing them could be developed. Field-cage studies by Lingren *et al*. (1968), van den Bosch *et al*. (1969) and Lopez *et al*. (1976) with a bigeyed bug, *Geocoris punctipes* (Say), the common damsel bug, *Nabis americoferus* Carayon, and the spined soldier bug, *Podisus maculiventris* (Say), respectively, demonstrate their ability to suppress bollworm/tobacco budworm populations in cotton.

Ridgway *et al*. (1977) reviewed the technical feasibility of suppressing bollworm/tobacco budworm larval populations in cotton by periodic releases of the common green lacewing's eggs or larvae. Release of 2-to 3-day-old larvae consistently produced significant reductions of bollworm/tobacco budworm on cotton. Reductions in bollworm/tobacco budworm larval populations were obtained by releasing as few as 10,000 common green lacewing larvae per acre, and high levels of reduction were obtained in the field by releasing 100,000 to 200,000 thousand per acre.

BOLL WEEVIL

Importation — The boll weevil evolved on noncrop hosts, *Hampea* spp., in Central America (Burke *et al*., 1986). Subsequent colonization of wild cotton by the boll weevil followed by cultivation of cotton along the eastern coastal lowlands of Mexico ultimately provided a "bridge" into the Lower Rio Grande Valley of Texas. Northward expansion by the weevil, coupled with the ability to overwinter as an adult in facultative diapause, allowed its "escape" from co-evolved natural enemies. In fact, some parasite species, e.g., *Bracon compressitarsis* Wharton, attack the boll weevil on *Hampea* spp. but not cotton. Consequently, the boll weevil is often viewed as a key pest that is largely invulnerable to biological control in the United States (Bottrell, 1976).

The earliest attempt to import and establish natural enemies involved a parasitic mite, *Pediculoides ventricosus* Newport (Hunter and Hinds, 1905). Cook (1904, 1905) imported the "kelep ant," *Ectatoma tuberculatum* (Oliver), from Guatemala, but it failed to establish in Texas. Two parasites, *Triaspis vestiticida* Viereck and *Bracon vestiticida* (Viereck), imported from Peru and Colombia, parasitized boll weevil larvae but failed to establish after field release (Berry, 1947). Two parasites, *Bracon kirkpatricki* Wilkinson from Africa and *Bracon greeni* Ashmead from India, imported for establishment on the pink bollworm, parasitized boll weevil larvae in the laboratory, but failed to overwinter in Mississippi (Cross *et al.*, 1969).

Some parasites attacking the boll weevil and a closely related species, *Anthonomus hunteri* Burke and Cate, in southern Mexico include *Catolaccus grandis* (Burks), *Catolaccus hunteri* Crawford, *Heterospilus annulatus* Marsh, *H. megalopus* Marsh, *Bracon compressitarsis*, *Urosigalphus schwarzi* Gibson, *Zatropis incertus* Ashmead, *Lelaps* sp., *Paracrias anthonomi* Woolley and Schauff, *Nealiolus* sp., *Phanerotoma* sp., and *Spilochalcis* sp. (Cate *et al.*, 1990). Several species have been reared in the laboratory (Cate, 1987).

Marsh (1982) reported that the two braconids, *Heterospilus annulatus* and *Heterospilus megalopus*, released at four Texas sites, apparently did not establish. *Catolaccus grandis*, was released during 1967 to 1969 in Mississippi resulting in high rates of parasitism and in-season recycling by the parasite (Johnson *et al.*, 1973). Cate *et al.* (1990) reported that a single release of 1200 female *C. grandis* provided economic control of the boll weevil in a cotton field for a six-week period. However, in both cases, the parasite did not establish.

Conservation — Numerous predators and parasites have been observed to attack the boll weevil in the United States (Pierce *et al.*, 1912; Cross and Chestnut, 1971). However, only in unique circumstances have they been documented as causing significant mortality. For example, Sterling and collaborators (Fillman and Sterling, 1983; Sterling *et al.*, 1984) report that, where the red imported fire ant, *Solenopsis invicta* Buren, exists in east Texas, it may be an effective predator of boll weevil larvae. Parasites, indigenous to the United States, that attack the boll weevil are typically polyphagous and utilize the boll weevil facultatively.

At least 55 indigenous entomophagous arthropods have been recorded as attacking the boll weevil in the United States (Pierce, 1908; Hunter, 1910; Pierce *et al.*, 1912; Chestnut and Cross, 1971). Of these, *Bracon mellitor* Say predominates, sometimes accounting for as much as 90 percent of the total parasitism (Marlatt, 1933). An oligophagous parasite, *Urosigalphus anthonomi* Crawford, has been detected in surveys near Brownsville, TX, parasitizing up to 50 percent of the boll weevil larvae collected (Pierce *et al.*, 1912; Summy, 1991). Other parasites occurring in significant numbers include *Aliolus curculionis* (Fitch), *Eurytoma gossypii* Bugbee, *Catolaccus hunteri*, *Zatropis incertus*, and *Eupelmus cyaniceps* Ashmead (Cate, 1985).

Indigenous parasites of the boll weevil characteristically have a wide host range (polyphagous or oligophagous), and, consequently, do not respond to boll weevil population dynamics as would a more host-specific parasite. For example, *B. mellitor* typically occurs too late in the season to maintain the boll weevil at subeconomic levels. Moreover, Adams *et al.* (1969) report that *B. mellitor* prefers to oviposit on weevil larvae in floral buds (squares) not completely abscised from the plant. However, present-day commercial cotton varieties typically shed their squares and the boll weevil larva completes its development to adulthood inside the fallen square. Moreover, *B. mellitor* development is poorly synchronized with development by the boll weevil (Morales-Ramos and Cate, 1993). The parasite *U. anthonomi* is of interest, but it has not been successfully reared in the laboratory. *Bracon thurberiphagae* is a primary parasite of the thurberia form of the boll weevil, but it is restricted to searching for hosts in *Gossypium thurberi*.

Augmentation — Pierce (1908) increased the percentage parasitism of boll weevil larvae by collecting parasites from one location and releasing them in another. Pierce *et al.* (1912) proposed encouraging the growth of plant species which attract and support hosts of polyphagous parasites, including the suggestion that these alternate host plants might then be destroyed thereby forcing the polyphagous parasites into cotton. Bottrell (1972) suggested the use of the synthetic pheromone Grandlure® to attract overwintering weevils into a portion of the cotton field thereby increasing the density of host larvae. The idea was to attract *B. mellitor* into cotton earlier in the season. McGovern and Cross (1976) increased the effectiveness of *B. mellitor* by use of the frego-bract character in commercial cottons; parasitism was increased from 7-56 percent.

Others surmised that it might be possible to mass propagate parasites and augmentatively release them for control of the boll weevil (Anonymous, 1958). In fact, Johnson *et al.* (1973) reported releases of *C. grandis* during 1967, 1968, and 1969, resulting in rates of parasitism ranging up to 72 percent as well as in-season recycling by the exotic parasite. Though they were unsuccessful in establishing the parasite, they suggested that it "might be used as part of an integrated control program...if the parasite can be mass reared...". Regardless, no determined attempts were made to suppress the boll weevil by augmentative releases of parasites until 1992 (Summy *et al.*, 1993).

King (1993) hypothesized in 1988 that some of the United States' most intractable key pests, such as the boll weevil, may be controlled through propagation and inoculative/augmentative releases of selective parasites. It was further hypothesized that failure to become established, as in the case of exotic parasites of the boll weevil, was not critical in an inoculative/augmentative release program. In fact, it was concluded that population densities of boll weevils tolerated by cotton growers, in season, are so low that they cannot support a naturally-occurring parasite population. These hypotheses are documented in two USDA Agricultural Research Service CRIS Work Projects (1988, 1989) and in the Proceedings of a Work Planning Session, September 19-20, 1989 (Memo, E. G. King/W. Klassen, ARS Associate Deputy Administrator, and others, 1990). As part of the Work Planning Session, E. F. Knipling developed a theoretical model postulating the suppressive effects of a selective parasite inoculatively/augmentatively released against the boll weevil; this model is elaborated on in Knipling (1992).

An outcome of the 1989 Work Planning Session was selection of *C. grandis* as the lead candidate for large-scale propagation and release for control of the boll weevil. This parasite apparently is well adapted to the in-season biotic and abiotic environment of the United States cotton agroecosystem based on results from attempts to establish it (Johnson *et al.*, 1973; Cate *et al.*, 1990). Though the parasite did not establish, these studies demonstrated that *C. grandis* effectively searches for boll weevil-infested squares on the ground as well as on the plant.

A series of experiments from 1992 through 1994 demonstrated the effectiveness of *C. grandis* augmentative releases. Summy *et al.* (1993, 1994) report on exceptionally high rates of parasitism of boll weevil larvae, as well as their population suppression, following inoculative/augmentative releases of *C. grandis*. Augmentative releases of *C. grandis* in Texas and Alabama cotton fields at rates of 500 to 1000 females/acre per week during early season resulted in 50 to 100 percent parasitism of boll weevil third instars during the release periods (Morales-Ramos *et al.*, 1994; Summy *et al.*, 1994). The parasite releases were made over a six- to eight-week period in Texas and a three-week period in Alabama. Lint yield from parasite-release fields in Texas did not differ significantly from the insecticide-treated IPM control fields, but the test was terminated prematurely in Alabama due to a lack of boll weevil immatures to rear the parasites.

Catolaccus grandis is highly fecund relative to its host, the boll weevil. During their most fertile ages the parasite is capable of producing several times more eggs than the boll weevil (Morales-Ramos and Cate, 1992; Gast, 1966). Weekly releases of the parasite during the F_1 and F_2 larval-pupal generations are projected to have a highly suppressive effect on the boll weevil population (Morales-Ramos *et al.*, 1993). So, parasite fecundity is not a limiting factor in biological control of the boll weevil. Moreover, this high fecundity facilitates mass propagation of the parasite, *in vivo* or *in vitro*.

The parasite prefers boll weevil third instars, but also oviposits in squares containing host prepupae and pupae and occasionally second instars. It apparently searches effectively for host larvae in shed squares, but a cage study (Tillman, 1993) demonstrated a preference for infested squares on the plant as opposed to abscised infested squares on the ground surface. Another study (Summy *et al.*, 1993) revealed a preference by field-released parasites for infested squares over infested bolls during early season. These findings affirm the strategy for using the parasite to attack and strongly suppress the F_1 and F_2 host larval/pupal generations, which are typically in squares on the soil surface, thereby reducing the third and fourth weevil generations to non-pest status.

At temperatures ranging from 16°C to over 36°C the development of *C. grandis* is well synchronized with its obligate host, the boll weevil (Morales-Ramos and Cate 1993). In contrast, development of the polyphagous parasite, *Bracon mellitor* is not well synchronized. The developmental time of *C. grandis* and the boll weevil from egg to adult at 30°C is about 12 days each.

Initial efforts to rear *C. grandis* required placing third instar larvae into hollowed cotton squares, sealing the hollowed square with artificial medium, and exposing the artificially implanted larvae to gravid *C. grandis* females (Johnson *et al.* 1973). Cate (1987) reported a simple but elegant process, encapsulating the third instar host larvae in Parafilm® in lieu of artificially infesting hollowed squares. Morales-Ramos *et al.* (1992) modified and improved the encapsulation process. Further automation of the process described by Morales-Ramos *et al.* (1992) is given by Roberson and Harsh (1993). The potential for *in vivo* mass propagation of *C. grandis* exists because of the advances that have already been made in the mass propagation of the host (see Roberson and Wright 1984).

Catolaccus grandis has been reared from egg to adult on an artificial diet (Guerra *et al.*, 1993; Rojas *et al.*, patent pending/in manuscript), and the economic feasibility of the inoculative/augmentative release approach to areawide boll weevil suppression may be dependent on this technological advance. On the other hand, use of inoculative/augmentative releases of *C. grandis* in environmentally-sensitive areas as a component in the boll weevil eradication programs may be economically feasible using *in vivo*-reared parasites.

Two substantial limitations have been identified in attempts to develop a use pattern for releasing *C. grandis* in the cotton agroecosystem. First, this parasite is highly sensitive to the chemical insecticides that are likely to be used for control of the boll weevil as well as other pests (Summy *et al., 1994)*. However, if the application of these chemicals is strategically timed, they can be used for control of early-season pests, such as thrips and plant bugs. Moreover, at least one application of a relatively short residual chemical may be applied early to eliminate overwintering weevils invading the cotton fields.

The second limitation involves the ability of the parasite to detect infested squares on the ground that have been covered with soil. In one controlled test, infested squares were covered with about one millimeter of soil to simulate the likely effect of cultivation. The parasite females apparently could not detect and parasitize the host larvae. Consequently, mechanical cultivation at the time of, and following parasite release, will have to be curtailed to achieve maximum effectiveness by the parasite (Summy *et al.*, 1994).

The inoculative/augmentative release strategy of *Catolaccus grandis* for control of the boll weevil can be integrated into short-season, cotton-production systems. There are a number of attributes of this system that make it amenable to the parasite inoculative/augmentative release strategy. Shortening the growing season through management practices, including planting of rapidly maturing cultivars, escapes high, late-season weevil and other pest populations. Moreover, shortening the season allows earlier stalk destruction and plowdown thereby further reducing the number of weevils overwintering and dispersing into cotton fields the following year. Imposing insecticide applications early season, near pinhead square occurrence, to kill invading overwintered weevils reduces populations to their lowest seasonal density. Harvest-aid chemicals can be valuable in preparing the crop for earlier harvest, and indirectly, in suppressing diapausing weevils (Cleveland and Smith, 1964).

Release of *C. grandis* to parasitize and kill F_1 and F_2 weevil immatures imposes an additional mortality factor heretofore not possible in extant production systems. In fact, attainment of very high rates of parasitism by *C. grandis* during the F_1 and F_2 generations can practically eliminate in-field reproduction by the boll weevil, thereby precluding the need for subsequent insecticide treatments for control of the weevil (Summy *et al.*, 1994; King *et al.*, unpublished data).

Proper timing and use of short-residual materials prior to releases of *C. grandis* controls early season pests (including overwintered boll weevil), yet minimally impacts the parasite. Properly timed, this practice can greatly reduce or eliminate the need for boll weevil control later in the season (Walker, 1980a). Later, mid-season pests, such as the bollworm or tobacco budworm, may require insecticide treatments, which would curtail subsequent releases of *C. grandis*. However, avoidance of additional insecticide treatments for 30 to 45 days may allow predators and parasites to increase in sufficient numbers to curb damaging pest populations. In fact, during 1994 field tests with *C. grandis*, no insecticide applications were necessary for late-season pests such as the bollworm and sweetpotato whitefly in fields where *C. grandis* was released but were necessary in the IPM-treated control fields (King *et al.*, unpublished data). Often, late-season pests can be tolerated because the majority of the crop is of sufficient maturity that potentially harvestable bolls are no longer vulnerable to insect damage, and feeding or oviposition on other fruiting forms does not affect realized yield.

The role of mechanical cultivation in cotton is primarily for weed control. Yet, as reported earlier, covering infested squares with soil allows the immature boll weevil to escape parasitism. We have hypothesized that weed control in the narrow-row (30 inch), short-season system may be achieved with reduced herbicide and mechanical cultivation. Smart (1993) demonstrated experimentally that more rapid shading of interrow spaces occurs, correlated with increased canopy, in the narrow-row system as opposed to the conventional 40-inch system. So, the narrow-row system potentially may complement parasite release by reducing weed populations and the need for mechanical cultivation.

Early stalk destruction after harvest has long been touted as a means of reducing boll weevil and pink bollworm overwintering populations. Nevertheless, it was not until the 1950s that equipment became available to realistically accomplish timely stalk destruction and plowdown (Chapter 14, this book). Since that time it has become more apparent that early stalk destruction as well as many other pest control measures are most effective when practiced on an areawide basis because of the dispersal capability of these pests (Henneberry *et al.*, 1991).

Based on tests conducted in 1992 (Summy *et al.*, 1993; and Morales *et al.*, 1993), apparently it is possible to virtually eliminate boll weevil reproduction in defined areas by augmentative releases of *Catolaccus grandis.* However, simulations of parasite releases demonstrate that boll weevil ingression into the test area and parasite egression from the test area limits the power of the augmentation approach. Experience with the boll weevil as well as with other dispersing insects has demonstrated that suppressive tactics applied over large areas and to all plants inhabited by the insect (areawide suppression) are more powerful than a field-by-field approach.

PINK BOLLWORM

Importation — Classical biological control efforts against the pink bollworm were initiated in Egypt during the period 1928 to 1935 with the importation of *Bracon kirkpatricki* from Kenya and Sudan (Alfieri, 1929) and *Bracon mellitor* from Hawaii (Kamal, 1935). Both of these parasites failed to become established (Clausen, 1978). The importation of *Bracon lefroyi* (D & C) in 1935 from India resulted in establishment, but no appreciable impact (Kamal, 1951). Initial efforts in the United States during the period 1932 to 1955 included the importation into Texas of the: (a) European corn borer strain of *Exeristes roborator* Fabricius and *Bracon brevicornis* Wesm. from southern Europe; (b) *Bracon kirkpatricki* from Africa; (c) *Bracon mellitor* and *Chelonus blackburni* Cam. from Hawaii; (d) *Bracon nigrorutum* (Cushm.) and *Chelonus pectinophorae* Cushm. from Korea; and (e) *Bracon brevicornis*, *Bracon gelechiae* Ashm., *Chelonus narayani* Rao, *Chelonus heliopae* Gupta and *Cotesia (=Apanteles) angaleti* Mues. from India (Noble and Hunt, 1937; McGough and Noble, 1955, 1957). Several of these parasite species were recovered during the season of release, although none became established (Clausen, 1978). More recently, Legner and Medved (1979) summarized attempts to establish 14 hymenopterous parasite species in the Lower Colorado Valley of California and Arizona. Included were: (a) *Goniozus* sp. from Ethiopia; (b) *Parasierola emigrata* (Rohwer) from Hawaii; (c) *Cotesia angaleti* Muesebeck from India; (d) *Cotesia (=Apanteles) oenone* Nixon from Australia; (e) *Bracon gelechiae* from India; (f) *Bracon kirkpatricki* from Kenya; (g) *Bracon mellitor* from Mississippi; (h) *Chelonus blackburni* from Hawaii; (i) *Chelonus curvimaculatus* Cameron from Africa; (j) two *Chelonus*. spp. from Ethiopia; (k) *Chelonus* sp. from Australia; (l) *Exeristes roborator* from Europe; and (m) *Pristomerus hawaiiensis* Ashmead from Hawaii. Reproduction during the season of release was documented for eight species. None of them became established (Legner and Medved, 1979). The most recent attempts involved the importation into California of *Goniozus aethiops* Evans from Ethiopia (Gordh and Evans, 1976), *Goniozus pakmanus* Gordh from Pakistan (Gordh and Medved, 1986) and *Trichogrammatoidea bactrae* Nagaraja from Australia (Hutchinson *et al.*, 1990). Establishment of the latter species has not been documented.

Conservation — In addition to the exotic parasites, pink bollworm is attacked by a large complex of native predators in the southwestern United States (Telford and

Hopkins, 1957; Wene and Sheets, 1962; van den Bosch and Hagen, 1966). Orphanides *et al*. (1971) suggested that pink bollworm eggs were the stage most vulnerable to predation, and noted that larvae of common green lacewing and adults of *Collops marginellus* LeConte, bigeyed bug, *Notoxus calcaratus* Horn, the common damsel bug, and the minute pirate bug, *Orius tristicolor* (White), may destroy substantial numbers of pink bollworm eggs under laboratory conditions. Irwin *et al*. (1974) quantified predation of pink bollworm eggs, placed under calyxes (bracts) of bolls, during 48-hour intervals, and noted that: (a) 75 percent of such eggs were detected and destroyed by common green lacewing larvae; (b) 45 percent by the western bigeyed bug, *Geocoris pallens* Stål; (c) 25 percent by the minute pirate bug; (d) 16 percent by *Spanogonicus albofasciatus* (Reuter); (e) 1 percent by the common damsel bug; and (f) 0 percent by *Collops marginellus*. Henneberry and Clayton (1985) quantified rates of egg predation by several predator species, and noted the highest consumption rate of 96 eggs per day by adult *Collops vittatus* (Say), followed by 63-67 eggs per day for mixed common green lacewing and convergent lady beetle larvae, 39 eggs per day for adult *Nabis* spp., 14 eggs per day for *Sinea confusa* Caudall, 8 eggs per day for *Geocoris* spp. and 5 eggs per day for the minute pirate bug. Henneberry and Clayton (1985) concluded that several predators commonly found on cotton in Arizona and California have the potential to reduce pink bollworm populations.

Attempts to evaluate the impact of native predators on field infestations of pink bollworm have produced variable results. Bryan *et al*. (1976) documented the occurrence of generally large predator populations on cotton during the production season, but also noted a significant decline in abundance of several species (particularly the common green lacewing, *Collops vittatus*, convergent lady beetle, minute pirate bug, *Noctoxus calcaratus* and ants) during mid-August, a period in which the abundance of various lepidopterous prey was generally increasing. Such trends suggested that predator populations tend to be more dependent upon populations of aphids than lepidopterous prey (Bryan *et al*., 1976). Irwin *et al*. (1974) suggested that most native predators tend to be relatively ineffective against pink bollworm eggs except at relatively high predator densities. However, Henneberry and Clayton (1985) documented egg predation ranging from 95 percent in July to 35 percent in September. They suggested that native predators may have a significant impact against pink bollworm.

Augmentation — Despite their failure to become established in the United States, many of the exotic parasite species appear to be promising candidates for augmentation. The release of more than two million *Bracon kirkpatricki* and about 280,000 *Chelonus blackburni* into about 113 acres of Arizona cotton resulted in a significant reduction in the need for insecticidal treatment in release sites compared to controls (Bryan *et al*., 1973a, 1973b). Parasitism by *Bracon kirkpatricki* ranged up to 25 percent, which the authors considered an underestimation, whereas *Chelonus blackburni* appeared to be largely ineffective, which the authors attributed to release of insufficient numbers. More recently, Bryan *et al*. (1976) documented parasitism of about 32 percent by *Bracon kirkpatricki* and about 9 percent by *Chelonus blackburni*, but concluded that such rates were insufficient to control pink bollworm. Inundative release of several parasite species in the Lower Colorado Desert of Arizona and California produced variable levels of pink bollworm control (Legner and Medved, 1979). Most effective was *Chelonus* sp. nr. *curvimaculatus* Cameron, which was credited with an adjusted 69.6 percent infested boll reduction at the equivalent release rate of 1,079 females per acre (Legner and Medved, 1979). Augmentation of exotic parasites appears to be a feasible approach to pink bollworm control, and has been enhanced considerably by the development of artificial diets for pink bollworm (Adkisson *et al.*, 1960; Stewart, 1984) and several parasite species (Bryan *et al.*, 1969, 1971).

Several augmentation strategies designed to enhance the impact of the native predator complex attacking pink bollworm appear to be feasible. The effectiveness of releases of the common green lacewing against bollworm/tobacco budworm on cotton has been clearly demonstrated (Ridgway and Jones, 1969). A second approach involves the generation of field "nurseries" of native predators in crops such as alfalfa and sorghum, which subsequently move into cotton (Stern *et al.*, 1967; Fye, 1971; DeLoach and Peters, 1972; Fye and Carranza, 1972; Robinson *et al.*, 1972). Field studies have generally suggested that native predators tend to be most effective against reduced pink bollworm infestations, which tends to promote a relatively high predator-prey ratio, and have therefore stressed the importance of cultural controls as an adjunct to biological control (Bryan *et al.*, 1976).

PLANT BUGS

Importation — The term plant bugs is commonly used to refer to several pest species in the family Miridae (see Chapter 2, this book, for a listing of species and their biology and ecology). For purposes of this discussion biological control efforts have focused on two species: the western lygus bug, *Lygus hesperus* Knight and the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois). Several efforts to import parasites of *Lygus* from Europe and establish them in North America have been made, but all have failed. The most intense effort involved the rearing and release of the braconid *Peristenus stygicus* Loan (Van Steenwyk and Stern, 1976, 1977). Lesser numbers of *Peristenus digoneutis* Loan and *Peristenus rubricollis* (Thomson) also were released (Hormchan, 1977; Coulson, 1987). A good review of the effort to establish *Lygus* parasites in North America is found in Coulson (1987). In 1985 two braconid parasites, *Leiophron schusteri* Loan and *Peristenus nigricarpus* (Szepligeti), were obtained from mirids in Kenya and successfully reared in the USDA, ARS Stoneville, Mississippi Research Quarantine Facility (Jones *et al.*, 1985) using nymphs of tarnished plant bug and western lygus bug. Releases of small numbers of adults of both species were made in Mississippi in 1987 (Snodgrass, unpublished data).

Conservation — Plant bugs are attacked by predators and parasites on cotton, other crops and on alternate or wild hosts. Numerous references are made in the literature to various arthropods feeding on plant bugs. However, little quantitative data is available on the importance of these predators in controlling plant bug populations. Most studies have been done in the laboratory using species of bigeyed bugs or damsel bugs. These have been studied since they are abundant in cotton and will feed on plant bugs. Crocker and Whitcomb (1980) observed that, under natural conditions, species of bigeyed bugs feed opportunistically on diverse small to minute arthropods and obtain additional nutrition by feeding on insect corpses and several herbaceous angiosperms. One of the small arthropods fed upon are pirate bugs. Pirate bugs are also important predators in cotton, and predation by bigeyed bugs is probably detrimental to total insect control of pests in cotton.

Plant bugs and bigeyed bugs also prey upon each other (Champlain and Butler, 1967; Dunbar and Bacon, 1972; Leigh and Gonzalez, 1976). Tamaki *et al*. (1978) found the large bigeyed bug, *Geocoris bullatus* (Say), to be an effective predator of early instar nymphs. Gupta *et al*. (1980) found that the large bigeyed bug preferred the pea aphid, *Acyrthosiphon pisum* (Harris), over plant bugs and had trouble capturing late instar plant bugs. Leigh and Gonzalez (1976) found western bigeyed bug to be an effective predator of eggs and nymphs of western lygus bug. Predation between western lygus bug and bigeyed bugs is thought to be related to developmental time of nymphs as related to temperature. Champlain and Sholdt (1967) found that the western lygus bug developed faster than bigeyed bugs at the cool temperatures which are found in early spring. The more rapidly developing western lygus bug population could depress bigeyed bugs by predation of the smaller slower developing bigeyed bug nymphs. Cohen (1982) confirmed that the bigeyed bug required higher temperatures than the western lygus bug for optimum development.

Damsel bugs and bigeyed bugs also prey on each other. Atim and Graham (1984) found that *Geocoris punctipes* and the western damsel bug, *Nabis alternatus* Parshley, would feed on each other, and that size was the determining factor as to which species was predator and which was prey. Thus, there is a complex relationship between *Lygus* and its predators in cotton. How these predators interact with *Lygus* and other prey is largely unknown. Assessing the value of predators in control of *Lygus* in cotton will be difficult, especially if the spiders, which are usually one of the bigger groups of predators in cotton, are also considered.

The main nymphal parasites of *Lygus* in North America are the braconids *Peristenus pallipes* (Curtis), *Peristenus pseudopallipes* Loan, and *Leiophron uniformis* (Gahan). *Peristenus pallipes* is found in most areas of the United States but not in the Southwest (Clancy and Pierce, 1966). *Leiophron uniformis* is found from the Southwest to the East coast and Canada, while *Peristenus pseudopallipes* is found mainly in Canada. *Peristenus pallipes* and *Peristenus pseudopallipes* are univoltine while *Leiophron uniformis* produces two to four generations each year (Loan, 1965; Clancy and Pierce, 1966; Lim and Stewart, 1976).

Eggs of *Lygus* are parasitized by the mymarid, *Anaphes iole* Girault. It could be the most important parasite of *Lygus* in the United States, since it is found in most areas of the country and is multivoltine (produces several broods per year) (Clancy and Pierce, 1966; Romney and Cassidy, 1945; Sillings and Broersma, 1974; Scales, 1973; Graham *et al*., 1986).

Few studies have ever determined the rate of parasitism of *Lygus* in cotton. Graham *et al.* (1986) found that *Anaphes iole* parasitized western lygus bug eggs in cotton in Arizona at rates as high as 36 percent from May through August. They found no parasites from nymphs collected in cotton. Most studies of the parasitism of *Lygus* have been conducted in crops other than cotton—crops which receive few or no insecticide treatments, and in which *Lygus* produces higher populations for a longer period of time. Parasitism of *Lygus* on wild host plants near crops has also been frequently studied. In Canada rates of parasitism of tarnished plant bug by *Peristenus pallipes* and *Peristenus pseudopallipes* range from 8 to 60 percent in alfalfa, forage legumes and weeds (Loan, 1965, 1970, 1980; Lim and Stewart, 1976; Loan and Craig, 1976). Shahjahan and Streams (1973) reported parasitism averaging 20 to 30 percent for tarnished plant bug on weed hosts. Scales (1973) reported parasitism of tarnished plant bug as high as 62 percent in weeds in the mid-delta of Mississippi. Clancy and Pierce (1966) found the pale legume bug, *Lygus elisus* Van Duzee, was parasitized by *Leiophron uniformis* at rates of 25 to 50 percent on goosefoot grass, *Chenopodium* spp. Rates of parasitism are usually higher in areas undisturbed by agricultural practices (Sillings and Broersoma, 1974).

In addition to agricultural practices, other factors can influence rates of parasitism of *Lygus*. One or more species of the weeds commonly called fleabanes in the genus *Erigeron* have been identified in several different geographical areas as being important wild hosts of *Lygus* (Tugwell *et al.*, 1976; Latson *et al.*, 1977; Cleveland, 1982; Anderson and Schuster, 1983; Snodgrass *et al.*, 1984; Fleischer and Gaylor, 1987). Streams *et al.* (1968) found *Peristenus pallipes* parasitized tarnished plant bug nymphs on plants in the genus *Erigeron* while mostly ignoring nymphs on other plant species in a field in Connecticut. They thought that volatile semiochemicals (naturally occurring behavior modifying chemicals) from *Erigeron* attracted the parasite, and this was confirmed by Shahjahan (1970).

In most areas of the United States where cotton is grown, rates of parasitism of *Lygus* have not been studied. It is not known how much control they presently exert on *Lygus* populations, or what their potential is for control if agricultural practices such as insecticide use are modified to favor them. Consequently, designing strategies for *Lygus* control in cotton that better utilizes *Lygus* parasites is difficult. The information that is available suggests that additional parasites are needed. Where studied in the Southeast, the main nymphal parasite of the tarnished plant bug is *Peristenus pallipes* (Scales, 1973; Hormchan, 1977). This parasite is univoltine (produces one brood per year) and is not present to parasitize the tarnished plant bug during several of its generations on wild or alternate hosts during the year. A multivoltine parasite that could overwinter in the Southwest could have a major impact on western lygus bug populations. The multivoltine egg parasite *Anaphes iole* is present in the Southeast (Scales, 1973); however, very little is known about its impact on tarnished plant bug populations in this area.

Augmentation — The development of an artificial diet for western lygus bugs (Debolt, 1982) has made production of large numbers of nymphs and eggs possible.

This greatly increases possibilities for biological control of western lygus bugs since large numbers of nymphal or egg parasites also might be reared in the laboratory for release in the field. The potential for using inundative releases of parasites to control *Lygus* is discussed in Debolt (1987) and holds promise for *Lygus* control in the future.

Too little is known about the biology and behavior of *Lygus* predators and parasites to estimate their effects on *Lygus* populations. More information is needed on the control they exert on *Lygus* on wild or alternate hosts as well as on cotton. In many areas where cotton is grown, the parasites present have not been determined. The presence of *Lygus* on wild or alternate host plants throughout the year presents good opportunities to control this pest prior to its movement into cotton by reducing the size of the overwintering generation or reducing the size of the first and/or second generation produced in the spring. This could be done by a variety of methods. Some methods, such as the use of insecticides or herbicides, could also harm parasite and predator populations. Better information on the value of *Lygus* parasites and predators is needed in order to make the proper control decisions, and make better use of the amount of control provided by these beneficial arthropods.

BIOLOGICAL CONTROL WITH MICROBIALS

The use of insect pathogens for biological control of insect pests is generally accepted as a safe and efficacious method. Except in some recent cases where genetically altered microorganisms have been opposed (Ferguson, 1988), insect pathogens have not provoked the adverse reactions from the general public as have chemical insecticides. The microbials that are under serious study for use in insect pest management systems are usually known to be environmentally safe and to have almost no adverse effect on the crop or on non-target species. Except for the genetically altered microorganisms, insect pathogens are naturally occurring in the insect populations. In that sense, they may already exist and interact in the crop ecosystems as limiting factors of some populations. When pathogens are applied as a management component, the attempt is to exploit the specific disease processes of the individual pathogens in order to maximize their effectiveness in the biological control of insect pests. The following discussion summarizes: (a) the microbial agents available either for research or for on-farm use; (b) reports of efficacy of microbials in the management or control of cotton insect pests; and (c) some various tactics being studied to increase their effectiveness. A more in-depth review of the pathogens found in cotton insects and mites and their effects on populations, regardless of their commercial amenability, is presented by Harper and Carner (see Chapter 5, this book).

The insect pathogens studied for possible use in the management of cotton pests include representatives of the viruses, bacteria, fungi, protozoa and nematodes. The ecology of the pest species and the traits of the pathogen often indicate innate factors that determine which pathogen has the best chance of success in individual management systems. One important consideration is usually the feeding habit of the target pest. Although some pathogens may be transmitted in or on the egg (Hamm and

Young, 1974), most viruses, bacteria and protozoa are transmitted by the insect ingesting the pathogen along with its food. Therefore an insect larva such as the cabbage looper feeding on leaves, is more likely to consume and thus become infected by those pathogens than a pink bollworm larvae, feeding inside the squares or bolls. Since the immature stages of the boll weevil develop entirely within the cotton fruit, it is even more protected from pathogens which must be consumed. An analogy may be drawn comparing the bacteria, viruses and protozoa to the stomach poison-type chemical insecticides and the fungi and nematodes to contact-type insecticides. The entomopathogenic fungi and insect nematodes, which may invade the host without being ingested, often have other traits which make them less attractive as microbial agents for use in exposed areas such as on cotton foliage because they are often very sensitive to variation in microhabitat. Even after the target insect population is infected with the pathogen, crop protection still depends upon the disease processes of the particular microbial organisms.

Of the microbials, the viruses and bacteria currently are considered to have the greatest potential for commercial development and use as biological control agents. More than 1000 virus-host relationships in over 700 species of insects and mites (about 370 baculoviruses) have been reported (David, 1975; Martignoni and Iwai, 1981) and this is considered by some to be just a small fraction of the actual numbers present (Kurstak and Tijssen, 1982). Although many of the reported viruses have been found to affect pests of agricultural importance, few have offered control potential to date. Of those viruses, the baculoviruses (nuclear polyhedrosis viruses and granulosis viruses) have the most desirable properties. These properties include their safety, relative stability and virulence. They are considered among the safer pathogens for study since they are uniquely associated with invertebrates, and usually have a limited host range. They also have a potential infectivity such that the LD_{50} may be as low as a single polyhedron per bollworm/tobacco budworm larva (Burges, 1981). The negative aspects of their use as biological control agents in cotton include their relatively long incubation period, problems related to the target insect ingesting the virus, and deactivation of the virus by environmental factors (Bullock, 1967; Ignoffo *et al*., 1972; Yearian and Young, 1974; Young and Yearian, 1974; Jacques, 1977; Bell, 1983). Since viruses must be produced in live tissue, industry generally views their production as somewhat difficult, however several efficacious production procedures are known (Ignoffo, 1966; Shapiro, 1982; Sheih and Bohmfalk, 1980). Research has shown that many of these problems can be overcome. Ingestion of the virus by the target insect may be increased by improved application and formulation techniques that place more of the pathogen in the target area (Smith *et al*., 1977, 1978; Smith and Bouse, 1981), or by the use of formulations containing feeding stimulants that increase feeding on the pathogen (Bell and Kanavel, 1975, 1977, 1978; Luttrell *et al*., 1982, 1983). Problems with environmental deactivation of the virus may be overcome by the use of protectants which increase field persistence of the virus (Bull, 1978; Ignoffo and Batzer, 1971; Smith and Hostetter, 1982). Despite their good traits, only the baculovirus from the bollworm is registered for use on cotton in the United States, and none are in present commercial production. Sandoz, Inc. mass produced the bollworm/tobacco budworm virus from 1976 until about 1982 under the trade name Elcar®. Bohmfalk (1982) discussed some possible explanations for its lack of acceptance. Primarily, application of the virus did not result in a rapid kill desired by the growers. The problems associated with the relatively long period between ingestion of the virus and the expression of the disease symptoms (incubation period) have yet to be overcome and are due to the pathological characteristics innate to the disease. Basically, the virus may appear within the nuclei of certain tissues of the insect host within 24 hours after ingestion, but external appearance and behavior may not be noticeably changed during the incubation period. After the symptoms are noticed, the larvae usually die within about three days.

Of the bacterial candidates for biological control of cotton insects, by far the most promising are strains of *Bacillus thuringiensis* Berliner (B.t.). Research uses and commercial sales of B.t.-based products have been steadily expanding. This bacterium persists worldwide and natural variation is widely observed. Many varieties, or serovars, have been recognized in the hundreds of isolates (Martin and Dean, 1981; Luthy *et al.*, 1982; DeLucca *et al.*, 1981), and their pathogenicity to various insects differs widely from very active to none (Dulmage, 1981). As a biological control agent in cotton, B.t., unlike the baculovirus, can be used to rapidly affect caterpillar pest populations and reduce crop injury. Again, this is due to the specific pathological characteristics of the microbial. When B.t. and its associated toxins are ingested, the gut cells of larvae of susceptible species are affected in such a way as to immediately inhibit feeding (Faust and Bulla, 1982). The bacteria themselves, unlike the viruses, may be inefficient as infective agents, but produce effective toxins that serve as narrow-spectrum toxins of many crop insect pests (Kurstak and Tijssen, 1982). These include a thermolabile (changes with heat) toxin (δ-endotoxin) contained within a crystal produced within the cell, and a thermostable toxin (a-exotoxin). Strains producing the exotoxin are not presently registered for use in the United States. As with the viruses, the effectiveness of this microbial depends largely on feeding activity of the target pest which results in ingestion of the microbial. Also, the activity of the B.t. is adversely affected by the environment and repeated applications at two- to three-day intervals may be necessary for control (Beegle *et al.*, 1981). Probably one of the main advantages of bacteria in comparison to the viruses as control agents is that they may be mass produced by fermentation procedures. Consequently, they are easier to produce and less expensive.

Several cotton insect pest species are killed by fungi, either individually or in epizootics (outbreaks involving several species). The reason cited for the lack of widespread use of fungal agents is that there are too many variable conditions which make their application unreliable and which would require the proper conditions for every combination of fungus and pest insect (Weiser, 1982). Of the fungi tested as biological control agents, only deuteromycete fungi have been produced in somewhat large scale (e.g., species of *Beauveria, Metarrhizium, Nomuraea, Verticillium, Hirsutella*). Some of these have been field tested against cotton pests (Ferron, 1978, 1981; Ignoffo, 1981). Although several of these fungi have potential as biological agents of cotton pests, especially in the areas of cotton with normally high humidity, only two fungi are being seriously researched as possible control measures for the sweetpotato whitefly in cotton.

There are numerous reports of nematode parasitism in insect populations, but most are from observations made in host plants other than cotton. Members of the Steinernematidae and Heterorhabditidae families have a mutualistic association with specific bacteria that can rapidly kill insect hosts, thus there has been much interest in their use as biological control agents (Woodring and Kaya, 1988).

Many species of insects, including several cotton pests, are known to be hosts of protozoans. However, few protozoan pathogens of insects have been field tested as biological control agents, perhaps because the incubation period is so long that crop damage usually is not controlled. They tend to cause slow, debilitative symptoms that do not lead to the rapid mortality needed in most crop protection systems, including cotton. Since the protozoans usually produce chronic rather than acute diseases, they are considered as being more useful as long-term control agents for the suppression of insect populations.

TOBACCO BUDWORM AND COTTON BOLLWORM

There are presently two registered pathogens for use in the management of tobacco budworms and bollworms, the bollworm nuclear polyhedrosis virus and the δ-endotoxin of *Bacillus thuringiensis* (B.t.). Of these, only B.t. is in commercial production at present. The last commercial production of bollworm nuclear polyhedrosis virus was registered and sold as Elcar® for use against bollworm/tobacco budworm in cotton by Sandoz, Inc. Sandoz ceased production by 1982, due primarily to competition from the new pyrethroid insecticides. Although B.t. is registered for use against bollworm/tobacco budworm in cotton, relatively little is used for control of population outbreaks.

Field studies have shown that applications of B.t. at dosages of 3.6-7.3 X 10^9 International Units (IU) of potency per 0.16 acre will suppress a bollworm/tobacco budworm larval population and result in increased cotton yield over an untreated check (Bell and Romine, 1980; Pfrimmer *et al.*, 1971; Pfrimmer, 1979). However, the degree of control generally was less than that obtained using effective chemical insecticides. The control obtained with B.t. has been more consistent than that with the bollworm/tobacco budworm nuclear polyhedrosis virus, primarily due to the respective characteristics of the pathogens after ingestion by the larval host as previously described. Whereas the virus is slow acting and the larva continues to feed, the ingestion of B.t. acts to immediately reduce feeding. Larvae are known to grow at a slower rate after feeding on B.t., but they tend to recover, continue their feeding and emerge as adults after a period of time (Dulmage *et al.*, 1978; Bell and Romine, 1986). Although control comparable to that obtained with chemical insecticides was reported using B.t., the quantity of formulation necessary was too great for such applications to be economically feasible (McGarr *et al.*, 1970). The level of control of bollworm/tobacco budworm on cotton produced by multiple applications of the bollworm/tobacco budworm nuclear polyhedrosis virus has been erratic. In some tests, the control was shown comparable to that obtained with chemical insecticides (Ignoffo *et al.*, 1965; Allen *et al.*, 1967a, 1967b; Andrews *et al.*, 1975), whereas others showed a 10 to 40 percent yield increase compared to check plots (Shieh and Bohmfalk, 1980), or marginal to no control when used alone in field tests (McGarr, 1968; Pfrimmer, 1979). Burges (1981) discussed the use of the nuclear polyhedrosis virus in 150 to 200 field trials for control of bollworm/tobacco budworm in cotton as well as other field crops. Control of "light" to "moderate" infestations with the virus was reported as comparable to a chemical standard, but at higher infestations, control by the virus was inferior.

Other nuclear polyhedrosis viruses isolated from bollworm/tobacco budworm and other species have been reported to be efficacious for control of bollworm/tobacco budworm on cotton. Although it has a very diminished effect on bollworms, the nuclear polyhedrosis virus from the alfalfa looper, *Autographa californica* (Speyer), was shown to be very virulent against the tobacco budworm and other cotton pests (Vail and Jay, 1973; Vail *et al.*, 1970). The nuclear polyhedrosis virus isolated from *Helicoverpa armigera* was field tested and demonstrated control in one of two years tested (Roome, 1975). Several of these nuclear polyhedrosis viruses are also known to exhibit broader host ranges than the isolate registered for use.

Several attempts have been made to increase the effectiveness of the nuclear polyhedrosis virus and B.t. against bollworm/tobacco budworm in cotton. These include the development of formulations to protect the microbial from deactivation by sunlight and to increase ingestion through feeding stimulants (Bull *et al.*, 1976; Ignoffo *et al.*, 1976; Patti and Carner, 1974; Bell and Kanavel, 1978). In most instances, the addition of these materials to nuclear polyhedrosis virus or B.t. sprays increased the effectiveness of the microbial. Two feeding-type spray adjuvants were marketed for commercial use with nuclear polyhedrosis viruses and B.t.; Gustol® was developed and manufactured by Sandoz, Inc. and COAX®, manufactured by Traders Oil Mill Co. Both were shown to increase feeding by bollworm/tobacco budworm larvae and to increase the persistence of nuclear polyhedrosis virus on cotton (Bell and Kanavel, 1978; Smith and Hostetter, 1982). In most reported studies, the addition of these adjuvants generally increased the effectiveness of the microbials (Bell, 1983). In one field test, treatment with a mixture of B.t. with the nuclear polyhedrosis virus from the alfalfa looper and COAX® resulted in less than 10 percent square damage compared to up to 60 percent damage in untreated cotton and an increase in yield from 292 pounds per acre seed cotton to 1,270 pounds per acre (Bell and Romine, 1980).

Another area of research to increase efficacy has been in the study of application methods. Yearian and Young (1982) reviewed some of the aspects associated with the formulation and application methodology as it applied to efficacy of nuclear polyhedrosis virus. In general, although the viruses and bacteria may be applied utilizing equipment designed for chemical insecticides, it was shown that some droplet sizes and density were more desirable than others (Smith *et al.*, 1977). Since the activity of these pathogens depends upon ingestion, methods of application that result in more thorough coverage may increase effectiveness (Falcon, 1978).

Finally, one of the more promising new technologies with exciting possibilities for use in microbial control, including cotton insect pests, is through genetic manipulation (or genetic engineering) of known pathogens. The aspect of these altered microbials led to the beginning of several companies based on the ideas that these new pathogens can compete with chemical insecticides. Research to date by these companies has been focused mostly on the development of new products based on B.t. As more information is developed, these studies might lead to varieties of increased stability, host range and potency, and thus to increased effectiveness of microbials (Martin and Dean, 1981; Geiser, 1986). Several constructs of the B.t. gene have been inserted into advanced cotton strains and commercial varieties are now available (see Chapter 17)..

BOLL WEEVIL

Pathogens infecting boll weevils include: the sporozoans *Mattesia grandis* McLaughlin and *Glugea gasti* McLaughlin; the bacterium *Serratia marcescens* Bizio; the fungi *Mettarrhizium anisopliae* (Metschnikoff) Sorokin, *Nomuraea rileyi* (Farlow) Sampson and *Beauveria bassiana* (Balsamo); and, the nonoccluded *Chilo* iridescent virus (McLaughlin, 1965, 1969; McLaughlin *et al.*, 1972; Bell, 1983; Wright and Chandler, 1991). None are registered for use at this time. Although several entomopathogenic fungi are known, and field testing was conducted with protozoan pathogens, none resulted in levels of economic control that encouraged commercial possibilities (McLaughlin, 1962; McLaughlin *et al.*, 1969). While boll weevils were shown to be susceptible to a nonoccluded (not enclosed) *Chilo* iridescent virus (McLaughlin *et al.*, 1972), none of the viruses isolated to date have shown promise for use as field control agents of that pest. There is hope for future microbial insecticides of the boll weevil through the ever-increasing varieties of *Bacillus thuringiensis*. A variety (MYX 1806) is presently being produced by Mycogen Corporation, under an Emergency Use Permit. It has activity against another coleopterans (beetles). A variety having activity against adult weevils would be needed to be useful as a control agent due to their feeding habits.

PINK BOLLWORM

Although pink bollworms are susceptible to *Bacillus thuringiensis* and some measure of control has been shown (Bullock and Dulmage, 1969), the level of control has not been reproducible and no microbials are recommended for control of pink bollworm. The nuclear polyhedrosis virus isolated from the alfalfa looper infects pink bollworms as well as several other lepidopteran pests of cotton (Vail *et al.*, 1972) and was field tested for possible control applications. In field tests, only about one percent of the larval population was infected, presumably because the larvae did not ingest the virus. Although the use of a feeding stimulant formulation significantly increased the incidence of infection (Bell and Kanavel, 1975, 1977), the degree of control was not deemed practical because of the quantity and cost of materials. The results did, however, indicate that an early-season application of the formulation might be useful as a population suppression method.

The entomopathogenic nematode, *Steinernema riobravis* Poinar, Cabanillas, and Raulston, is a highly virulent and heat tolerant species that was discovered attacking bollworm pre-pupae and pupae in corn fields in the Lower Rio Grande Valley of Texas (Cabanillas *et al.*, 1994). Methods have been developed for small scale field testing and efficacy monitoring (Lindegren et al., 1994). They showed that when applied as a water suspension to soil in cotton fields, nematode rates as low as 10 infective juveniles per cm^2 resulted in greater than 90 percent parasitism of pink bollworm larvae. *Steinernema riobravis* may have a potential role for managing cotton insect pests (bollworm/tobacco budworm, pink bollworm, boll weevil and others) that spend a portion of their life cycle in or at the soil surface. This species and others are commercially available, EPA exempt, and can be delivered with conventional ground, air, or irrigation systems.

Other pathogens infect the pink bollworm and can be considered potential control agents. For example, a cytoplasmic polyhedrosis virus found in a laboratory culture (Ignoffo and Adams, 1966) produces chronic and debilitative effects on the insect. At present, the pathogen is not considered a promising candidate due to the quantity of virus required and problems associated with production (Bell and Henneberry, 1980).

OTHER COTTON INSECTS

The nuclear polyhedrosis viruses of the cabbage looper and the beet armyworm occur naturally in larval populations and are important in the regulation of their respective hosts. Further, varieties of B.t. are commercially available for their control when needed. Since the feeding behavior of these two species favors ingestion of the applied microbials, they are more easily controlled by the virus and bacterial pathogens compared to the more specific feeders. Both species are also susceptible to a broad range of known pathogens including the nuclear polyhedrosis virus from the alfalfa looper (Vail and Jay, 1973).

The cotton leafperforator, *Buccalatrix thurberiella* Busck, is considered a sporadic pest of cotton in the western United States. Vail *et al.* (1977) obtained partial control with multiple applications of the alfalfa looper nuclear polyhedrosis virus, and multiple applications of the HD-1 variant of B.t. at normal recommended rates resulted in an acceptable level of control (Bell and Romine, 1982). Although such microbial control methods probably would not be used against this pest, treatments directed against other pest insects could reduce the populations of this pest as well.

Many efforts are being made to increase the effectiveness and the uses of microbials in cotton insect control and management programs. The use of microbials remains very appealing from an environmental safety standpoint. However, either for operational or economic reasons, their use at present and in the near future appears limited. The development of more virulent strains of B.t. over a broad host range of pest species should aid in increased utilization of products based on that bacterium. The development of other pathogens as commercial products for cotton insect control may depend upon identifying specific areas for their use, or increased public involvement in environmental concerns.

SUMMARY

In 1994, administrators of the United States' Environmental Protection Agency, Food and Drug Administration, and the Department of Agriculture presented joint testimony stating their intent to focus efforts on "...reducing overall risks from the use of pesticides through integrated pest management programs (IPM) which lead to more sustainable agricultural production strategies and reductions in the use of pesticides." Reducing "pesticide risks" can be most expeditiously achieved by changing from chemically-intensive pest management to systems emphasizing biologically-based or other nonchemical-control strategies.

Over the last three to four decades cotton insect and mite pest management has evolved from the use of long-residual, broad-spectrum organochlorine insecticides and miticides, applied at predetermined intervals based on a pre-specified time interval, calendar date, or plant growth stage, to IPM systems that prescribe chemical treatments when damaging populations of the insects and mites are present—based on scouting. Importantly, the use of pest presence or damage thresholds as criteria for chemical treatment in lieu of other pre-determined criteria often spares predators and parasites and reduces the overall amount of chemical insecticides and miticides used. The development and use of computer-based decision-making technology that makes explicit (qualitatively and quantitatively) use of natural enemy populations is growing, and promises to further reduce "pesticide risks."

On the other hand, the United States' most intractable cotton insect pests are lacking in effective natural enemies; two of these pests are exotic, viz., the boll weevil and pink bollworm. And, attempts to introduce natural enemies that co-evolved with them in their site of origin have been unsuccessful—leading to the prevalent belief that these pests cannot be biologically controlled. Also, plant bugs often function as key pests by causing early-season insecticide treatments for their control. Plant bugs are effectively attacked by numerous predators and parasites in wild host habitats but not in cotton fields. Chemical treatments for these key pests often induces the occurrence of other pests, such as whiteflies, aphids, bollworms, tobacco budworms, loopers, and armyworms, by killing their natural enemies.

The technical feasibility of augmenting natural enemies through mass propagation and strategically timed releases or applications is being practiced on a limited commercial basis in the United States. Pathogens, particularly a nuclear polyhedrosis virus for control of bollworms and tobacco budworms, and the delta-endotoxin from the bacterium, *Bacillus thuringiensis*, have been marketed in the United States on a limited basis. The egg parasite, *Trichogramma* spp., and lacewings, *Chrysoperla* spp., are also occasionally sold to cotton producers, but the high cost for producing and releasing them in numbers and times required to be effective, is prohibitive.

The ectoparasite, *Catolaccus grandis*, effectively suppressed boll weevil populations in cotton fields. The parasite is easily reared on artificial diet-reared boll weevil third instars, but this approach probably is not economically feasible except in extenuating circumstances, e.g., elimination of the boll weevil from environmentally-sensitive areas as part of the boll weevil eradication programs. However, preliminary results indicate that the parasite can be reared on artificial diet and perform in the field as well as weevil-reared parasites. Development of this mass propagation technology has potential for opening the path toward operational and economic feasibility of the augmentation approach for areawide suppression of the boll weevil. Release of the parasite during early season in previously eradicated areas that have been reinvaded by boll weevils may be a cost-effective and environmentally-rational approach for eliminating rare individuals while they are still in the immature stage.

Development of biologically-based IPM systems in cotton maximizes the value of predators and parasites. Often, these natural enemies maintain pest populations at subeconomically important levels. Management guidelines should make explicit use of natural enemy populations in making control decisions. Regardless, seasonally-disrupted system such as cotton production can be expected to intrinsically limit natural enemy numbers, diversity, and effectiveness. Consequently, natural enemies often appear too few and too late. Moreover, exotic pests such as the pink bollworm, the boll weevil, and sweetpotato whitefly often are lacking in co-evolved, selective natural enemies. Failure to establish co-evolved natural enemies from the pest site of origin does not preclude the mass propagation and seasonal introduction and augmentation of these natural enemies. Biological control of early-season pests and the avoidance of chemical insecticides and miticides spares naturally occurring and augmented beneficial organisms thereby opening the path to reducing "pesticide risks", increasing production profitability and achieving sustainability.

Chapter 16

GENETIC CONTROL

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INTRODUCTION

The control of insects which annoy man or attack his food and fiber crops largely had been the exclusive domain of entomologists (and perhaps toxicologists) up to the early 1960s when geneticists became involved in certain new techniques called "genetic" or "autocidal" control procedures. A Russian geneticist suggested the use of chromosomal translocations to influence the reproduction of harmful species (Serebrovsky, 1940). However, this suggestion effectively was lost to entomological research until resurrected by Curtis (1968) [for a complete discussion of the history of genetic thought in insect control procedures see Whitten (1985)].

All methods of genetic control require the introduction of detrimental traits into the target population by the release of suitable carrier insects. Released insects are usually reared under laboratory conditions that emphasize mass-production. The quality of a released insect is a poorly understood concept that usually is secondary to production of high numbers. By its very nature, laboratory rearing often produces insects that are less fit than the native insects for life outside the laboratory. However, as LaChance (1979) indicated, the components of fitness for the released and native insects are not necessarily the same. Released insects need not be identical to natives to be effective. The released insects must mate with enough members of the target population to introduce their genes into that population, or, in the case of sterile insects, reduce egg hatch sufficiently to effect a negative rate of reproduction.

The most widely publicized and successful proposal for the use of genetic techniques in insect control is the Sterile Insect Release Method (SIRM) or Sterile Insect Technique (SIT) first conceived by E. F. Knipling in 1938 (Lindquist, 1955). Other well known genetic techniques are inherited sterility and backcross sterility. These three methods have been evaluated on cotton insects, particularly the boll weevil, *Anthonomus grandis grandis* Boheman, the tobacco budworm, *Heliothis virescens* (F.), the bollworm, *Helicoverpa zea* (Boddie), and the pink bollworm, *Pectinophora gossypiella* (Saunders). With the exception of the pink bollworm, no method of genetic control has progressed much beyond the pilot test stage for any cotton insect. A USDA, APHIS directed program using sterile pink bollworms in California's San Joaquin Valley has been underway since 1969. It is funded primarily by cotton growers in California with some federal and state help.

At a *Helicoverpa/Heliothis* workshop, Stoneville, Mississippi, June 12-14, 1984, LaChance (unpublished) proposed adoption of the following terminology to avoid semantic difficulty in describing mechanisms for genetic control of species in these genera:

STERILE INSECT RELEASE METHOD

The Sterile Insect Release Method (SIRM) or Sterile Insect Technique (SIT) is a procedure wherein a fully sterilizing dose of radiation is administered to both males and females. Under these conditions the males are at least 99 percent sterile when outcrossed to normal females; the same is true when irradiated females are outcrossed to untreated males. Dominant lethal mutations induced in both the sperm and the ova (egg cells) of the treated species form the basis of the sterile insect release method.

Studies of insect reproduction have demonstrated that when insects are treated with X-ray, gamma radiation or certain mutagenic chemicals the treated insects become unable to produce the normal number of live progeny (Knipling, 1979). Treated males are usually at least 99 percent sterile when outcrossed to normal females, and the same is true when treated females are outcrossed to normal males. Treated insects are released in large numbers into a field environment and are expected to mate with the feral (wild, native) insects, thus interfering with reproduction. The number of insects released must be of such a magnitude that the proportion of normal X normal matings is essentially zero. If matings between treated insects and normal insects are successful, then reproduction of the field population will be disrupted, and the population will decline. The success of Sterile Insect Release Method depends on several factors:

1. Techniques for producing large numbers of the target insect;
2. Techniques for sterilizing large numbers of the target insect;
3. Reasonably competitive insects that can be released after treatment;
4. Tools that will assess field populations accurately before and after the release of the treated insects; and,
5. A treatment area large enough (or adequately isolated) to exclude the possibility of immigration of fertile females into the release area.

With the exception of item 2, these criteria also apply to other autocidal techniques.

Except for research or demonstration purposes, use of genetic methods for population suppression or eradication has been very limited. Eradication of the screwworm, *Cochliomyia hominivorax* (Coquerel), from the United States, conceived by E. F. Knipling (Lindquist, 1955) and completed in 1966 (Bushland, 1975), remains the classic example of insect control by Sterile Insect Release Method. Following the success of this program, this method was attempted on many other insect pests. The protection of California's fruit industry by the release of sterile Mexican fruit flies, *Anastrepha ludens* (Loew), and the short-term eradication of Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), populations from Los Angeles County, California (LaChance, 1979) are other examples of successful implementation of the Sterile Insect Release Method. However, problems with reintroduction and possible establishment of these pests occur.

INHERITED STERILITY

Inherited sterility is the use of substerilizing doses of radiation administered to males and females. Depending on the dose given, the males and females can be partially fertile when outcrossed to untreated insects, or the males can be partially fertile and the females completely sterile. The dose can be adjusted so that the released males and females are completely sterile when they intermate. The F_1 progeny of these males and females can be completely to partially sterile, depending on the dose administered to the parents. Insects exposed to doses of radiation which do not produce full sterility produce F_1 progeny that can exhibit levels of sterility equal to or higher than those of their treated parents (North, 1975). This F_1 (or delayed) sterility has been suggested to be of use in control programs.

BACKCROSS STERILITY

Backcross sterility describes the release of sterile hybrid insects propagated by the use of backcross techniques. These insects have been derived from an original cross involving tobacco budworm, *Heliothis virescens* (Fabricius), males and *Heliothis subflexa* (Guenee) females (Laster, 1972). The fertile female progeny are backcrossed to tobacco budworm males each generation and continue to produce fertile females and sterile males. The backcross is a way to maintain the strain so that hybrid sterility can be expressed. Both the terms backcross and hybrid sterility are acceptable, but, because F_1 hybrid insects are not released and backcross insects are, backcross sterility has become the more used term.

OTHER GENETIC CONTROL CONCEPTS

Other genetic control concepts involve: (a) the release of insects homozygous for induced or natural chromosomal translocations; (b) selection and release of strains of insects bearing conditional lethal traits or recessive lethal genes; (c) releasing insects bearing compound chromosomes; (d) the overflooding of wild populations with cytoplasmically incompatible insects; (e) isolation and release of strains with distorted sex ratios; (f) forcing of deleterious genes through a population with segregation-distorting chromosomes (meiotic drive); or (g) release of sterile hybrids (progeny of crosses between closely related species). Each of these genetic techniques has a common requirement, the mating of a laboratory-reared insect with one from the field population. The Sterile Insect Release Method differs from other genetic approaches because all insects released are sterile. All of the other genetic control techniques listed above require the release of at least one fertile sex so that the character can be transmitted to the field population. As will be discussed later in this chapter, this factor has been a stumbling block in the use of some of the more sophisticated autocidal control techniques.

The relative efficiency of various genetic methods for population suppression and a list of pertinent references has been compiled by Knipling and Klassen (1976). Additional information can be found in Hoy and McKelvey (1979) and Knipling (1979).

COTTON INSECTS

The subfamily Heliothinae of the family Noctuidae contains some of the most economically important insect pests of agricultural crops worldwide. Species of the corn earworm complex and the tobacco budworm complex are members of this subfamily. Traditionally, the bollworm or corn earworm and the tobacco budworm have been grouped together and referred to as the *Heliothis* complex. However, Hardwick (1965) revised the bollworm-corn earworm species. He divided them into seventeen species in five species groups and separated them from the genus *Heliothis*. He proposed the genus name *Helicoverpa* for this group. Acceptance of this genus name change has been met with mixed responses from entomologists. Poole (1989a,b) accepted the proposed revision by Hardwick (1965) as scientifically correct because *Helicoverpa* is morphologically distinct and phylogenetically separate from all other genera in the sub-family Heliothinae. Matthews (1987), in his classification of the Heliothinae, also agreed with Hardwick (1965). The corn earworm is identified as *Helicoverpa zea* (Boddie) in the Entomological Society of America (1989) list of approved common names. Because these changes have a sound scientific basis, it seems fitting that they should be adopted by the scientific community and used accordingly. The remainder of this discussion will follow the genus terminology of Hardwick (1965), and the species groups for each complex are listed in Table 1.

The bollworm and tobacco budworm are serious pests of a large number of agricultural crops. The bollworm is the only North American species within the genus *Helicoverpa*. Twelve species of *Heliothis* occur in North America (only three species are listed in Table 1), and the tobacco budworm, *Heliothis virescens*, is the primary pest in this genus. *Heliothis subflexa* is known to feed only on groundcherry, *Physalis* spp., and is not a pest in the Mid-South. It could be a serious pest of the husk tomato (tomatillo), *Physalis ixocarpa*, in Mexico or other areas where it is grown commercially. *Heliothis subflexa* is most important for hybridization with tobacco budworm, *Heliothis virescens* to produce genetic sterility. *Heliothis phloxiphaga* Grote and Robinson is not considered a pest, but it has been collected from safflower, *Carthamus tinctorius*.

STERILE INSECT RELEASE METHOD

Varying degrees of success have been demonstrated by this method, particularly with lepidopterous pests such as the codling moth, *Carpocapsa pomonella* (L.) (Proverbs and Newton, 1962a,b; Proverbs *et al.*, 1969), the tobacco hornworm,

Table 1. Grouping of *Helicoverpa* and selected *Heliothis* species, their distribution and economic importance (Hardwick, 1965; Poole, 1989b).

Species	Distribution	Economic importance[1]
Helicoverpa		
The *zea* group		
zea Boddie	New World	+++
confusa Hardwick	Hawaii	-
minuta Hardwick	Hawaii	-
pacifica Hardwick	Jarvis Island	-
assulta Guenee	Old World	++
toddi Hardwick	Africa	-
fletcheri Hardwick	Africa	-
tibetensis Hardwick	Tibet	-
The *punctigera* group		
punctigera (Wallengren)	Australia	++
The *armigera* group		
armigera (Hübner)	Old World	+++
helenae Hardwick	St. Helena Island	-
The *gelotopoeon* group		
gelotopoeon Dyar	South America	+
bracteae Hardwick	South America	-
titicacae Hardwick	South America	-
atacamae Hardwick	South America	-
The *hawaiiensis* group		
hawaiiensis (Quaintance and Brues)	Hawaii	-
pallida Hardwick	Hawaii	-
Unassigned group (Poole, 1989b)		
tertia Roepke	Indonesia	-
Heliothis		
virescens (Fabricius)	New World	+++
subflexa (Guenee)	New World	-
phloxiphaga Grote and Robinson	New World	-

[1]+++ = severe pest, ++ = moderate pest, + = occasional pest, - = not economically important or pest status unknown.

Manduca sexta (L.) (Cantelo *et al.*, 1973) and the pink bollworm. Irradiated pink bollworm moths have been used in Sterile Insect Release Method programs since 1968 (Miller *et al.*, 1984) to keep this species from becoming established in the San Joaquin Valley of California where approximately one million acres of cotton are grown.

Bollworm—Eradication of the bollworm from St. Croix was attempted in 1968-69 using irradiated insects (Snow *et al.*, 1971). This program was confronted with a number of complicating factors and was terminated without reaching its eradication goal (Snow *et al.*, 1971).

Tobacco Budworm—Following termination of the bollworm eradication program on St. Croix, a cooperative sterile insect release program for the tobacco budworm was initiated in 1971 between USDA, ARS, Brownsville, Texas, and St. Croix. Pilot test funds were made available to support this effort in 1972 (unpublished report of the tobacco budworm study on St. Croix from September 1971 to October 1973). This program did not accomplish its suppression objectives due largely to the non-competitive ability of the irradiated laboratory-reared insects that were released.

North and Holt (1968) reported that lepidopterous insects are extremely resistant to irradiation treatment when the criterion is induced male sterility. For example, 5 krads are required to sterilize adult male screwworms (Bushland and Hopkins, 1951), whereas 35-45 krads are required to sterilize adult tobacco budworms (Flint and Kressin, 1968). These high doses of radiation result in deleterious effects on the competitive ability of the treated insects. This lack of competitiveness can probably be attributed to radiation-induced somatic damage (North and Holt, 1968). Large amounts of radiation reduce the ability of the male to transfer sperm (Flint and Kressin, 1967, 1968; North *et al.*, 1975; Snow *et al.*, 1972). The successful mating of a bollworm or tobacco budworm is believed to require the incorporation of both eupyrene (normal sperm with nucleus) and apyrene (without nucleus) sperm in the spermatheca (sac connected to the female organ that receives and retains the sperm). The large nucleated eupyrene sperm are capable of fertilization, but they do not become motile until they are transported to the spermatheca of the female. The anucleated apyrene sperm possess motility when they enter the seminal vesicles and are involved in the transport of eupyrene sperm to the spermatheca (North and Holt, 1971). Transfer of eupyrene sperm by lepidopteran males is important in changing the female postcopulatory behavior. Females that have mated and received no sperm or only apyrene sperm continue to "call" for mates, tend to remate, and generally refrain from ovipositing (laying eggs) until they receive eupyrene sperm. Large amounts of radiation often reduce the ability of the male to transfer sperm; the irradiated sperm does not survive as long within the female; and, male vigor and longevity can be drastically lowered (LaChance, 1979). This combination of factors results in insects that are not competitive in Sterile Insect Release Method programs and dictates the need for ways to lower the doses of radiation for lepidopteran species. Consequently, inherited or partial sterility offers the probability of much greater success than total sterility for controlling the bollworm or tobacco budworm in Sterile Insect Release Method programs.

Pink Bollworm—Experiments on the use of Sterile Insect Release Method for the pink bollworm started in the early 1960s at Brownsville, Texas. The first tests used cobalt-60 gamma radiation on pupae (Ouye *et al.*, 1964) and the chemical sterilant, metepa, on adult males (Ouye *et al.*, 1965). By that time, Richmond and Ignoffo (1964) had adapted the individual rearing methods of Vanderzant and Reiser (1956) to the rearing of large numbers of pink bollworms.

Releases of high ratios (50 sterile: 1 native) of irradiated or chemically sterilized pink bollworm males into field cages containing native populations were very successful in controlling the increase in the population over the growing season (see Henneberry (1980) for a review of six field cage release experiments). However, until 1987, except for the Sterile Insect Release Method project in the San Joaquin Valley of California (Stewart, 1984), where numbers of native moths are very low, no large scale release programs had been able to duplicate the cage results. In most pink bollworm infested areas, the large numbers of moths present in the field population and/or the immigration of fertile females from untreated areas masked the effect of the released moths on population numbers.

In 1987, a pink bollworm management trial using a combination of Sterile Insect Release Method and pheromone disruption was conducted on 1000 acres of cotton planted in the Coachella Valley, California (Staten, 1987; Staten *et al.*, 1988). In this trial, sterile insects were released over all cotton growing areas in the Valley throughout the growing season. High-rate pheromone ropes were used only in fields which were not maintaining a 60 sterile : 1 native ratio at pinhead square stage (Staten *et al.*, 1987). Conventional insecticides were applied based on the recommendations of the growers' pest control advisors.

In this management trial, the criterion for success was a reduction in the number of insecticide treatments that these fields had experienced in past growing seasons. In 1985, before any management trials, insecticides were first employed on June 1 and 7.2 treatments per field were applied valleywide. Fifty-six of 57 fields were treated. In 1986, high pheromone rope treatments were used valleywide without sterile insect releases and only 1.8 treatments were made per field with 17 of 31 fields receiving treatment. During the 1987 Sterile Insect Release Method trial no insecticides were applied in June or July; only six of 27 fields were treated with insecticides through August; and only 7 of 27 fields were treated through September. An average of 1.03 applications of insecticide per field were applied valleywide. The trial in 1988 was even more encouraging, since no conventional insecticide applications occurred in the management area of Coachella Valley (R. T. Staten, personal communication). Secondary pest populations (such as whitefly) were also observed to be lower.

Thus, it appears that the integration of Sterile Insect Release Method and pheromone disruption as control procedures, along with careful monitoring of insect populations, reduced the number of conventional insecticide treatments required in the Coachella Valley of California. Further integration of other management practices—such as pest-resistant (nectariless, okra leaf) and short-season cotton varieties, crop termination with a plant growth regulator, early plowdown, and use of non-chemical sprays (such as *Bacillus thuringiensis*)—for control of leaf-eating insects, such as the bollworm or saltmarsh caterpillar, should lead to further reductions in pest populations.

Boll Weevil—A review of the status of boll weevil sterility and the technology available for eradicating the boll weevil was presented in 1983 (Wright and Villavaso, 1983; Knipling, 1983). A brief history of boll weevil sterility, the effectiveness of sterile weevils in the field, and the potential use of sterile weevils as a genetic means of population suppression will be presented here.

In the case of the boll weevil, the sterile male technique has been the only method of genetic control attempted. A paper on the theoretical release of boll weevils carrying recessive lethal mutations is available (LaChance and Knipling, 1962), but as of yet, no colonies of boll weevils with recessive lethals are in existence.

Irradiation was the first method used to sterilize the boll weevil. Dosages of irradiation large enough to produce sterility also caused what was then considered to be unacceptably high mortality (Davich and Lindquist, 1962). Longevity in both the field and laboratory also was significantly reduced, and levels of sterility were not consistent. From results of a field cage test, Davich *et al*. (1965) estimated the mating competitiveness of irradiated males to be roughly 20 percent that of normal males.

Chemosterilization was tried as an alternative method to sterilize the weevil, but it also reduced vigor and sterility was not permanent (Borkovec *et al*., 1978; Earle and Leopold, 1975; Gassner *et al*., 1974; Haynes, 1963; Haynes *et al*., 1975; Lindquist *et al*., 1964; McHaffey and Borkovec, 1976). However, chemosterilization with busulfan and hempa appeared to be the best sterilizing treatment available in the early 1970s, and it was chosen as the method for sterilizing the weevils released in the Pilot Boll Weevil Eradication Experiment [PBWEE] conducted in South Mississippi, Louisiana, and Alabama from 1971-1973. Males released in the experiment were both mass-reared and mass-sterilized. Tests of the competitiveness of weevils treated by the chemosterilization technique were conducted on weevils reared and sterilized on a small scale (less than 1000 or so insects) and then released into 1/16 acre screened cotton plots (Villavaso and Earle, 1976). These males were 25-33 percent as competitive as untreated males.

The eradication area for the experiment averaged about 2600 acres during the three-year test with the total eradication and buffer areas averaging about 20,000 acres (Boyd, 1976). Events leading to this experiment, results of the experiment, and the reports of two committees convened to evaluate whether eradication was achieved or would be achievable with the technology then available are presented in the report of Boyd (1976).

A sterilization treatment in which small doses of irradiation were given to adult male confused flower beetles, *Tribolium confusum* Jacquelin duVal, over a period of time rather than in one large dose became known as fractionated irradiation (Ducoff *et al*., 1969, 1971). The treatment appeared to produce both high sterility and longer post-irradiation survival. This type of treatment had been deemed to be unsatisfactory for the boll weevil (Flint *et al*., 1966), but was revived in the mid-1970s as a series of 25 doses of irradiation administered to adult boll weevils at four-hour intervals (Earle *et* *al*., 1978; D. Birkenmeyer, D. Childress, and R. Leopold, USDA, ARS, Metabolism and Radiation Research Laboratory, Fargo, North Dakota, unpublished data).

The use of fractionated irradiation on boll weevil pupae was begun in the mid-1970s. Males emerging from pupae subjected to a series of 25 irradiation treatments of approximately 250 rad per treatment (Haynes *et al*., 1977) were 23 percent as competitive as normal males (Villavaso *et al*., 1979). In comparison, adult males allowed to remain on the surface of the larval media for 3-4 days after emergence and then treated with a single dosage (acute irradiation) of seven krad followed by a five second dip in a 0.02 percent solution of diflubenzuron (Dimilin®) in acetone (R. A. Leopold and D. T. North, personal communication; Earle *et al*., 1978) were 36 percent as competitive as normal males. Although it worked relatively well, pupal fractionation was dropped because of its unwieldiness and its failure to produce males any more competitive than those treated with acute irradiation.

Diflubenzuron (Dimilin®) had been found to be an effective means of preventing hatch of eggs laid by irradiated females mated to fertile males without causing increased mortality (Moore and Taft, 1975; Moore *et al*., 1978), but administration of diflubenzuron to males not yet hardened after emergence severely reduced their ability to inseminate females (Earle *et al*., 1979). The mating ability of males allowed to age four or more days before treatment with diflubenzuron was not affected. However, diflubenzuron was applied as an acetone dip, and acetone was found to severely impair the flight ability of treated weevils (Earle and Simmons, 1979; Haynes *et al*., 1981).

Pheromone production for both pupal fractionation and acute irradiation was approximately equal. Even though the pupal fractionation group was newly emerged, pheromone production averaged 2.0 micrograms per male per day for days one to three after emergence; this rose to 4.5 per male per day for days four to six. The weevils that received the single dosage of seven krad had been allowed to feed on the surface of the larval media for three to four days before treatment; however, their level of pheromone production was not significantly higher than that of the pupal fractionation group indicating that diet might be as important as age in the onset of pheromone production by males (Villavaso *et al*., 1979).

The laboratory work of Leopold, North and Earle had stimulated renewed interest in acute irradiation as a method to sterilize the boll weevil. Acceptable levels of field competitiveness in male weevils sterilized by acute irradiation reestablished the feasibility of using this treatment in mass-release programs (Villavaso *et al*., 1979). However, the use of acute irradiation would not have come about without the advent of the following three factors: (a) mass-rearing of boll weevils relatively free of pathogenic bacteria (Sikorowski *et al*., 1977; Sikorowski, 1984); (b) use of diflubenzuron (Dimilin®) to bring about complete sterility of treated females (Moore *et al*., 1978); and perhaps most importantly, (c) the lowering of the formerly acceptable standard of 50 to 70 percent survival of treated males for three weeks after treatment to a more realistic one. A sterilizing treatment is now considered to be acceptable if males are able to attract and inseminate females for at least seven days after treatment. (Villavaso *et al*., 1980).

The first field tests designed to estimate competitiveness of irradiated males were conducted in 1977 (Villavaso *et al*., 1979). Sterile and fertile males were released into isolated boll weevil-free plots of cotton along with virgin females. One week later, squares with oviposition punctures were collected from the plots. Hatch of eggs collected from these squares along with hatch from crosses between sterile males X normal females, normal males X normal females, and the ratio of sterile to normal males in the field were used to estimate competitiveness according to a formula derived by Fried (1971):

$$\frac{Ha - Ee}{Ee - Hs} \times \frac{N}{S}$$

Where

Ha = percent egg hatch for normal males X normal females
Hs = percent egg hatch for sterile males X normal females
Ee = percent egg hatch observed in the experimental plots
N = the number of normal males
S = the number of sterile males

The formula gives an estimate of the overall competitiveness of the sterile males as measured by egg hatch. No assumptions are made as to the individual factor or factors that might be responsible for the degree of competitiveness achieved. The Fried formula gives competitiveness as a decimal equivalent. Multiplying by 100 converts this figure to percentage. Use of the isolated plot technique and the formula of Fried are the standard methods for determining competitiveness of sterile boll weevils.

Using basically the same procedures established in 1977, small plot tests were conducted simultaneously in Louisiana and North Carolina (Villavaso *et al*., 1980) to determine the competitiveness of males sterilized by three methods. The three sterilization methods were: (a) fumigation with bisazir followed by dipping in penfluron (Borkovec *et al*., 1978); (b) irradiation with 10 krad of gamma irradiation followed by dipping in diflubenzuron (Leopold and North, personal communication; Earle *et al*., 1978); and (c) treatment of pupae with doses of 250 rad every four hours until a total dosage of 6250 rads had been administered (Haynes *et al*., 1977). The males sterilized by the three methods were 23, 17 and 12 percent, respectively, as competitive as untreated males of the same laboratory reared strain. The fumigated males and those given the single dosage of irradiation were fed artificial diet for five days prior to irradiation (Wright *et al*., 1980).

In 1979 sterile males were released as part of the Boll Weevil Eradication Trial (BWET) on approximately 19,000 acres of cotton in Virginia and North Carolina. A fall diapause program in which all cotton acreage was treated with organophosphate insecticides significantly reduced the number of weevils entering diapause. It was followed by spring applications of sterile insects, pheromone trapping and aerial applications of organophosphates and the insect growth regulator diflubenzuron (Dimilin®). Though the boll weevil was eradicated from the trial area by this combination of techniques, the effect of each technique could not be measured separately. Only seven native weevils were captured in the trial area prior to the release of 11.2 million sterile weevils; thus, the role played by the sterile insects in eradication remains unclear. The treatment selected to sterilize the weevils released in the Boll Weevil Eradication Trial consisted of feeding weevils on slabs of diet containing 0.01 percent diflubenzuron for the first five days after they had emerged followed by 10 krad of gamma-irradiation (Wright *et al.*, 1980). This treatment was chosen because of its simplicity and predictability and because of the potential health hazard associated with the fumigation treatment (Villavaso *et al.*, 1980). Diflubenzuron (Dimilin®) was administered in the diet rather than as an acetone dip because acetone was found to have an adverse effect on the flight ability of dipped weevils (Earle and Simmons, 1979; Haynes *et al.*, 1981). Administration of diflubenzuron to newly emerged weevils was known to have a serious detrimental effect on their ability to mate (Earle *et al.*, 1979), but it was considered to be the only available means of assuring complete sterility while avoiding the flight problem associated with dipping in acetone.

In 1979, 1980 and 1981, weevils treated by the same method used in the Trial were tested for competitiveness in the field. Competitiveness of the sterile males versus untreated laboratory-reared males averaged 10.6 percent for the first seven days following release when they were released with laboratory-reared virgin females. Competitiveness of sterile males versus native males averaged six percent when they were released with native virgin females. In general, the treated weevils were competitive only during the first four days of the seven-day period. Between days five and seven after release, competitiveness was no more than two percent indicating that biweekly releases of sterile weevils would be more effective than weekly releases. In fact, if weevils that are only effective for four days are released at seven day intervals, their pheromone might tend to concentrate the native weevils during these four days. Between days five and seven, the concentrated natives would have virtually no competition from sterile weevils, and this could increase the probability of native males mating with native females (Villavaso, 1981, 1982; Villavaso and Thompson, 1984). Additionally, Mitchell *et al.* (1983) reported no reduction in egg hatch when weevils treated by the method used in the Boll Weevil Eradication Trial were released against a very small native population on 120 acres of commercially grown cotton; this indicated that some factor or factors had prevented their being effective under field conditions.

In the early 1980s, a method of sterilization was developed that resulted in the highest competitiveness value that had been obtained for sterile boll weevils in small plot field tests. Males fed an ecdysteroid rather than diflubenzuron (Dimilin®) for five days prior to irradiation were 43.7 percent as competitive for laboratory reared females as untreated laboratory reared males. In comparison, the diflubenzuron fed irradiated males were only 12.5 percent as competitive (Villavaso *et al.*, 1983; Villavaso and Thompson, 1984). Weevils treated by the ecdysteroid plus irradiation technique were 50.4 percent as competitive as native males that naturally infested three small field plots (Villavaso *et al.*, 1986a). All of these estimates of competitiveness were obtained from males reared and sterilized on a small scale (several hundred to 5000 at a time). However, when weevils treated by this same technique were reared and treated on a large scale (several hundred thousand per week), they were estimated to be only 11.4 percent as competitive as the natives infesting 180 acres of cotton in the Mississippi Delta (Villavaso *et al.*, 1986b). Bacterial contamination of the mass-reared weevils and/or the crowded conditions during the 1.8 hour period of exposure to irradiation appeared to have a severe detrimental effect on the released weevils.

In 1983, mass-reared and sterilized weevils were released into the cotton fields by two new methods. The first consisted of hanging small paper bags each containing about 75 weevils on cotton plants at the rate of four bags per acre. The bags were torn open to allow the weevils to escape. For the second method, weevils were suspended in a 0.6 percent solution of furcelleran and dispensed onto the plants by means of a specially designed pumping device (D. K. Harsh, J. L. Roberson and E. J. Villavaso, USDA, ARS, unpublished). Both methods of release effectively placed weevils directly on the plants instead of randomly dropping them into the fields where they might land either on the plant or on the ground. Dropping weevils onto freshly cultivated or hot soils (greater than 115°F) in early 1983 resulted in very low numbers of weevils reaching the cotton plants (Roberson and Villavaso, unpublished). The loose soil prevented the weevils from leaving the ground where they had fallen, and if soil temperatures reached lethal levels as they often did during the release periods, the weevils died on the ground without ever reaching the plants. The importance of developing a method of release that resulted in a large portion of the weevils reaching the cotton plants was clearly seen, and a method by which released weevils would be containerized for mass-release was subsequently developed.

In 1984, mass-reared and sterilized weevils were released by the furcelleran method into six fields of commercially grown cotton totaling 69.5 acres in north central Mississippi (Villavaso *et al.*, 1989a). The weevil population in the fields was low (approximately four per acre) during the test due to the effects of the severe preceding winter. Diflubenzuron wettable powder (Dimilin® 25 percent WP) was used as an aqueous dip (Roberson and Villavaso, unpublished) or as an acetone dip (0.4 percent) prior to treatment with 10 krad of gamma irradiation. Use of the aqueous dip avoids the flight inhibition caused by acetone. Treating four day old weevils rather than newly emerged ones with diflubenzuron allows the cuticles of these weevils to harden and increases their ability to mate. Release of weevils directly on to the cotton plants in the furcelleran solution counteracted the flight inhibiting effect of acetone.

Egg hatch in the six fields was reduced to 15.2 percent while hatch in the three control fields (46.5 acres) was 94.4 percent. This was the most significant demonstration of the effectiveness of sterile weevils against relatively low populations of natives. A population of four weevils per acre is at least twice as high as that which sterile weevils might be used against in an eradication program, and the population was probably underestimated. Additionally, the sterile weevils were estimated to be only about 12 percent as competitive as the natives. Some of the then unidentified problems associated with the status of mass-rearing, handling and sterilizing of weevils apparently were responsible for the lowered competitiveness.

In 1985, mass-reared and sterilized weevils (irradiation plus aqueous dip in diflubenzuron) were containerized and mass-released in a large scale test in South Carolina. The LT_{50} (the day on which 50% or more of the males had died) of the samples of males held on cotton plants averaged 7.7 days, and competitiveness of the mass-reared, mass-sterilized weevils was increased to 19 percent. Antibiotics added to the pre-irradiation diet may have been beneficial in increasing longevity of these weevils (Reinecke *et al.*, 1986).

In 1986, there were reports that the vision of mass-reared weevils was impaired (Agee, 1986), and that the addition of carotenoids to the diet would remedy the impairment (Dickens and Agee, 1987). The competitiveness of the visually impaired weevils (71 percent) and that of weevils whose visual impairment was corrected by the use of carotenoids (77 percent) was not significantly different, and it was determined that the visual impairment was not an important factor in competitiveness (Villavaso *et al.*, 1988). Also in 1986, the competitiveness of visually impaired sterile weevils was tested in small field plots in Arizona against the Arizona natives. Competitiveness averaged 83 percent (Villavaso *et al.*, 1989b). The released weevils were mass-reared and then handled and sterilized in small groups of a few hundred. The high degree of competitiveness indicated that the quality of the mass-reared weevils had improved significantly over the previous year.

Prior to 1985, most of the research on the competitiveness of sterile weevils had been done in small isolated plots of 1/4 to 1 acre or in commercial cotton plantings of less than 200 acres (Villavaso *et al.*, 1979, 1980, 1986a,b, 1988). In 1987 and 1988, a test of the effectiveness of mass-reared, sterilized (irradiation plus aqueous dip in diflubenzuron), containerized and aerially-dropped weevils was conducted on about 5000 and 3000 acres, respectively, in Fayette County, Alabama. In 1987 the test area had native populations that were too high for the sterile weevil to be very effective. However, even with the high populations, the fertility of the native females was reduced by about 39 percent. The LT_{50} of samples of sterile males held in individual screened containers on cotton plants averaged 9.1 days. This exceeded the previous high for a test of this type by 15 percent. The 1988 weevil populations appeared to be smaller than those of 1987, and fields selected for intensive sampling showed the effectiveness of the sterile weevils (Smith *et al.*, 1989).

The degree of competitiveness that sterile weevils must exhibit in order to eradicate indigenous populations of boll weevils has not been determined. Eradication was achieved in the 1979 Boll Weevil Eradication Trial, but the extent to which the released weevils contributed to eradication could not be partitioned from that of the other methods of suppression used. This remains one of the major problems in assessing the value of sterile weevils in eradication efforts. Before eradication by means of sterile weevil releases can be demonstrated in large acreages of commercially grown cotton, the target population must be very low. A highly competitive sterile weevil might be effective in eradicating populations as high as five natives per acre. However, the chances of achieving eradication with sterile weevils alone probably decrease greatly as native populations increase to more than two per acre. When native populations are small enough to expect eradication, it becomes almost impossible to evaluate the effect of sterile weevils because of the difficulty in collecting data and the possibility of migration into the test area. The expense of testing over very large acreages (more than 3000 acres) where migration might be plotted by use of trap lines is too large for most research budgets to absorb. Different management practices from farm to farm, especially application of insecticides for other insects, confound the evaluation process.

When using small (less than 1 acre), isolated plots to evaluate the effectiveness of sterile weevils, a sufficient number of normal weevils must be released into the test plots to insure an adequate number of eggs for measuring egg hatch. This means that many more normal males and females must be put into the small plots than one would anticipate in any program where eradication was the goal. From the small plot data, the competitiveness of sterile weevils can be estimated. These estimates can then be used in models to predict the probability of eradicating very low weevil populations. However, many variables affect the performance of weevils released in the field, and they must be researched or assumed before models can be constructed. These include, but are not limited to, the number of native weevils entering the cotton fields, the time period over which they enter the fields, the expected rate of increase of the native population, their spatial distribution in the fields, and the relationship between the growth stage of the cotton plants and the temporal (of or relating to time) and spatial distribution of the native and the released weevils.

The temporal (time related) distribution of native populations emerging in the spring can alter the effectiveness of sterile weevils. Two populations of similar size might have dissimilar emergence patterns. In one year, most of the overwintered weevils might emerge before the cotton has begun squaring. In this case treatment with insecticide before the squares are large enough for larval development (pinhead square treatment) will have a devastating effect on the native population. In another year or the same year in a different location, most overwintered weevils might emerge after the appearance of squares large enough to support reproduction. In this case the effectiveness of the pinhead square treatment will be reduced. Thus, even though the spring populations were similar in size, sterile weevils will be competing with a much larger number of native weevils in the second case than in the first.

Sterile weevils will probably be released at a fixed number per week, but the ratio of sterile to native weevils will vary depending on how the natives emerge. If, for example, 200 native weevils fly into a 100 acre cotton field during the week after pinhead square treatment and sterile weevils that are effective for one week are being released at a rate of 100 per acre per week, the ratio of sterile to natives will be 50:1 for that week. If native weevils live for two weeks and the 200 natives emerge at a rate of 25 per week for eight weeks, then the sterile to native ratio will be much greater (400:1 for the 1st week and 200:1 thereafter). If the sterile weevils are 25 percent as competitive as natives, the 50:1 ratio becomes 12.5:1 and reproduction will probably occur. The 200:1 ratio becomes 50:1, and there is a much greater chance that the sterile weevils will prevent reproduction in the field. Thus the odds of sterile weevils preventing reproduction in two native populations of exactly the same size can be quite different.

Another problem associated with suppression by sterile weevils is the spatial distribution of the native weevils in the field. An average population of one native per acre uniformly distributed over a field would be amenable to eradication. However, if 80 native weevils settled in a 10 acre portion of a 100 acre field over a short period of time, and the remaining 20 natives dispersed over the other 90 acres, then a higher than acceptable rate of reproduction is almost certain to occur in that portion of the field where the native population is actually eight times the average for the whole field. The use of sterile weevils would be effective only against very low populations of natives where aggregations of emerging overwintered insects would be small enough to be controlled by the released weevils. Therefore, their use wouldn't be effective in fields with spatial distribution problems.

If sterile males are unable to attract and mate with native females before the native females mate with a native males, the effectiveness of the sterile males will be diminished. The eggs laid by native females tend to be highly aggregated (Pieters and Sterling, 1974). The F_1 weevils emerge from these aggregations or clumps (Mitchell *et al.*, 1976) in close proximity to one another, and the ratio of sterile to native weevils in such aggregations will be much lower than that over the field as a whole. These aggregations will be difficult for sterile weevils to control.

Effects of both clumping (spatial distribution) and emergence pattern (temporal distribution) on the effectiveness of sterile weevils can only be speculated, but it is reasonable to assume that both can have significant impact on the success of a sterile insect release program. These effects might best be estimated with the aid of computer simulation models.

Use of insecticides to decimate boll weevil populations followed by the use of pheromone traps to identify surviving pockets of reproductive activity, followed by more insecticide applications and more trapping has been successful in eradicating boll weevils from North Carolina and most of South Carolina. This method of eradication is continuing in most of the cotton growing areas of Georgia and Florida and significant portions of Alabama, and as long as the method is acceptable, sterile weevils will probably not be used for eradication. The odds for sterile boll weevils ever being used for other than research or demonstration appear to be low at present.

INHERITED STERILITY

Bollworm—LaChance (1985) stated that all models comparing inherited sterility (see discussion of inherited sterility in earlier section of their chapter) with total sterility demonstrated that inherited sterility is more effective in suppressing native populations of lepidopterous species than an equal number of fully sterile insects. Proverbs and Newton (1962a) first reported the incidence of inherited sterility in the codling moth. Since that report, many researchers have studied inherited sterility and its potential for population suppression for a number of lepidopterous pests (North, 1975; Laster *et al.*, 1988a).

Knipling (1970), using population models, demonstrated the advantage of inherited sterility over the sterile insect release method. The bollworm has been suggested as a potential candidate for control by inherited sterility (North and Holt, 1971; Knipling, 1979; LaChance, 1985; Carpenter *et al*., 1987a,b,c). North and Holt (1970) first reported inherited sterility in the bollworm. They observed reduced egg hatch from F_1 (first generation offspring) moths compared to P_1 (parental generation) moths, found that irradiated males transferred a normal amount and ratio of eupyrene: apyrene sperm (e.g. ratio of normal sperm: sperm without a nucleus), and suggested the possibility of population suppression by releasing partially sterile moths. Snow *et al*. (1972) studied the effects of irradiation on the ability of adult male bollworms to transfer sperm and the field attractiveness of females mated to irradiated males. They found that irradiated males transferred significantly less normal sperm than nonirradiated males, but the decrease was greater with sterile males than partially sterile males. Also, females containing irradiated sperm were as attractive as virgin females; females mated with untreated males were less attractive. They concluded there would be significant advantages, in terms of sperm transfer, from the use of partially sterile males in release programs.

The early work by North and Holt (1970) has been expanded with efforts directed toward refining the inherited sterility technique to control the bollworm. Carpenter *et al*. (1987a) found that females mated to normal males and males irradiated with 10 krads have the same mating propensity and experience the same intermating interval. Sperm competitiveness demonstrated by these irradiated males was reduced in F_1 males. Females mated to male progeny from the irradiated males outcrossed to normal females exhibited the same attractiveness and mating propensity as virgin females. These females apparently were able to detect the quality of a sperm complement and reduce their intermating interval if the quality was not satisfactory. Therefore, the sperm from the F_1 males would be less competitive than normal sperm because they would be displaced more quickly by sperm from a subsequent mating due to the shorter intermating interval.

Carpenter *et al*. (1987c) studied the effects of substerilizing doses of radiation and inherited sterility on reproduction of the bollworm. They noted a higher degree of sterility in the F_1 progeny than in the P_1 adults when irradiated males were mated with normal females, and radiation-induced deleterious effects were inherited through the F_2 generation. Carpenter *et al*. (1987a), using a population model to predict the effects of inherited sterility on a native population, projected that a single release of males irradiated with 10 krads at a 9:1 ratio (irradiated:normal) would reduce the native population by more than 99 percent after three generations. Therefore, inherited sterility appears to be the more promising means of suppressing the bollworm than any other release technology presently known.

Tobacco Budworm—Flint and Kressin (1967) noted that male tobacco budworm moths were 99 percent sterile after an irradiation dose of 35 krads. Female moths produced few eggs at this dose, but there was some egg hatch. These studies were not expanded to determine the extent of inherited sterility. Proshold and Bartell (1970) reported the effects of inherited sterility on reproduction, developmental time and sex ratio of this species. They found that irradiation reduced mating and fecundity (the ability to lay eggs), increased developmental time, increased larval and pupal mortality, and distorted the sex ratio in favor of the males. Proshold and Bartell (1972) further indicated the potential for reducing tobacco budworm populations by inherited sterility and reported that sterility factors were nearly eliminated by the third generation.

Laster (1972) discovered hybrid sterility by crossing *Heliothis subflexa* females with tobacco budworm males. Knipling (1979) stated that the calculated effects due to the release of both hybrid sterile males, if fully competitive, and hybrid fertile females for one generation are among the most impressive of the various genetic mechanisms considered. Since hybrid sterility for the tobacco budworm was discovered and its population suppression potential recognized, little effort on irradiation sterility for this species has been pursued.

Pink Bollworm—In the pink bollworm, F_1 males from parents treated with radiation failed to transfer sperm to their untreated mates and the females continued to seek mates (LaChance *et al*., 1973). Because of the apparent reproductive problems with F_1 males, as well as a lack of good isolated field populations, no experimental field release programs have been attempted using partially sterilized pink bollworms. The effects of low doses of radiation (1 - 10 krad) on the reproduction of P_1 and F_1 pink bollworms have not been examined fully, and the impact of such insects in field populations is unknown.

Boll Weevil—In the boll weevil, some reduction in the reproductive potential of F_1 through F_3 insects has been seen, but the results are highly variable (Haynes and Smith, 1989; Haynes, 1990; Villavaso, unpublished). The technique does not seem to offer much promise at present.

BACKCROSS STERILITY

Bollworm—Backcross sterility such as that which has been demonstrated for the tobacco budworm is not known for any other agricultural insect pest species. Because the sterility mechanism was found for the tobacco budworm, it is reasonable to assume that it may also occur in other phylogenetically related lepidopterous species. Efforts are in progress to search for a similar type of sterility for the bollworm.

Research was initiated in 1984 to search for backcross sterility for bollworm. This effort involves importing *Helicoverpa* species from various parts of the world into the Stoneville Research Quarantine Facility, Stoneville, Mississippi, crossing them with bollworm, and evaluating the progeny for male sterility. In a cytoplasmic incompatibility system, sterility may not be expressed in the F_1, but may develop in later backcross generations as the chromosomes of one species are transferred to the cytoplasm of the related species. For this reason, long term experiments involving several laboratory generations are necessary (Laster *et al*., 1985).

The search for bollworm backcross sterility is dependent upon foreign exploration, importation and colonization of the "exotic" species in quarantine in order to carry out crossing trials over several generations. Primary emphasis is placed on obtaining and evaluating the *Helicoverpa* species described by Hardwick (1965) (Table 1). Species that have been evaluated thus far, their origin, and reproductive status are listed in Table 2. From the standpoint of hybridization with *Helicoverpa zea*, *Helicoverpa armigera* appears to be homogeneous across its geographic range. Although the incidence of mating between the two species is low, progeny are produced from successful matings with no evidence of sterility (Laster, unpublished). Matings between *Helicoverpa fletcheri* from Mali, West Africa, and *Helicoverpa zea* gave results similar to those between *Helicoverpa zea* and *Helicoverpa armigera*. All attempted matings between *Helicoverpa punctigera* from Australia and *Helicoverpa zea* or *Helicoverpa gelotopoeon* from Argentina and *Helicoverpa zea* resulted in the pairs permanently locked in copula and no reproduction. Progeny were obtained from one

Table 2. Reproduction from exotic *Helicoverpa* species imported into the Stoneville Research Quarantine Facility and crossed with bollworm.

Species	Origin	Reproduction
armigera	Australia	yes
armigera	Egypt	yes
armigera	Indonesia	yes
armigera	Pakistan	yes
armigera	Thailand	yes
armigera	Zimbabwe	yes
armigera conferta	New Zealand	yes
assulta	Pakistan	yes[1]
assulta	Thailand	no
assulta	Zimbabwe	no
fletcheri	Mali	yes
gelotopoeon	Argentina	no
punctigera	Australia	no

[1]F_1 Progeny were obtained from one mating of bollworm x *H. assulta*. Haldane's (1922) effect was expressed and the colony was lost.

mating of *Helicoverpa zea* x *Helicoverpa assulta* from Pakistan. Progeny from this mating were all male following Haldane's Rule (1922) which states: "When in the F_1 offspring of two different animal races, one sex is absent, rare or sterile, that sex is the heterozygous sex." The hybrid from *Heliothis subflexa* females mated to tobacco budworm males is an exception to this rule because, in Lepidoptera the female is the heterozygous sex (Robinson, 1971). Although no backcross sterility has been found for bollworm, there still remains a large number of candidate species in various geographical locations for crossing with bollworm. The potential for population suppression of bollworm with backcross sterility justifies the effort in continuing the program.

Tobacco Budworm—Laster (1972) crossed *Heliothis subflexa* females with tobacco budworm males and discovered that the hybrid males were sterile. Hybrid females, when mated to tobacco budworm males, produced progeny with sterile males and reproductive females. This sterile male trait continued through successive backcross (BC) generations when backcross females were mated to tobacco budworm males. After a few backcross generations, these insects are genetically almost identical to tobacco budworm except that the males are completely sterile (Laster *et al.*, 1988a). The tobacco budworm genome operating in the *Heliothis subflexa* cytoplasm results in male sterility. However, the mechanism causing male sterility has not been determined.

The potential for suppressing wild tobacco budworm populations through use of backcross sterility in mass rearing and release programs was recognized. The sterile male producing females provide the driving force for population suppression. A number of models have been developed that project the decline of the natural tobacco budworm population following release of backcross insects (Laster *et al.*, 1976; Makela and Huettel, 1979; Levins and Parker, 1983; Roush and Schneider, 1985).

Biological investigations showed that backcross insects utilized the same host plants as the tobacco budworm (Laster *et al.*, 1978, 1982; Martin *et al.*, 1984), and that the final mating of females took precedence over previous matings (Pair *et al.*, 1977). Egg hatch was reduced through sterile male matings and the sterile male trait was infused into the tobacco budworm population (Laster *et al.*, 1978). A pilot backcross release program conducted on St. Croix during 1977-1980 demonstrated that the tobacco budworm population was suppressed during this period when compared with the population on Vieques, a neighboring island, for the same period (Proshold *et al.*, 1982).

Evaluation of backcross sterility in a typical agricultural area in the contiguous United States is needed to determine its effectiveness for tobacco budworm population suppression. All biological data indicate that backcross insects are competitive with normal insects in the feral (wild, native) population. Also, characteristics such as insecticide resistance, to give the backcross insects a competitive advantage, might be incorporated into the backcross (Firko and King, 1990).

Evaluation of tobacco budworm collected over a wide geographical range (Arizona, California, Mississippi, North Carolina, Texas, Mexico, South America, Puerto Rico and St. Croix) indicated no differences in their response to hybridization (Laster *et al.*, 1988*b*; Laster, unpublished). This indicates that a backcross release program should be widely adaptable and would have the following advantages over the other sterility inducing systems: (a) no treatment is necessary other than the original cross; (b) any life stage of the insect can be released; (c) backcross populations are perpetuated by the backcross females; and (d) the desired backcross frequency can be obtained either by release of large numbers for one generation or fewer numbers for several generations (Proshold *et al.*, 1982).

Pink Bollworm—No measurable hybrid sterility has been found in crosses between pink bollworm collections from areas within the United States, Mexico, Puerto Rico or St. Croix, Virgin Islands, (A. C. Bartlett, unpublished results). Raina *et al.* (1981) reported no incompatibility between a strain of insects from southern India and two strains of pink bollworm (one was a long-term laboratory colonized strain, the other a newly colonized strain) from Arizona. We have not been able to import live pink bollworms from other areas (e.g., Egypt, China, Macedonia, Turkey, USSR) to pursue this research as thoroughly as should be done.

LaChance and Ruud (1979) made crosses between strains of the pink bollworm from Australia and Arizona and found full fertility. They also made reciprocal crosses between both strains of the pink bollworm and a strain of *Pectinophora scutigera* (Holdaway) from Australia. These crosses were characterized by reduced interspecific mating, low fecundity and low fertility. Some F_1 fertile progeny were produced, especially when *Pectinophora scutigera* females were crossed with pink bollworm males. Those F_1 individuals were fertile in backcrosses to *Pectinophora scutigera* but infertile in crosses to the pink bollworm. The authors suggest that interspecific hybrids between these two species will not be obtained easily and that these results may not be useful in control procedures. It seems possible, by artificial selection procedures, to improve the rate of interspecific mating, fecundity and fertility, so that increased numbers of F_1 progeny could be produced. Because the interspecific hybrids are sterile when crossed with pink bollworms, there is a possibility that they could be used in sterile releases without the debilitating effects of radiation. Such usage may entail more research effort than is justified, if radiation sterilized insect releases continue to be as efficacious as shown in the Coachella Valley trial in California.

CONDITIONAL LETHAL MUTATIONS

Pink Bollworm—Strains of insects can be manipulated by artificial selection procedures to carry traits that are detrimental to a field population but that do not affect the ability of the strain to exist in the laboratory For example, in areas of the world where diapause is mandatory for carrying populations through host-free or environmentally unsuitable periods, the inability of the pink bollworm to go into diapause would be a conditional lethal trait. A non-diapausing (ND) strain could be reared readily in the laboratory, but progeny produced by this strain in the field would not diapause, and could not reproduce during the host-free period.

Bartlett and Lewis (1987) selected strains of pink bollworms for the inability to respond to conditions in the laboratory (short photoperiod and low temperature) which normally induce diapause. The non-diapause character is controlled by dominant or partially dominant alleles and is polygenic.

The nature of the inheritance of the non-diapause character suggests that single releases of the non-diapause strain should be made in extremely large numbers near the end of the reproductive season. However, if females were released in the numbers needed to insert the character into field populations, they would lay fertile eggs and almost certainly increase the numbers of larvae present in the bolls. Increased larval numbers would lead to increased crop loss. The increased loss coupled with the cost of the release program, is not likely to be accepted by most farmers. In common with other genetic control procedures, it would be most beneficial if only males carrying the trait could be released. In this way, crop loss due to the addition of fertile females to the population would be avoided since the released males would mate only with native females.

SEX-LINKED RECESSIVE LETHAL MUTATIONS

Pink Bollworm—Lepidopterous males carry two X chromosomes (homogametic), while the females have only one (heterogametic). Strunnikov (1979) proposed the use of strains of Lepidoptera with balanced recessive lethal mutations on the sex chromosomes of the male as a method for control of lepidopterous pests.

Males carrying balanced recessive lethal mutations have two different recessive lethal genes, one on each X chromosome at different loci. When such males are crossed with any female, no female progeny are produced, unless crossing-over occurs between the two loci. Strunnikov (1979) postulated that the use of such genetically altered insects would be 1.3 times as effective in the F_1 as the single release of fully sterile males and that the effect would increase over generations.

In addition to the usefulness of balanced sex-linked recessive lethal mutations in control procedures, such stocks would be useful in genetic sexing of strains where only males should be released to drive a detrimental character (such as non-diapause) into a field population. In fact, the two systems (conditional lethal and balanced lethal) would act in concert to reduce pest populations during the growing season and the host-free season.

Bartlett (1988) demonstrated that sex-linked recessive lethal mutations can be induced readily in the pink bollworm and, by means of a sex-linked recessive eye color mutation, can be maintained over many generations in the laboratory. The production of a balanced sex-linked lethal strain has not yet been accomplished in the pink bollworm, nor in the codling moth (Anisimov, 1988). However, the possibility of developing such strains is being investigated actively at this time.

TRANSLOCATIONS

Pink Bollworm—Pink bollworms have been exposed to irradiation for the production of chromosomal translocations in a number of experiments (A. C. Bartlett, unpublished). Visible eye-color genetic markers have been used to recover reciprocal translocations. However, radiation induces a number of detrimental mutations (recessive lethals, deletions, duplications, etc.) along with the reciprocal translocations. A single heterozygous translocation produces about 50 percent sterility in the insect carrying the translocation. Thus, the reduced fertility due to the translocation, plus the problems with fertility caused by induced detrimental mutations, lead to rapid loss of translocation-bearing strains. Implementation of control using translocations thus awaits further experimentation with agents that will induce translocations without causing other reproductive problems.

CYTOPLASMIC INCOMPATIBILITY

Pink Bollworm—No information is available nor have any experiments been attempted to isolate cytoplasmic incompatibilities in the pink bollworm, or cases of meiotic drive. Part of the reason for this lack of information is the fact that only nine simply inherited visible mutations are presently available as chromosome markers. None of these markers are linked, so only 9 of 30 chromosomes are marked.

FUTURE POSSIBILITIES

BOLLWORM AND TOBACCO BUDWORM

Although backcross sterility for the bollworm has not been discovered, there remains a number of *Helicoverpa* species in various geographical locations (Hardwick, 1965) that have not been evaluated in crossing trials with the bollworm. Each of these species is a possible candidate for producing hybrid sterility when crossed with the bollworm. Efforts to obtain and evaluate these species should be continued. Even if backcross sterility is not developed for the bollworm, the potential for controlling this species with inherited sterility is very encouraging. This technology should be refined and thoroughly tested for practical application.

Much of the backcross sterility technology for the tobacco budworm has been developed and evaluated to a limited extent. This technology needs to be evaluated in an areawide program in a typical agricultural production area. Techniques for using this technology for areawide tobacco budworm suppression need to be refined for practical application.

Genetic control methods offer considerable promise for suppressing both bollworm and tobacco budworm populations. Total sterility and inherited sterility are effective for both species whereas backcross sterility is only available for the tobacco budworm. Problems associated with insecticide resistance in these species and their destruction of food and fiber crops dictate the need for alternate control methods. The potential benefits in controlling these species by genetic means make continued development of these programs worthwhile.

PINK BOLLWORM

Some of the technical limitations of genetic control procedures for the pink bollworm have already been overcome. Rearing techniques are well-developed and in place. Insects produced by these techniques are vigorous and competitive. The tools for accurate assessment of field populations and the evaluation of the effects of the procedures have been used and improved on in actual field trials. In fact, recent control programs have been successful using the sterile insect release method and pheromone disruption. These techniques can be integrated easily with other existing technologies to further ensure success. However, in case certain populations of the pink bollworm are reluctant to succumb to the encroaching of man into their territory, new methodologies are beginning to be developed. At present, the methods of molecular biology are being employed to refine early genetic techniques. For example, yolk protein genes have been cloned in three insect species. The expression of these genes is stage-, sex- and tissue-specific. Sufficient information is available on the effects of hormonal regulation of protein production of yolk protein genes to indicate that these genes could be used to produce single sexed progeny in genetically engineered strains. The practical use of this information awaits the development of germline transformation vectors for insect pest species.

The identification and testing of candidate genes to introduce into the genome of the pink bollworm will be an expensive and long-term proposition since so little has presently been accomplished in this species or in Lepidoptera in general. However, once such candidates are identified and transformation vectors isolated, specific phenotypes can be altered rapidly and placed into service utilizing the considerable rearing and control expertise presently available for this important pest of cotton.

BOLL WEEVIL

Though no definitive work has been done, one might reasonably assume that the effectiveness of sterile weevils would increase as postirradiation survival time and mating capability increased. Thus, experiments to improve the effectiveness of sterile boll weevils have focused on these two traits. A strain of boll weevil was genetically selected with postirradiation survival in the laboratory 1.65 times that of the control and with significantly increased mating capability (Enfield *et al*., 1981). Differences in postirradiation survival reached a plateau at about the 12th generation, and relaxing selection pressure for five generations did not result in a decline of longevity (Enfield *et al*., 1983). In greenhouse and field tests, males of the selected strain lived 1.25 times longer than those of the strain currently in mass production (19.5 vs 15.2 days). Attractiveness and mating propensity during the second week after irradiation was somewhat greater than that of the mass reared strain. These differences did not result in increased competitiveness in the field, apparently because the mass-reared strain lived much longer than had been previously observed (Villavaso *et al*., in press). Preliminary experiments that minimized cross-contamination, crowding, and handling produced a much longer lived mass-reared sterile weevil. (J. L. Roberson and E. J. Villavaso, unpublished). Research is underway to develop, on the scale that would be required for areawide programs, a workable system for minimizing crowding and handling while maintaining sterility.

SUMMARY

For genetic control of an insect population to be successful, detrimental traits must be introduced into that population from a released carrier population. Most methods of genetic control use prevention of egg hatch in the target population as the final mode of action, e.g., sterile insect method, inherited sterility, and backcross sterility. Other methods include the use of chromosomal translocations, conditional lethals, and cytoplasmic incompatibility. With the exception of irradiated pink bollworm moths in the San Joaquin Valley of California, no method of genetic control has been used on any cotton insect for other than research or demonstration purposes. because genetic control is species-specific and environmentally benign, research to perfect commercially usable technology will probably be supported for the foreseeable future.

Chapter 17

HOST PLANT RESISTANCE

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INTRODUCTION

Germplasm resources available to researchers include wild species of *Gossypium*, obsolete cultivars (varieties), current cultivars, germplasm released by public research scientists and the wild or feral extra long staple cotton *Gossypium barbadense* L. and upland cotton, *Gossypium hirsutum* L., collections.

Resistance of cotton to insects, diseases and nematodes is relative, i.e., variation in response is evident among almost any diverse group of germplasm one chooses to investigate. Most researchers use some type of accepted cultivar as a control in their experiments and only report a strain as being resistant when it receives significantly less damage than the control cultivar. Host plant resistance is one component of the production system for cotton. The cultivar becomes the foundation upon which all other components of the crops production and pest control systems operate. Thus, relatively small differences in genetic potential between cultivars can become important.

Early research in Africa led to the development of hirsute (hairy) cultivars of cotton to resist jassids (leafhoppers, *Empoasca* spp.). Painter (1951) provides an excellent discussion of early development of leafhopper resistance. The development of leafhopper resistant cultivars of cotton in South Africa and later in India offer the first instance of using resistant cultivars of cotton to control a major pest (Parnell, 1925; Hutchinson, 1962). The growing of very hairy cottons essentially eliminated leafhopper as major pests of cotton in tropical Africa.

The boll weevil, *Anthonomus grandis grandis* Boheman, moved into the United States Cotton Belt in 1892. Early cotton breeders responded by developing earlier maturing cotton cultivars which evaded some damage from boll weevil, yet still allowed a crop to be produced, albeit less profitable. Following World War II, organic insecticides were developed which were very effective in controlling cotton pests, especially the boll weevil. Consequently, breeders began to develop cotton cultivars which again used a longer part of the potential growing season. These longer-season cotton cultivars produced more lint and were more profitable than the short-season cultivars. Reviews of the progress and problems associated with boll weevil control have been presented by Adkisson *et al.* (1982), Frisbie and Walker (1981), Parker *et al.* (1980), Walker (1980a,b), Walker (1984), Walker *et al.* (1978) and Walker *et al.* (1984).

Beginning about 1960 several states and the United States Department of Agriculture, Agricultural Research Service began extensive research programs aimed at identifying characteristics in cotton which were useful in the development of cultivars with increased levels of resistance to several insect pests. Reviews have been written by Jenkins (1982a,b), Maxwell *et al.* (1972), Niles (1980) and Wilson (1982).

This chapter will not attempt to exhaustively survey and report the literature on host plant resistance in cotton, but will attempt to document the present state of the art in this area of science.

GERMPLASM SOURCES OF PEST RESISTANCE

CULTIVATED COTTONS

Earliness — In the Mid-South, a cotton plant initiates about 60 flower buds (squares) over a 12-week period and eventually matures 10-15 bolls per plant. An average stand of 30,000 plants per acre equates to 1.8 million squares and 290,000 to 445,000 [=10-15 bolls/plant] mature bolls. This number of bolls would represent an estimated lint yield of 2.4 to 3.6 bales per acre. This estimate represents an effective fruit set and harvest, yet it is only 15-25 percent of the squares initiated by the plant. The number of fruit initiated, and the time and rate of their initiation and maturation have direct relationships to insect pests and the damage that they cause.

When plants harbor lower pest populations because they are early maturing this is considered host evasion rather than true resistance (Painter, 1951). Nevertheless, earliness is a very important component in insect control, as already stated in the case of the boll weevil. Because of the nature of the fruiting cycle in cotton, breeders can exert a great amount of control over the plant. After many years of developing full-season cultivars and depending heavily upon insecticides, breeders once again are developing early-season cultivars and growers are using these in systems to produce cotton at a profit. Researchers and producers in Texas were among the first to utilize these systems to advantage. Theoretical and applied approaches were developed by Adkisson *et al.* (1982), El-Zik and Frisbie (1985), Frisbie (1981), Namken *et al.* (1983) and Walker and Niles (1980).

Even in other areas of the United States, cotton cultivars grown in 1987 were far different from those grown in most states in 1972. In 1972, two cultivars, 'Stoneville 213' and 'Deltapine 16' accounted for 50 percent of the United States acreage; however, by 1986 it required six Stoneville and 13 Deltapine cultivars to account for 43 percent of the United States acreage (Bridge and McDonald, 1987). In 1986 the five most popular cultivars accounted for only 37 percent of the United States acreage. Thus, the cultivars being grown by United States growers are changing rapidly (Bridge and McDonald, 1987). These changes are in the direction of earlier maturing cultivars which bear directly on the pest problems in the crop. Earlier maturing cultivars are in many instances more resistant to pests. This resistance involves escape or pest evasion as well as direct forms of resistance. Early cultivars thus produce a crop which receives less damage from insect pests than those grown in prior years. This is effective host plant resistance in practice.

Bridge and McDonald (1987) present data which show a decrease in number of days from planting to harvest of 32 days (last 28 years) at Stoneville, Mississippi; 45 days (last 20 years) at Sumner, Mississippi; 28 days (last 21 years) at College Station, Texas; and 33 days (last 19 years) at Florence, South Carolina. These are dramatic increases in earliness. Yields have also increased during this time.

The major shifts in cultivars began in Texas in the early 1970s and in the late 1970s in the Mid-South. These shifts were associated with the release of the Tamcot (Bird, 1976; Bird *et al.*, 1986) cultivars in Texas and the release of 'Stoneville 825' in 1978 followed by 'DES 56', 'DES 422', 'DES 119', 'Stoneville 603', 'Deltapine 41', 'Deltapine 50' and 'Deltapine 20' in Mississippi. In 1978, the Rio Grande Valley area of Texas was growing 25 percent early-maturing cultivars whereas the Corpus Christi area was growing 82 percent early-maturing cultivars. By 1986 these figures were 98 and 100 percent. The Mid-South area had 8-25 percent in early maturing cultivars in 1976 and 78-99 percent (depending upon the state) in 1986. The shift to earlier maturing cultivars is just beginning in the irrigated desert areas of southern California (Kerby *et al.*, 1988, 1990). Also, a shift could occur in the San Joaquin Valley of California, where considerable research has been done on short-season strains (Burch, 1988).

Morphological Traits — There are a number of plant traits which affect insect pests of cotton (Table 1). With many there are trade offs, as they confer resistance to one insect while increasing susceptibility to one or more others.

The Stoneville 825 cultivar is nectariless (i.e., lacks extrafloral nectaries, but has floral nectaries). It has been grown on large acreage. Nectariless improves resistance to the bollworm, *Helicoverpa zea* (Boddie), and tobacco budworm, *Heliothis virescens* (F.); less eggs are deposited on nectariless cotton (Meredith, 1990). It also confers resistance to plant bugs by causing reduced oviposition and the nectar food source for nymphs (Schuster *et al.*, 1976; Parrott *et al.*, 1982). It confers resistance to pink bollworm, *Pectinophora gossypiella* (Saunders), particularly in conjunction with the okra leaf trait (Wilson, 1987). Nectariless also confers resistance to the cotton leafperforator, *Bucculatrix thurberiella* Busck., (Henneberry *et al.*, 1977). Nectariless also affects the food source for predators that feed on nectar and, thus their numbers are decreased. No major adverse agronomic or fiber properties have been found to be associated with nectariless (McCarty *et al.*, 1983; Meredith and Bridge, 1977).

Pilose plants are densely pubescent (hairy). This pubescence increases resistance to plant bugs and boll weevil, but oviposition (laying of eggs) by bollworm/tobacco budworm moths and whiteflies increases. Pubescence is associated with resistance to thrips in the seedling stage.

Pilose is a gene with detrimental effects on agronomic properties and yield. However, there are other pubescence genes that do not have this effect. Pilose and the other pubes-

Table 1. Morphological traits of cotton and their effects on pest resistance and agronomic traits.

	Leaf-hoppers	Boll weevil	Bollworm/ Tobacco budworm	Plant bugs	Bandedwinged whitefly	Cotton leafperforator	Pink bollworm	Thrips	Agronomic traits
Glabrous	S		R	S	R	R		S	N
Pilose	R	R	S	S	S	R	R	R	D
Okra-leaf		R		S	R		R		N
Frego		R	R	S					N
Red plant		R				S	S		D
Yellow pollen			R						N
Orange pollen			R						N
Nectariless			R	R		R	R		N
High gossypol			R	R			R		N
Male sterile			R						
Cytoplasms									
barbadense			R						N
tomentosum			R						N
arboreum		R							D
herbaceum		R							D
anomaleum		R							D
harknesii		R							D

R indicates the trait increases resistance to this pest.

S indicates the trait increases susceptibility to this pest.

N indicates the trait has a neutral effect on yield and agronomics.

D indicates the trait has a decreasing effect on yield and agronomics

cent traits increase the trash content of mechanically harvested cotton; thus, it is not likely to be used in the United States.

As stated earlier, pubescent cottons were the first trait used in Africa for leafhopper control and were very effective for that purpose. Lack of plant pubescence (glabrousness or smoothleaf) reduces bollworm/tobacco budworm oviposition and numbers of whiteflies and cotton leafperforator. On the other hand, glabrous cottons are susceptible to plant bugs, thrips and *Empoasca* spp., jassids (leafhoppers).

The okra-leaf trait increases the earliness of cotton strains and is thus useful in boll weevil control. It also changes the microclimate and allows more desiccation by high temperatures to squares with immature boll weevil larvae. It has also shown resistance to bandedwinged whitefly, *Trialeurodes abutilonea* (Haldeman) (Jones *et al.*, 1975). It is useful for pink bollworm control.

Three strains which possess both the nectariless and okra-leaf traits have been released. They are more resistant to pink bollworm than currently grown commercial cultivars (Wilson, 1987).

High yielding cultivars with the okra-leaf trait have been developed for use in Louisiana (Burris *et al.*, 1981). The okra-leaf trait also reduces boll rot due to the more open canopy (Andries *et al.*, 1970). A cultivar of okra-leaf cotton (SIOKRA) grown in Australia improved cotton pest management (Personal communication, Brian Hearne and Norm Thompson, CSIRO Division of Plant Industry, Cotton Research Unit, New South Wales Agricultural Research Station, Australia) and produced high yields (Reid *et al.*, 1989). Okra leaf increases penetration of insecticidal sprays into the plant canopy. It seems to be more sensitive to environmental stress than normal-leaf cultivars and will suffer yield reductions under adverse growing conditions (Landivar *et al.*, 1983a,b; Meredith and Wells, 1987).

Frego bract increases resistance to boll weevil, and in some breeding lines, to bollworm/tobacco budworm while increasing susceptibility to plant bugs. Frego bract allows better penetration of insecticide and decreases boll rot because the bracts do not enclose the boll. High yielding lines have been developed that combine frego bract with the nectariless and rapid fruiting traits. These lines are competitive in yield with normal bract cultivars. Their usefulness in boll weevil control is discussed under the section on boll weevil in this chapter.

Red-pigmented plants are apparently more difficult for the boll weevil to locate. Once weevils are on red cotton, however, it is as susceptible as green cotton (Hunter *et al.*, 1965; Isley, 1928). Red plants are more susceptible than green plants to pink bollworm and to cotton leafperforator. Red has a slightly negative effect on yield of cotton (Jones and Brand, 1981). It has been used successfully in trap crop situations in Louisiana and in Georgia for boll weevil control where the major part of the field is planted in red cotton and the trap rows in green (Weaver and Reddy, 1977). It is not as useful for this purpose as is frego bract, nor is it as effective as using adapted cultivars for the major part of the field and using early, highly susceptible, strains for the trap rows (Jones *et al.*, 1987a).

Yellow or orange pollen mutants show antibiosis to tobacco budworm when compared with the predominant cream pollen cultivars. No serious effort to use these in the development of cultivars has been reported. However, since most upland cultivars have cream pollen, this result may indicate that other pollen colors have a detrimental effect on yield.

Biochemical Mutants — High levels of gossypol and other allelochemicals have been shown to be antibiotic to bollworm/tobacco budworm larvae. Much research has been directed towards using high gossypol as a source of resistance to the bollworm and tobacco budworm, but this trait has shown resistance to other insects as well. In 1988, high yielding cotton germplasm with high levels of gossypol were registered with the Crop Science Society of America (Jones *et al.*, 1988b). The usefulness of this trait and some of its possible problems are discussed under the section on bollworm/tobacco budworm. At this stage of the development of resistant cultivars, it appears that high levels of gossypol can be used without a detrimental effect on agronomic properties and yield.

Exotic Cytoplasms — Cytoplasms from two tetraploid and four diploid cottons have been evaluated for resistance to pests (Table 1). The diploid cytoplasms result in less oviposition by the boll weevil (McCarty, 1974; McCarty *et al.*, 1977). These diploid cytoplasms however, generally have a detrimental effect on yield (Meredith *et al.*, 1979b). *Gossypium tomentosum* (Nuttall) cytoplasm is antibiotic to bollworm/tobacco budworm larvae and results in about a 15 percent reduction in larval size (Jenkins *et al.*, 1986; Meredith *et al.*, 1979b).

Germplasm releases — Several *Gossypium hirsutum* germplasms with single or combinations of resistance traits (glabrous, nectariless, frego bract, okra leaf, high gossypol) have been developed and registered (Table 2). Three of these are useful for control of pink bollworm (Wilson, 1987). These germplasms are in several cultivar backgrounds and generally have yields similar to the recurrent cultivar parent (Lee, 1977; Meredith and Bridge, 1977; Shepherd, 1982 a,b,c,d; Shepherd and Kappelman, 1982a; Shepherd *et al.*, 1986a,b; and Wilson, 1987). The nectariless and okra-leaf traits are also being transferred into Pima (*Gossypium barbadense*) background (Personal communication, R. Percy, Western Cotton Research Laboratory, United States Department of Agriculture, Agricultural Research Service, Phoenix, Arizona).

PRIMITIVE RACE COLLECTION

Breeding for resistance to pests requires a reservoir of genes for resistance. A good source of genes is the collection of primitive cottons. A number of these have been evaluated for pest resistance (Table 3). Most reports of evaluations do not include breeding lines which are not resistant. Thus, the data reported in Table 3 show resistance for each pest where it has been reported. However, the lack of a resistance indication does not mean that the line is susceptible; it may not have been evaluated for the particular pest.

Multiple pest resistance is common in the race collection. There are 228 lines resistant to one or more pests. There are 33 lines high in gossypol which should confer resistance to the bollworm/tobacco budworm complex. There are 56 lines which have been identified as resistant to bollworm/tobacco budworm. There are 59 lines resistant to boll weevil, 99 resistant to pink bollworm, six resistant to mites, and 11 resistant to plant bugs. These lines and this collection are valuable resources for future work on resistance to pests of cotton. The evaluations which provided data for these counts or resistant lines show that much useful variability is available in this collection. Its use will require long-term breeding goals since much of the collection is photoperiodic and will not flower in the long days of the United States Cotton Belt in the summer. Conversion programs are underway in the authors' USDA, ARS laboratories in Mississippi and Arizona to breed day-neutral genes into the *Gossypium hirsutum* and *Gossypium barbadense* lines, respectively, in this collection. This is also a long-term program; however, each year a group of lines is released to the public from this research program (McCarty *et al.*, 1979).

Table 2. Registered germplasm of cotton with morphological or biochemical mutants conferring resistance to one or more pests[1].

Registration No.	Strain	Originator	Year Registered
36-37	2 smoothleaf strains	Lee	1977
27-35	9 nectariless (NE) strains	Meredith & Bridge	1977
167-174	8 frego strains	Shepherd	1982
175-182	8 nectariless strains	Shepherd	1982
183-185	3 okra-leaf, frego bract strains	Kappelman	1982
186-193	8 okra-leaf strains	Shepherd	1982
194-201	8 smoothleaf strains	Shepherd	1982
270-277	8 okra-leaf, frego bract strains	Shepherd *et al.*	1986a
278-285	8 nectariless, frego bract strains	Shepherd *et al.*	1986b
260,263, 264,266	4 nectariless, okra-leaf strains	Wilson	1986
305,307	2 nectariless, okra-leaf strains	Wilson	1987
306	1 nectariless, okra-leaf, smooth strain	Wilson	1987
313-315	3 high gossypol strains	Jones *et al.*	1988b

[1]Registered with the Crop Science Society of America, 677 South Segoe Rd., Madison, Wisconsin 53711.

Table 3. Accessions in upland cotton, *Gossypium hirsutum* race collection with pest resistance.

Accessions with high gossypol: 102, 114, 115, 144, 152, 165, 187, 197, 216, 231, 258, 277, 297, 306, 345, 487, 490, 495, 497, 499, 606, 642, 663, 664, 665, 674, 707, 766, 805, 934, 952, 1036, 1150

Boll weevil resistant race accessions: 11, 18, 26, 78, 80, 94, 109, 118, 128, 140, 147, 185, 192, 196, 209, 260, 265, 267, 292, 293, 294, 295, 297, 304, 323, 326, 330, 333, 336, 339, 340, 347, 461, 600, 625, 679, 681, 720, 725, 730, 732, 756, 759, 760, 763, 764, 771, 786, 790, 805, 938, 952, 955, 1067, 1105, 1119, 1134, 1149, 1150

Bollworm/tobacco budworm resistant race accessions: 16, 72, 91, 100, 102, 104, 110, 113, 119, 130, 163, 164, 165, 167, 171, 187, 195, 201, 206, 219, 228, 247, 254, 295, 490, 600, 620, 670, 675, 681, 682, 687, 693, 697, 707, 709, 766, 776, 802, 805, 953, 999, 1001, 1006, 1015, 1036, 1040, 1041, 1066, 1067, 1102, 1106, 1108, 1121, 1132, 1150

Pink bollworm resistant race accessions: 7, 17, 20, 21, 25, 31, 39, 40, 41, 53, 55, 58, 62, 65, 72, 78, 93, 99, 101, 102, 103, 127, 142, 158, 160, 164, 167, 168, 169, 170, 175, 176, 180, 181, 185, 202, 203, 207, 216, 218, 220, 226, 228, 232, 245, 247, 254, 257, 265, 273, 293, 302, 303, 306, 316, 330, 331, 333, 335, 336, 339, 342, 377, 389, 469, 489, 497, 503, 570, 596, 610, 616, 620, 635, 636, 639, 646, 657, 658, 668, 679, 682, 703, 705, 711, 712, 763, 764, 775, 937, 955, 960, 1048, 1053, 1125, 1158, 1177, 1180, 1182

Spider mite resistant race accessions: 1, 5, 110, 118, 144, 165

Plant bug resistant race accessions: 78, 113, 158, 195, 247, 254, 481, 655, 658, 682, 701

RESISTANCE TO INSECTS AND MITES

BOLL WEEVIL

The boll weevil is a major pest in much of the Cotton Belt. It has been eradicated in North Carolina and South Carolina; eradication projects are proceeding in Florida, Georgia, and parts of Alabama, Arizona, and California. Planning is underway to eradicate it in other states.

The correct management of the boll weevil supports effective pest management programs for other cotton insects. The use of resistant cultivars, i.e., early season cultivars having a useful level of resistance as well as pest evasion, coupled with recommended management practices, has relegated the boll weevil to a manageable status in much of Texas (Adkisson *et al.*, 1982; El-Zik and Frisbie, 1985; Frisbie, 1981; Namken *et al.*, 1983; Parker *et al.*, 1980; Walker, 1980a,b; Walker *et al.*, 1978; Walker, 1984; Walker *et al.*, 1984).

Because of these events, most seed breeding firms are not actively pursuing programs to develop cultivars with specific resistance to boll weevil, but they are developing early, short-season cultivars which aid in its management. These cottons first became available as cultivars in Texas in the mid-1970s and in the Mid-South in the early-1980s. Growers have several cultivars to choose from in each region. Table 4 lists those which have been officially registered with the Crop Science Society of America.

Many cultivars developed by private seed companies are never registered with the Crop Science Society of America (Table 5). Many germplasm resources are available to use in developing cultivars with resistance to boll weevil (Table 6). The most prevalent type of resistance is a reduction in oviposition (Buford *et al.*, 1967; Buford *et al.*, 1968; Jenkins *et al.*, 1964; Jenkins *et al.*, 1969; Jenkins *et al.*, 1978; Lambert *et al.*, 1980; McCarty and McGovern, 1987; McCarty and Jones, 1988; McCarty *et al.*, 1986b; McCarty *et al.*, 1977; McCarty *et al.*, 1982a; Weaver and Reddy, 1977). Several cases of antibiosis have also been reported (Bailey *et al.*, 1967; Black and Leigh, 1963; Hunter *et al.*, 1965; Jenkins *et al.*, 1964). The very pubescent cottons are less preferred by the boll weevil (Hunter *et al.*, 1965; Wannamaker *et al.*, 1957).

Over 60 accessions in the collection of wild races of cotton are resistant to the boll weevil. Resistance is expressed as reduced oviposition (Jenkins *et al.*, 1978). These race stocks are generally photoperiodic, but some have been developed into day-neutral lines and still retain the resistance to boll weevil (Table 5). MWR-1 and MWR-2, boll weevil resistant lines, have been released to the public and registered with the Crop Science Society of America (McCarty et al., 1986b). Day-neutral lines from *Gosspium hirsutum* race accessions 80, 759, 1149, 109, 293, 326, 330, 763 and 1180 are resistant to the boll weevil in the field (Jones *et al.*, 1987a; McCarty and Jones, 1989; McCarty *et al.*, 1982a). A listing of the race lines resistant to boll weevil and their known cross resistance to other pests are shown in Table 3.

Host plant resistance research with the boll weevil has led to the discovery of numerous substances in cotton that act as feeding deterrents, feeding stimulants, attractants or arrestants for the boll weevil (Benedict *et al.*, 1987; Hedin *et al.*, 1974; Hedin

Table 4. Registered cultivars and germplasm of cotton which are early, short season types[1].

Registration No.	Cotton line	Type	Originator	Year registered
61	Tamcot SP21	Cultivar	Bird	1976
62	Tamcot SP23	Cultivar	Bird	1976
63	Tamcot SP37	Cultivar	Bird	1976
69	DES24	Cultivar	Bridge & Chism	1978a
70	DES56	Cultivar	Bridge & Chism	1978b
74	Tamcot CAMD-E	Cultivar	Bird	1979
73	Tamcot SP21S	Cultivar	Bird	1976
75	Tamcot SP37H	Cultivar	Bird	1979
156	DES-04-6	Germplasm	Bridge	1980
157	DES-04-11	Germplasm	Bridge	1980
158	DES-04-606	Germplasm	Bridge	1980
163	HYC 76-59	Germplasm	Sappenfield	1981
225	UARK-1	Germplasm	Smith	1983
226	UARK-2	Germplasm	Smith	1983
86	PD-2	Germplasm	Culp *et al.*	1985
88	DES-119	Cultivar	Bridge	1986b
87	Tamcot CABCS	Cultivar	Bird *et al.*	1986
303	Miscot 7813	Germplasm	Bourland	1987
304	Miscot 7841	Germplasm	Bourland	1987
308	DES 237-7	Germplasm	Bridge	1987
92	Arkot 518	Cultivar	Smith	1988
94	Tamcot CD3H	Cultivar	Bird *et al.*	1988
319-332	CS-8601 to CS-8614	Germplasm	Smith & Niles	1988
316	Miscot 7913-51	Germplasm	Bourland	1988
317	Miscot 7913-83	Germplasm	Bourland	1988
318	Miscot 7913-84	Germplasm	Bourland	1988

[1]Registered with the Crop Science Society of America, 677 South Segoe Rd., Madison, Wisconsin 53711.

Table 5. Cultivars (varieties) of cotton developed by private seed companies for short-season production.

Cultivar	Developer
Stoneville 506	Stoneville Pedigreed Seed Company
Stoneville 112	Stoneville Pedigreed Seed Company
Stoneville 132	Stoneville Pedigreed Seed Company
Stoneville 453	Stoneville Pedigreed Seed Company
Stoneville 825	Stoneville Pedigreed Seed Company
Deltapine 20	Deltapine Seed Company
Deltapine 50	Deltapine Seed Company
Deltapine 41	Deltapine Seed Company
Coker 208	Coker Pedigreed Seed Company
Coker 304	Coker Pedigreed Seed Company
Coker 235	Coker Pedigreed Seed Company
Centennial	Sun Valley Seed Company
White Lightning	Seeds of Tomorrow
Short Cut	Seeds of Tomorrow

et al., 1977; Jenkins *et al.*, 1963; Keller *et al.*, 1962; Keller *et al.*, 1963; Maxwell *et al.*, 1963a, b; Maxwell *et al.*, 1965; McKibben *et al.*, 1985). Some of these have found practical use as adjuncts to baits or pheromones such as the commercial product NoMate Blockade® and the Boll Weevil Bait Stick (McKibben and Smith, 1991).

The frego bract character effectively can reduce the population of boll weevils; thus, it is an effective trait to use in developing cultivars resistant to the boll weevil (Jenkins, 1982ab; Jenkins and Parrott, 1971; Jenkins *et al.*, 1969; Jones *et al.*, 1983; McCarty *et al.*, 1983). Boll weevil oviposition (egg laying) in plots of frego-bract cotton was suppressed 66, 71, 75 and 94 percent below oviposition in non-frego cotton plots in field studies with this trait (Jenkins and Parrott, 1971). A problem with the use of frego bract is its sensitivity to plant bugs. Addition of the nectariless trait helps in this regard as does breeding frego bract into early maturing cultivars (Jones *et al.*, 1983; Milam *et al.*, 1982).

The trap crop principle using lines which vary in their preference by the boll weevil has been demonstrated in Louisiana (Burris *et al.*, 1982); Jones and Brand, 1981; and Jones *et al.*, 1987 a,b). The cottons Tamcot CAB-CS, TX CAMD 21S-7-81 and TX BLLEBOS 1-83 are more attractive to boll weevil than 'Deltapine 41'; they also fruit earlier. Therefore, they are especially useful in the trap crop system for boll weevil control (Jones *et al.*, 1987a).

Table 6. Summary of evaluations for resistance to boll weevil in cotton.

Resistant source and type	Reference
Antibiosis	
Gossypium arboreum, Gossypium davidsoni, Gossypium thurberi	Bailey *et al.*, 1967
Gossypium thurberi, Pima S-1	Jenkins *et al.*, 1964
Gossypium barbadense	Black & Leigh 1963
Hopi Russian 5A, CB2545	Hunter *et al.*, 1965
Reduced oviposition	
Triple Hallmark SI, Seaberry SI, Russian SI, Brown Egyptian	Buford *et al.*, 1967, 1968
5 frego, 4 red, SI Seaberry	Jenkins *et al.*, 1969
MWR-1, MWR-2	McCarty *et al.*, 1986b
Male sterility	Weaver *et al.*, 1977
Lansii 11, AC134, Albar 627, G077-2, BPA52/NC63, Tx-Ly-18-72 gl, DES-HERB-16, DES-ARB-16	Lambert *et al.*, 1980
75 *Gossypium hirsutum* race lines	McCarty *et al.*, 1977, 1982a
	McCarty, 1987
	Jenkins *et al.*, 1978
Nonpreference	
Hairy plants	Hunter *et al.*, 1965
MU-9, Pilose, R1	Wannamaker, 1957

BOLLWORM/TOBACCO BUDWORM COMPLEX

Much effort is directed towards control of these two species of cotton. Many of the presently recommended control practices depend upon using early, short-season cultivars as a foundation for pest management. This approach is used very effectively in Texas (Adkisson *et al.*, 1982; El-Zik and Frisbie, 1985; Frisbie and Walker, 1981; and Walker *et al.*, 1978).

Considerable effort has been directed toward understanding the relationship between cotton and the bollworm/tobacco budworm complex. These pests feed on several host plant species and usually feed on a succession of hosts during the year. Control of bollworm/tobacco budworm on host plants other than cotton has the potential to solve their pest status on cotton. In the Mid-South, tobacco budworms oviposit most of their eggs in the upper one-third of the plant, usually near the terminal, except during the late part of the season (Ramalho *et al.*, 1984). First and second instar tobacco budworm larvae are generally found in the upper one-third of the plant canopy except late in the season. Instars three through six are found moving throughout the plant canopy. All larval instars are found primarily on structures that arise from the first position on a branch (Ramalho *et al.*, 1984). In field studies on the bollworm, site of oviposition had little effect on the level of establishment; however, in laboratory studies larval development was affected by feeding site with larvae on flowers and bolls developing faster and growing larger than those on squares, leaves and terminals (Farrar *et al.*, 1985). First instar larvae of tobacco budworm avoid feeding on gossypol glands (Parrott *et al.*, 1983).

Cotton contains many chemicals which retard the growth of bollworm/tobacco budworm larvae. Numerous laboratory studies have shown that these are effective (Bell and Stipanovic, 1977; Bell *et al.*, 1974; Chan and Waiss, 1981; Chan *et al.*, 1978a,b,c; Elliger *et al.*, 1978; Jenkins *et al.*, 1983; Lukefahr and Martin, 1966; Lukefahr and Houghtaling, 1969; Waiss *et al.*, 1981). Numerous cotton lines have been developed or evaluated with various levels of one or more of these chemicals which reduce the growth of larvae (Table 7). Yellow or orange pollen reduces the growth of larvae (Bailey, 1981; Hanney *et al.*, 1979). Nectariless strains of cotton reduce oviposition of moths as do glabrous leaves (Lukefahr *et al.*, 1971; Lukefahr *et al.*, 1975).

In the collection of wild cottons, over 60 lines show antibiosis toward larvae of tobacco budworm or bollworm (Parrott *et al.*, 1978; Personal communication, J. E. Jones, Louisiana State University, Baton Rouge, Louisiana) (Tables 3 & 7). Additionally, 32 lines from the collection are high in gospol (Dilday and Shaver, 1976a,b; Dilday and Shaver, 1980) (Table 7). Nine of the high gosspol accessions show antibiosis (antagonistic association) against bollworm/tobacco budworm. The remaining high gossypol lines also should be resistant.

A diverse group of cottons were grown in Mississippi and tobacco budworm larvae were grown from emergence to five days of age on the different cotton lines. Concurrently, the lines were sampled and analyzed for certain classes of chemicals alleged to be antibiotic to the larvae. Tannin level was not related to larval growth. Negative relationships were shown between level of gossypol and larval growth, and level of a mixture of flavonoids and anthocyanin and growth (Jenkins 1982b; Jenkins *et al.*, 1983; White, 1981; White *et al.*, 1982a,b).

Many cotton constituents are antiobic to tobacco budworm larvae when added to diets. The amount of chemical necessary to reduce growth 50 percent varies from 0.03 to 0.46 percent of the diet (Bell and Stipanovic, 1977; Bell *et al.*, 1974; Chan and Waiss, 1981; Chan *et al.*, 1978a,b; Jenkins *et al.*, 1983; Waiss *et al.*, 1981) (Table 8).

Larvae grow much faster on artificial diet than on cotton plants, presumably because of the number and amount of allelochemicals[1] in the plant and the better nutrition available in the artificial diet. At the end of day one, larvae on diet are two times larger than those on cotton. At the end of five days those on cotton weigh 2.5 milligrams, whereas, those on diet weigh 20 milligrams. At day 9, those on cotton weigh 60 milligrams and those on diet weigh 300 milligrams (Jenkins, unpublished data). The small larvae, however, are quite capable of damaging cotton.

[1]Allelochemicals are naturally occurring behavior-modifying chemicals that mediate interspecific interactions. See Chapter 11 for more information on such chemicals.

Table 7. Summary of evaluations for resistance to bollworm/tobacco budworm in cotton.

Resistant source	Reference
Antibiosis	
High gossypol	Lukefahr & Houghtaling, 1969
	Lukefahr *et al.*, 1975
Gossypium tomentosum cytoplasm	Meredith *et al.*, 1979b
Yellow pollen	Hanney *et al.*, 1979
Orange pollen	Bailey *et al.*, 1984
BJA592, Laxmi, Satu-65, MOHG, HGBR-8N	Lambert *et al.*, 1982a
Gossypol, quercetin, rutin	Lukefahr & Martin, 1966
BW76-31	Stokes & Sappenfield, 1981
Heliocides H1 & H2, Hemigossypolone	Elliger *et al.*, 1978
Catechin, chrysanthemin, isoquercetrin, delphinidin, quercetin, condensed tannins, cyanidin gossypol	Jenkins *et al.*, 1983
T-934 Socorro Island Wild	Dilday & Shaver, 1980
Race accessions 91, 122, 113, 100, 104, 195, 228, 201, 102, 110, 171, 119	Parrott et al., 1978
48 *Gossypium hirsutum* race accessions	Jones, Personal Communication[1]
Red plant color	Bhardwaj & Weaver, 1983
Gossypium arboreum, Gossypium bickii, Gossypium herbaceum, Gossypium somalense	Benedict *et al.*, 1987
Reduced Oviposition	
Smoothleaf	Lukefahr *et al.*, 1971
Nectariless	Lukefahr *et al.*, 1975
NC-1, NC-2	Lee, 1977
Ability to yield under infestation	
CAMD-E, PD 875, PD 8619, ST-506	Jenkins *et al.*, 1986
High gossypol	
33 *Gossypium hirsutum* race accessions	Dilday & Shaver, 1976a,b
	Dilday & Shaver, 1980

[1]J. E. Jones, Professor of Agronomy, Louisiana State University, Baton Rouge, Louisiana 70893.

Table 8. Percent allelochemical required in laboratory diet to reduce bollworm/ tobacco budworm larval growth 50 percent.

Allelochemical	Evaluated by: Chan	Stipanovic	Missississippi State University
Gossypol	0.12	0.05	0.12
Hemigossypolone	0.03	0.29	—
H1	0.12	0.10	—
H2	0.13	0.46	—
Catechin	0.13	—	0.05
Epicatechin	—	—	0.11
Quercetin	0.05		0.05
Condensed tannin	0.15		0.05
Methyl sterculate	0.41		—
Cyanidin	—		0.15
Delphinidin	—		0.13
Flavonoids & anthocyanin mixture (F7)	—		0.07

Table 9. Regression equation for allelochemical effects on first instar tobacco budworm larvae grown on diet for 5 days.

Allelochemical	Regression form	a	b	Coefficient of determination r^2	Significance of Regression	r
Catechin	$Y=aX^b$[1]	7.06	-0.562	0.90	**	**
Chrysanthemin	$Y=aX^b$	7.911	-0.707	0.81	**	**
Isoquercitrin	$Y=aX^b$	4.49	-0.888	0.85	**	**
Quercetin	$Y=aX^b$	3.29	-0.705	0.90	**	**
Condensed tannin	$Y=aX^b$	2.07	-0.880	0.90	**	**
Cyanidin	$Y=a+bX$	105.10	-332.9	0.71	**	**
Delphinidin	$Y=a+bX$	124.40	-540.4	0.89	**	**
Gossypol	$Y=a+bX$	101.61	-390.3	0.56	**	**

**Significant at 0.01 level.

[1]$Y = aX^b$ is same as $\log Y = \log a + b \log X$.

From: Jenkins *et al.*, 1983.

Regression equations for larval growth as a function of level of allelochemical in artificial diet indicated a linear relationship for the chemicals cyanidin, delphinidin and gossypol. Curvilinear relationships were found for catechin, chrysanthemin, isoquercitrin, quercetin and condensed tannin (Table 9) (Jenkins *et al.*, 1983). Using these relationships to calculate the level of allelochemicals necessary to reduce growth of larvae 90 and 95 percent, 0.235 and 0.248 percent gossypol are required, respectively. For isoquercitrin, a curvilinear relationship exists and 0.538 and 1.848 percent are required for a 90 and 95 percent reduction in growth (Table 10) (Jenkins *et al.*, 1983). These levels are within the limits of those found naturally in cotton plants.

Increasing the natural level of allelochemicals in cotton has been the goal of several research programs. In this context, the interaction of cotton genotype and environment and the type of gene action involved in allelo-chemical production are both important. Fortunately, these are within ranges which allow their use by cotton breeders.

Six types of chemical analyses were performed on a group of cotton lines (strains) from which samples were collected weekly. Data for selected weeks are shown in Table 11 (White *et al.*, 1982b). Each of the chemicals varied over the season whether considered from individual strains (lines) or as means over all strains. Components of variance analyses for the chemicals showed that weeks (i.e., stage of growth) was a much larger component than strains; however, significant variability was evident among the strains and there was not a large strains by week interaction. This indicates that in each cotton strain the level of the allelochemical varied across weeks, but it varied in a similar manner in each of the cotton strains in the experiment. Broadsense heritability estimates were 93 to 99 percent (Table 12) (White *et al.*, 1982a).

Genetic studies on three cotton crosses produced estimates of the various types of gene action. For each chemical, except aniline reacting terpenes, additive effects were the largest component. Dominance effects were important for phenolics as well as aniline reacting terpines (Table 13) (White, 1981; White *et al.*, 1982b). Thus, breeders can select for higher levels of these chemicals and expect to be successful. Samples for comparison purposes should be collected at the same time because of the week-to-week variation; however, genetic effects should not be confounded by a major genotype by environment interaction (Dilday and Shaver, 1980; White *et al.*, 1982b).

Plant breeders have actively cooperated with entomologists for several years to identify strains of cotton with antibiosis against the bollworm/tobacco budworm. Numerous obsolete cultivars, wild race accessions and special genetic stocks have been identified (Table 7). Techniques are now available which allow the breeder to select resistant plants from segregating progeny or progeny rows following crosses between resistant and susceptible lines. Most of the resistant lines were found originally in nonadapted cottons. Techniques have been developed for infesting plots with eggs; however, these were not considered to be as useful as those using first instar larvae. The technique of choice distributes first instar larvae mixed with corncob grits onto terminal leaves (Hall *et al.*, 1980; Jenkins *et al.*, 1982). Larval rearing and field distribution procedures have been developed for achieving uniform infestations (Jenkins *et al.*, 1982; Parrott *et al.*, 1986). These techniques are useful in their present

Table 10. Predicted amounts of allelochemicals necessary in diet to achieve desired level of growth reduction in tobacco budworm, based upon regression equations. (From Jenkins *et al.*, 1983.)

	Desired percent of weight on control diet								
Allelochemical	100	75	50	25	10	5	2	1	0
	% allelochemical								
Catechin	0.009	0.015	0.131	0.105	0.538	1.848	9.430	32.360	—
Chrysanthemin	0.028	0.042	0.074	0.196	0.727	1.913	6.988	18.620	—
Isoquercitrin	0.030	0.042	0.066	0.145	0.406	0.886	2.485	5.425	—
Quercetin	0.008	0.012	0.021	0.056	0.207	0.552	2.025	5.412	—
Condensed tannin	0.012	0.017	0.027	0.059	0.167	0.367	1.041	2.285	—
Cyanidin	0.015	0.090	0.166	0.241	0.286	0.301	0.310	0.313	0.316
Dephinidin	0.045	0.091	0.138	0.184	0.212	0.221	0.227	0.228	0.230
Gossypol	0.004	0.068	0.132	0.196	0.235	0.248	0.255	0.258	0.260

Table 11. Allelochemical concentration in cotton terminal leaves over time. Mean of 20 strains. (From White *et al.*, 1982b.)

Compound	Sampling dates (week postemergence) 5	7	9	11	13	Season mean
	Percent dry weight basis					
Tannin	5.8	13.0	18.1	17.5	21.3	16.1
E1, 1	5.9	10.2	13.8	13.9	16.2	12.6
Catechin	6.7	11.9	14.5	12.4	13.9	12.6
Phenolics	4.7	5.5	7.6	11.6	19.7	10.2
Gossypol	0.28	0.38	0.28	0.24	0.20	0.27
Flavonoids & anthocyanin	0.38	0.63	0.48	0.45	0.36	0.45

Table 12. Estimates of components of variance for cotton allelochemicals from a group of 20 cotton strains sampled for 10 weeks. (From White *et al.*, 1982a.)

Compound	Mean squares[1] Strains	Week	SxW	Broad sense heritability
Tannin	930**	3004**	171**	97.7
E1, 1	4**	10**	1**	97.5
Catechin	222**	834**	25**	98.3
Phenolics	18	3029**	0	93.2
Gossypol	1.5**	0.3**	0	99.2
Flavonoids & anthocyanin	8**	1**	1**	98.9

[1] ** significant F value at 0.01 level.

Table 13. Mean squares from Generation Mean Analysis from three sets of crosses illustrating genetic effects involved in allelochemicals in cotton. (From White *et al.*, 1982a.)

	Genetic effects for crosses								
	Set 1			Set 2			Set 3		
Allelochemical	A	D	RE	A	D	RE	A	D	RE
	milligram/gram dry weight								
E1,1 tannin	.0046*			.0032*					
Catechin				18739*					
Total phenolics							210.0*	93.0*	
Aniline reacting terpines		27.7*	9.0*		29.9*	17.7*			
Gossypol	10.0*						4.2*		1.8*
Flavonoid/ anthocyanidin	10.1*			6.5*					

A = Additive effects.
D = Dominance effects.
RE = Residual epistatic effects.
* = Significant effect at 0.05 level of significance.

form to commercial plant breeding firms. One company is presently using these techniques in its breeding program to develop cultivars (varieties) resistant to tobacco budworm.

The cultivar 'DES 119' is presently being grown on a large acreage in the Mid-South. Using the larval infestation technique, we evaluated DES 119, during its various stages of development, and reported its resistance levels. When the cultivar was released by the breeder, it was described as being tolerant to tobacco budworm (Bridge, 1986b).

Rapid progress towards developing cultivars highly tolerant to tobacco budworm without any loss in yield or agronomic and fiber properties now should be possible. Public research scientists in USDA's Agricultural Research Service, and in the state agricultural experiment stations have developed the techniques and germplasm necessary for this progress. Germplasms with the desired combinations of resistance, yield, agronomic and fiber properties have been released; they have been registered by the Crop Science Society of America since 1981, with most of it in 1984 and 1988. Many of the cotton lines listed in Table 14 carry these combinations (Bourland, 1987, 1988; Bridge, 1986a,b; Jenkins *et al.*, 1984; Jenkins *et al.*, 1988a,b,c; Jones *et al.*, 1988b; Mahill *et al.*, 1984; Stokes and Sappenfield, 1981; Stringer *et al.*, 1983; Stringer *et al.*, 1987).

There is no reason why high yielding cultivars with high levels of tolerance to tobacco budworm cannot be developed (Hsieh *et al.*, 1987; Jenkins *et al.*, 1987; Jones *et al.*, 1987; Stringer *et al.*, 1987). The DES 119 cultivar is a start in this direction. It is up to the commercial cotton breeders to take advantage of this available germplasm in developing other suitable cultivars (varieties).

In addition to these programs, a number of genetic engineering firms are inserting several constructs of the δ-endotoxin gene from *Bacillus thuringiensis* Kurstaki into advanced strains of cotton. In 1990 public research scientists in cooperation with Monsanto Agricultural Company evaluated five cotton strains into which the *B.t.* gene had been genetically engineered. When all pests were controlled, these strains were equal in yield to the non-transformed parental cultivar Coker 312. This shows that the *B.t.* gene insertion did not have a detrimental effect on yield. When pest insects were allowed to damage the plots, very little damage was found in the transgenic strain plots; whereas, extensive bollworm/tobacco budworm; pink bollworm; cotton leafperforator; and saltmarsh caterpillar, *Estigmene acrea* (Drury). Smaller bolls and seed as well as some changes in lint percentage and some fiber properties were observed in the transgenic strains (Jenkins *et al.*, 1991; Jenkins *et al.*, 1993; Micinski and Caldwell, 1991; Benedict *et al.*, 1991, Gannaway *et al.*, 1991; Wilson and flint, 1991; Williamson and Deaton, 1991).

In 1989, scientists with USDA's Agricultural Research Service and with the genetic engineering company Argracetus conducted a field evaluation of four strains containing the *B.t.* gene. The expression of the *B.t.* gene in these strains was not at a level that offered any control of bollworm/tobacco budworm in field plots. Yields of the transformed strains were good; bolls and seed were smaller and lint percentage higher than in the non-transformed parental Coker 312 strains (Jenkins *et al.*, 1991).

When developing strains with high gossypol as the mechanism for resistance to bollworm/tobacco budworm, the breeder must attempt to keep a low level of gossypol in the seed and at the same time increase gossypol to an acceptable level for resistance in the square. This does not seem to be an insurmountable obstacle. No published data were found on the level of gossypol in the seed of recently developed germplasms which are resistant to tobacco budworm (Table 14). It may be possible to develop a cultivar with glands in the square and no glands in the seed (Altman *et al.*, 1987; Dilday *et al.*, 1982; and Dilday, 1986). We know that gossypol and related compounds are involved in resistance in some lines; however, in others much of the resistance is not due to gossypol. If large acreages of high-gossypol cotton are grown, it is likely that a strain of bollworm/tobacco budworm tolerant of higher levels of gossypol would be selected. A strain with higher tolerance to gossypol has been developed through direct selections in the laboratory; however, this strain was 38 percent less fertile than the control strain (Raulston *et al.*, 1985). Thus, in this instance there were opposing forces operating. The number of generations out of the total generations each year that the species would be under selection pressure from high gossypol cotton is also a major consideration. There are several instances of selection for resistance to insecticides in bollworm/tobacco budworm. Researchers in host plant resistance should expect resistance to gossypol to develop and be prepared with other sources of resistance. This goal is already being considered as all the germplasms or cultivars tolerant to tobacco bud-

Table 14. Registered lines of cotton resistant to bollworm/tobacco budworm[1].

Registration No.	Cotton line	Type	Originator	Year registered
162	BW 76-31	Germplasm	Stokes & Sappenfield	1981
242	MDH-118	Germplasm	Mahill *et al.*,	1984
243	MDH-121	Germplasm	Mahill *et al.*,	1984
244	MDH-126	Germplasm	Mahill *et al.*,	1984
245	MDH-128	Germplasm	Mahill *et al.*,	1984
246	MHR-1	Germplasm	Jenkins *et al.*,	1984
88	DES-119	Cultivar	Bridge	1986b
313	LaHG 063	Germplasm	Jones *et al.*,	1988b
314	LaHG 065	Germplasm	Jones *et al.*,	1988b
315	LaHG 660	Germplasm	Jones *et al.*,	1988b
316	Miscot 7913-51	Germplasm	Bourland	1988
317	Miscot 7913-83	Germplasm	Bourland	1988
318	Miscot 7913-84	Germplasm	Bourland	1988
345	MHR-10	Germplasm	Jenkins *et al.*,	1988b
346	MHR-11	Germplasm	Jenkins *et al.*,	1988b
347	MHR-12	Germplasm	Jenkins *et al.*,	1988b
348	MHR-14	Germplasm	Jenkins *et al.*,	1988c
349	MHR-15	Germplasm	Jenkins *et al.*,	1988c
350	MHR-16	Germplasm	Jenkins *et al.*,	1988c
351	MHR-17	Germplasm	Jenkins *et al.*,	1988a
352	MHR-18	Germplasm	Jenkins *et al.*,	1988a
	PD 875	Germplasm	Culp *et al.*,	1979
	PD 895	Germplasm	Culp *et al.*,	1979

[1]Registered with Crop Science Society of America, 677 South Segoe Road, Madison, Wisconsin, 53711.

worm are not high in gossypol. Our data show that evasion, through early, fast fruiting is also a major component of the resistance in several of these germplasms.

For several years, researchers have cooperated in two Regional Evaluation Tests. One of these involves strains being developed for tolerance to tobacco budworm, and the second involves strains being developed for early, short-season, production. At the Mississippi State location, we have conducted each test under conditions of full protection from insects and with a uniform artificial infestation of tobacco budworm. In some years, one or two other locations have had sufficient natural infestations of bollworm/tobacco budworm to evaluate resistance as well as agronomic performance. Progress has been made in developing high yielding, resistant strains. In 1978, the four highest yielding strains in the bollworm/tobacco budworm test produced only 86 percent of the yield of 'Stoneville 213', the check cultivar. Average yields of the top four were 91, 92, 105 and 114 percent of Stoneville 213 in 1982 through 1985, respectively, when bollworm/tobacco budworm were controlled. When they were allowed to damage the plots, yields of these same strains were 116, 103, 144 and 267 percent of 'Stoneville 213' in 1982-1985, respectively. Thus, progress also has been made in tolerance to tobacco budworm (McCarty, 1987).

In 1987 at Mississippi State, Mississippi, yields of strains in the bollworm/tobacco budworm test ranged from 11 percent less than 'Stoneville 213' to equal when insects were controlled; when high levels of tobacco budworm were allowed to develop, the range was 22 percent to 55 percent higher than 'Stoneville 213' (Table 15). In a 1987 evaluation of early, short-season strains at Mississippi State, Mississippi, yields were from three percent less to eight percent more than 'Stoneville 213' when insects were controlled, and from 15 to 29 percent higher when tobacco budworms were allowed to develop in the plots (Table 16).

Crop damage from infestations of tobacco budworm larvae varies during the growing season. In general, infestations of larvae during the early stages of fruiting result in lower yields and delayed maturity; whereas, mid-season to late-season infestations have little or no effect on yield or maturity (McCarty *et al.*, 1982b; McCarty *et al.*, 1986a). These differences are related to the manner in which the cotton plant produces bolls. Most (65 percent) of the yield of cotton is produced from bolls at the first position on fruiting branches; bolls at position two account for an additional 20 percent of the yield (Knight *et al.*, 1988; Jenkins *et al.*, 1990a,b). There are differences among cultivars in the number of bolls produced on each fruiting branch. These differences translate into fruit being set at different times during the season by different cultivars. Thus, one

Table 15. Yield of selected strains of cotton from 1987 regional test for tobacco budworm resistant strains grown at Mississippi State, Mississippi with and without tobacco budworm. (From: Regional Cotton Variety Test, 1987. Processed by National Cotton Variety Testing Program, USDA, ARS, P. O. Box 19687, New Orleans, Louisiana 70179.)

Strain	Developer	Lint yield	
		With tobacco budworm	Without tobacco budworm
		lbs/acre	
ST HG-6-1	Stoneville Pedigreed Seed Company	815	1050
La HG 810065	J. Jones	918	1108
La HG 810060	J. Jones	898	1019
Miscot 7913-835	F. Bourland	759	1005
Miscot 7913-51H	F. Bourland	721	1128
ST 213 Check	Stoneville Pedigreed Seed Company	590	1127
LSD .05[1]		189	198

[1]Least significant difference required for significance at .05 level.

Table 16. Yield of selected strains of cotton from 1987 regional test of early, short season strains grown at Mississippi State, Mississippi, with and without tobacco budworm. (From: Regional Cotton Variety Test, 1987. Processed by National Cotton Variety Testing Program, USDA, ARS, P. O. Box 19687, New Orleans, Louisiana 70179.)

Strain	Developer	Seed cotton yield	
		With tobacco budworm	Without tobacco budworm
		lbs/acre	
ST 6413	Stoneville Pedigreed Seed Company	3431	4133
DES 936	Bridge	3977	4029
Coker 84-610	Coker Pedigreed Seed Company	3276	4040
ST 7913	Stoneville Pedigreed Seed Company	3811	3858
ST 213 Check	Stoneville Pedigreed Seed Company	3456	3759
LSD .05[1]		1373	709

[1]Least significant difference required for significance at .05 level.

should expect different levels of tolerance to tobacco budworms among cultivars (Jenkins, *et al.*, 1990a,b; Jenkins *et al.*, 1986; McCarty *et al.*, 1986a).

The cotton plant possesses structures called capitate hairs on both surfaces of leaves. Strains differ in the density of capitate hairs (Bryson *et al.*, 1983; Kosmidou-Dimitropoulou *et al.*, 1980). These are secretory (associated with secretion) hairs and may be involved in resistance. However, in a survey of 29 cotton lines varying in resistance to tobacco budworm, no association was found between density of capitate hairs and growth of tobacco budworm larvae (Bryson *et al.*, 1983).

Glandless cottons have the potential to increase the value of seed products through increased utilization in feed and food products for nonruminants, including humans. Most research indicates that glandless cottons are more susceptible to bollworm/tobacco budworm than glanded cottons. However, this is not true for all glandless lines. Some glandless lines are no more susceptible than standard glanded cultivars (Meredith *et al.*, 1979a) or than isolines of glanded cotton (Jenkins *et al.*, 1966; Oliver *et al.* 1967).

PINK BOLLWORM

The pink bollworm is the most serious insect pest in many cotton growing areas of the world (Noble, 1969). In the United States, at present, it is a pest of economic importance in the irrigated areas of western Texas, New Mexico, Arizona, and southern California. It has the potential of becoming an economic pest farther east, but it is largely controlled by a combination of quarantine regulations, cultural practices and early maturing cultivars that ensure a long host-free period (Noble, 1969). It has not become established in the San Joaquin Valley of California as a serious pest. Presumably, the ongoing sterile moth release program that was started in the late 1960s has prevented the pink bollworm from becoming established in the Valley (Henneberry, 1980).

Cotton growers in the irrigated deserts of the West have depended upon full season cultivars, a long growing season and repeated applications of insecticides to produce the highest average lint yields in the United States. However insecticides are becoming less effective, and hence more expensive, because of the development of insecticide resistance in the pink bollworm. Heavy use of insecticides also leads to other problems, including outbreaks of secondary pests and deleterious effects on other organisms. This situation has encouraged growers to consider using short-season production practices and early maturing cultivars. Another development is the use of high levels of gossyplure, the pink bollworm pheromone, for early-season control (Staten *et al.*, 1987). However, this strategy is expensive and is warranted only where pink bollworm populations may become high. A cultivar having natural resistance to pink bollworm would be a welcome addition to the grower's defense arsenal against this insect pest.

Painter (1951) and Niles (1980) reviewed the earlier research on resistance of cotton to the pink bollworm. In this chapter we review recent research and discuss the current state of the art in the development of resistant germplasm.

A wide variety of cotton germplasm has been evaluated in both upland short-staple (*Gossypium hirsutum*) and extra-long staple (*Gossypium barbadense*) cottons, including current and obsolete cultivars, germplasm lines, morphological mutants, and day-neutral and photoperiodic primitive race stocks (Wilson et al., 1981).

Several methods are used to evaluate germplasm. They include: (a) exposing cottons to natural field infestations; (b) infesting field or greenhouse plants with eggs or larvae; (c) releasing moths into the greenhouse or field cages; and, (d) bioassays of insect development on artificial diets to which boll content or carpel wall material have been added. The standard method for evaluating field-grown cottons is to determine percent seed damage caused by pink bollworm as shown on radiographs of seed samples (Wilson and George, 1985). In other tests, we have counted eggs and entrance holes, monitored development time and survival of larvae and pupae, and have weighed pupae.

Upland cottons that have shown natural resistance in the field include nectariless, okra-leaf, super okra-leaf, pilose, high-terpenoid and early maturing germplasm lines and cultivars (Table 1). Other upland cottons that showed resistance were an obsolete American cultivar, 'Coker's Foster 300', an Indian cultivar, 'Laxmi', a cultivar from Pakistan, 'NIAB-78', and five breeding stocks of complex parentage—three from Texas (AET-5, AET-BR-2-1, and AET-BR-2-8) and two from Arizona (7203-14-7 and 7203-14-104) (Wilson *et al.*, 1981; Wilson, unpublished data). Singh and Sidhu (1984) reported that the Indian cultivar 'F414', showed some pink bollworm resistance in the Punjab. Chakravorty *et al.* (1982) reported that 'H-777', a cotton with high tannin and low seed protein, had lower seed damage than three other *Gossypium hirsutum* strains.

On the other hand, *Gossypium hirsutum* strains that had as much or more seed damage than the checks were red plant, late-maturing, glandless and frego-bract; strains carrying exotic cytoplasms from six other *Gossypium* spp. are also included (Wilson *et al.*, 1979; Wilson *et al.*, 1981).

American Pima strains, *Gossypium barbadense*, that showed resistance to the pink bollworm were pilos, okra-leaf, glandless, and Pima dwarf. Pima nectariless unexpectedly did not have less seed damage than 'Pima S-5' or 'Pima S-6' (Wilson *et al.*, 1977, 1981; Wilson, unpublished data). Pima red had significantly more seed damage than the checks.

Sixty of 321 primitive race stocks of *Gossypium hirsutum* evaluated showed some resistance in diet bioassays and 41 of 290 evaluated showed resistance in field plots in Puerto Rico (Wilson *et al.*, 1981) (Table 3). Seven of 41 race stocks showed resistance in field plots in Arizona. A majority of the race stocks that had shown resistance (antibiosis) in the diet bioassays also showed antibiosis when bolls on greenhouse-grown plants were hand-infested with young larvae. Of the seven race stocks selected as most promising in the greenhouse tests, three (T-39, T-167 and T-705) showed antibiosis after pink bollworm eggs had been placed on green bolls in the field (Wilson and George, 1984).

The subsequent focus of the pink bollworm research has been to transfer combined resistance traits into agronomically acceptable cottons. The most immediately useful traits are early maturity, nectariless, and okra-leaf.

A series of nectariless isolines averaged 72 percent as much seed damage and 99 percent as much lint yield as the nectaried counterparts while the comparable series of nectariless, okra-leaf isolines averaged 60 percent as much seed damage and 93 percent as much lint yield (Wilson, 1988). A nectariless, okra-leaf isoline and a nectariless, smoothleaf isoline yielded 13 and 14 percent more lint, respectively, than the nectariless counterpart cultivar, but did not have less seed damage. An early maturing nectariless, okra-leaf germplasm line, WC-12-NL, when compared at two locations and three seasons with a full-season, nectaried, normal-leaf cultivar, Deltapine 61, required 41 percent less insecticide to control the pink bollworm, and yielded 12 percent more lint (Wilson, 1988; Wilson, 1991).

Among the sources of antibiosis, the AET-5 strain and germplasm lines from individual plant selections from T-39 are serving as sources of resistance in the breeding program in Arizona (Wilson and George, 1984). In an experiment which was infested artificially with pink bollworm eggs, the germplasm line that had the lowest seed damage (nectariless, AET-t resistance) had 61 percent as much seed damage, yielded 99 percent as much lint, but was not significantly earlier than Deltapine 90 (Wilson, unpublished). Thus, nectariless and nectariless, okra leaf germplasm lines are available that combine significant resistance to pink bollworm with yield potentials approaching or equalling those of current cultivars (Tables 2, 17, 19). It remains to be seen whether transfer of the sources of antibiosis will add an increment of resistance to pink bollworm.

Eight germplasm lines with some resistance to pink bollworm were registered with the Crop Science Society of America in 1992 (Wilson, 1992). It may not be possible to develop germplasm with enough resistance to pink bollworm to preclude the use of other control measures. On the other hand, even a moderate level of resistance, combined with other non-insecticidal control methods, could allow the grower to produce a crop without the use of insecticides to control pink bollworm.

Table 17. Registered germplasm resistant to pink bollworm.[1]

Registration No.	Cotton line	Type	Originator	Year registered
305	WC-10NL	Germplasm	Wilson	1987
306	WC-11NSSL	Germplasm	Wilson	1987
307	WC-12NL	Germplasm	Wilson	1987
260	AET-5N	Germplasm	Wilson	1986
263	AET-5L	Germplasm	Wilson	1986
264	AET-5NL	Germplasm	Wilson	1986
266	AET-5NSL	Germplasm	Wilson	1986

[1]Registered with Crop Science Soceity of America, 677 South Segoe Road, Madison, Wisconsin, 53711.

COTTON LEAFPERFORATOR

The cotton leafperforator has a complex life history. The first three instars of the larval stage mine inside the cotton leaf, then the third instar emerges to form a one-day resting, or "horseshoe" stage. Fourth and fifth instar larvae feed externally on the leaf and are capable of causing considerable damage (Smith and Flint, 1977).

Fry and Henneberry (1977) and Wilson and Wilson (1975) reported methods of measuring leaf damage by the cotton leafperforator. A convenient method of estimating field damage is to collect mature leaves periodically and count "horseshoes". Data are expressed as the number of "horseshoes" per gram leaf weight, which compensates for differences in leaf size (Wilson and Wilson, 1977).

Resistance in nectariless cotton to the cotton leafperforator was reported by Benschoter and Leaf (1974) and Henneberry *et al.* (1977) (Table 1). George and Wilson (unpublished), however, found no difference between nectariless and the check cultivar or smoothleaf-nectariless stocks and the check cultivar in terms of cotton leafperforator "horseshoes" per gram leaf tissue.

A number of researchers have studied the relationship between cotton-leaf pubescence and the incidence of cotton leafperforator. Rejesus (1968) found no difference in oviposition between glabrous (smoothleaf) Seabrook Sea Island and the upland pubescent 'Coker 100A' (*Gossypium hirsutum*). Two smoothleaf upland strains had more eggs than a pubescent strain and two pilose strains and also more than the Arizona wild cotton, *Gossypium thurberi* (Todaro). Less leaf tissue was consumed on four glabrous strains and on 'Deltapine 16' (semi-glabrous) than on four normally pubescent strains.

Wilson and Wilson (1975) reported that strains that were either more glabrous or more pubescent than the normally pubescent upland cultivars were more resistant to cotton leafperforator. The TM-1 Pilose strain (1100 trichomes per square centimeter as compared to 125 trichomes per square centimeter for normal TM-1) had the lowest populations of cotton leafperforator and the least amount of leaf tissue consumed. Harding and Cowan (1971) reported that cotton leafperforator populations were slightly lower on TM-1 Pilose, and slightly higher on D_2 Smoothleaf-321 than on the hirsute check.

George and Wilson (unpublished) subsequently screened many race stocks, upland breeding stocks, mutants, and cultivars of *Gossypium hirsutum* for cotton leafperforator response. They found no consistent differences in stocks of frego bract, early maturing, high-gossypol, glandless, okra-leaf, super okra-leaf, and AET-cottons.

Harding and Cowan (1971) observed significantly higher populations of cotton leafperforator on red leaf cotton, but not significantly different populations on bronze, yellow-green, or virescent mutants. George and Wilson (unpublished) observed higher numbers of "horseshoes" on red-foliaged *Gossypium hirsutum* race stocks, accessions 1234 and 1235.

Among 34 entries of *Gossypium hirsutum* race stocks, George and Wilson (unpublished) found four with significantly fewer "horseshoes" than the check Deltapine 16. When retested, these same four had significantly fewer "horseshoes" than Deltapine 61, but they also had significantly more leaf trichomes. George and Wilson (unpublished) also screened a number of race stocks and race stock X cultivar derivatives reported to have high levels of condensed tannins in the leaves. In 1979, the number of "horseshoes" was more highly correlated with leaf pubescence than with tannin content. One exception was Texas 1055, which is glabrous and had fewer "horseshoes" than Deltapine-61. In 1980, several glabrous, high-tannin derivatives from T-1055 X Stoneville 213 had significantly fewer "horseshoes" than Deltapine-61. In 1981, none of those retested had significantly fewer "horseshoes" than Deltapine-61. F_2BR-1, a high-tannin cotton from North Carolina, had significantly more "horseshoes" than any other entry.

Wilson *et al.* (1977) reported that in mutants of Pima cotton, red leaf had significantly more "horseshoes" than the Pima S-4 or Pima S-5 checks. Pima Pilose and Young's dwarf Pima had fewer "horseshoes" than the check; but, virescent-7, okra-leaf, glandless and the two monomeric glanded Pimas did not have fewer "horseshoes" than the check. George and Wilson (unpublished) observed fewer "horseshoes" in Pima glandless than in Pima S-5 in a later test.

In summary, heavily pubescent cottons have shown good resistance to cotton leafperforator, glabrous cottons have shown some resistance, and red leaf cottons have been susceptible. Also, there is some indication that the nectariless character and cottons with high tannin levels confer some resistance to cotton leafperforator, but these characters need more testing. The *B.t.* gene in transgenic Coker 312 cotton strains conferred resistance to cotton leafperforator (Wilson and Flint, 1991).

PLANT BUGS

Several species of plant bugs attack cotton. The most prevalent ones in the United States are three species of mirids: the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois); western lygus bug, *Lygus hesperus;* and cotton fleahopper, *Pseudomatoscelis seriatus* (Reuter). Plant bugs are sucking insects and sometimes cause plants to branch abnormally or to shed squares or young bolls. Insecticidal control of plant bugs early in the season can sometimes lead to lepidopterous pests problems later in the season because of the destruction of predators and parasites.

The tarnished plant bug is most important economically in the Mid-South. In 1987, 68 percent of the yield loss caused by tarnished plant bug was in the Mississippi Delta and the rest was in other parts of Mississippi and Louisiana (King *et al.*, 1988). Unfortunately, a number of cotton mutants that are useful for resistance to other insects are susceptible to tarnished plant bug, as follows: glabrous (Jenkins *et al.*, 1977; Meredith and Schuster, 1979; Bailey, 1982); okra-leaf and super okra-leaf (Jones, 1982); frego-bract (Schuster and Frazier, 1977).

Fortunately, the nectariless and rapid fruiting traits confer some resistance to tarnished plant bug (Bailey *et al.*, 1980; Bailey, 1982; Bailey *et al.*, 1984). Therefore, breeding strategy has been to combine nectariless with susceptible traits to ameliorate the susceptibility (Jones, 1982; Milam *et al.*, 1982; Jones, 1983). A number of racestocks and various accessions of upland cotton have also shown resistance to tarnished plant bug (Table 18).

The tarnished plant bug has less preference for high gossypol cottons (Schuster and Frazier, 1977). Glandless strains varied in susceptibility to tarnished plant bug. Most of the glandless strains that suffered the least loss in yield, however, were also nectariless, hirsute, or rapid fruiting (Table 18) (Meredith *et al.*, 1979a). Two germplasm lines and one cultivar have been registered that have resistance to tarnished plant bug (Table 19).

The western lygus bug is an economically important pest in California, Arizona, New Mexico and western Texas. In the San Joaquin Valley of California, it is the most important pest in some years, but not in others. For example, in 1986, it caused a estimated loss of over 59,000 bales of lint, but in 1987, no loss was reported (King *et al.*, 1987, 1988).

The western lygus bug apparently feeds on cotton when preferred hosts, primarily alfalfa, are not available. The adults are mobile and may move into the cotton crop when alfalfa is cut, or when hosts are harvested or dry up as the season progresses. Nymphs are much less mobile than adults and may cause considerable damage.

Tingey et al. (1975a) found resistance to the western lygus bug in a number of *Gossypium hirsutum*, *Gossypium arboreum* L. and *Gossypium barbadense* strains. Several workers have observed resistance to this insect in nectariless cotton (Benedict *et al.*, 1981; Henneberry *et al.*, 1977; Benedict *et al.*, 1982).

The data are conflicting on the response of the western lygus bug to glabrous cotton. Tingey *et al.* (1975a) reported that growth, survival and nymphal emergence were no different on Bayou SM-6 glabrous than on Acala SJ-1. Wilson, R. L. and F. D. Wilson (unpublished) observed lower populations of adults (but not nymphs) on a Stoneville glabrous strain, and also on a glabrous, nectariless strain. George and Wilson (unpublished) observed that more squares were shed on glabrous than on hirsute isolines, but genetic background effects were operating. Benedict *et al.* (1982) reported that glabrous reduced oviposition (egg laying) by 30 percent, but increased growth rate and survival. The pilose trait caused increased oviposition, but decreased growth rate and survival. Tingey *et al.* (1975a) also reported lower nymphal weight on pilose than on a normally hirsute cultivar (Table 18).

Table 18. Summary of selected evaluations for resistance to *Lygus* spp. in cotton.

Resistant source and type	Reference
Antibiosis	
Nectariless	Benedict *et al.*, 1981
Pilose, DES-ARB-16, DES-HAF-277, DES-HAMS-277, DES-HAMS-16, DES-HERB-16, DES-LONG-227, DES-LONG-16, *Gossypium arboreum*, SA203, SA117, CB3031, T-110, T-254-24-14, 247-1-6-HGSm	Tingey *et al.*, 1975a,b
Yield under tarnished plant bug infestation	
Day neutral selections from T-78, 113, 158, 195, DES-ANOM-16, Bulgarian 3279, Hopi NM, Timok 811	Jenkins & Parrott, 1976
JPM-781-78-3	Jenkins *et al.*, 1979a
Pubescence	Meredith *et al.*, 1979
Glandless lines with either nectariless, hirsute or rapid fruiting	Meredith & Schuster, 1979
DES-35, DES-119	Bridge, 1986a,b

Table 19. Summary of resistant cotton germplasm and races available to breeders to use in developing resistant cultivars.

Trait or pest	Released to public: Resistant germplasms	Released to public: Resistant cultivars	Number of race accessions
Pink bollworm	7		99
Bollworm/tobacco budworm	20	1	56
High gossypol content			33
Spider mite			6
Plant bug	2	1	11
Boll weevil	20		59
Early short-season strains	7		
Nectariless strains	17	1	
Frego bract strains	8		
Smooth leaf strains	10		
Okra-leaf strains	8		
Okra-leaf frego bract strains	11		
Nectariless frego strains	8		
Nectariless okra-leaf	7		

Several workers reported that frego bract and glandless strains are more susceptible to western lygus bug than their normal counterparts (Leigh *et al.*, 1971; Tingey *et al.*, 1975b). Benedict *et al.* (1981) found no difference in oviposition on glanded and glandless isolines. Leigh *et al.* (1985) compared 52 glandless breeding lines with the check cultivar, Acala SJ-2, and found 20 that did not support significantly higher numbers of insects. In a second test, nymphal growth rate and insects per terminal were not higher on 5 of 37 glandless strains (including the 20 selected ones) than on the check, Acala SJ-2. Those authors concluded that it should be possible to select glandless breeding lines that are no more susceptible to western lygus bug than the glanded Acala SJ-2.

Benedict *et al.* (1982) found a number of cotton strains, among 600 evaluated, that showed an unknown type of chemical resistance to western lygus bug.

The cotton fleahopper is a pest primarily in the southwestern United States. In 1986 and 1987, the highest yield losses attributed to cotton fleahopper occurred in western and northwestern Texas (King *et al.*, 1987, 1988).

Considerable controversy has arisen over the benefits of glabrous versus pubescent cottons in decreasing cotton fleahopper populations and plant damage. Lukefahr *et al.* (1970) showed that pilose cottons harbored more cotton fleahoppers than less densely pubescent strains, which in turn supported more than the glabrous standard, 321. Walker *et al.* (1974) agreed that glabrous cottons had fewer cotton fleahoppers than did pubescent cottons, but also sustained greater damage and more yield loss in untreated versus treated plots because of hypersensitivity. They also showed that pilose cotton had more cotton fleahoppers than the other phenotypes, but showed good tolerance as reflected in a lower yield loss.

Lukefahr *et al.* (1976) and Lukefahr (1975) attributed the yield loss shown by certain glabrous cottons not to cotton fleahopper, but to leafhoppers (primarily *Empoasca* spp.). For example, Bayou SM-1 had fewer accumulative blooms than the pubescent 'Stoneville 7A' at Waco, Texas, where leafhopper populations were much higher in the glabrous strain, but not in the Rio Grande Valley, where leafhopper populations were uniformly low.

Nectariless strains have supported lower cotton fleahopper populations in some experiments, but not in others. Cowan and Lukefahr (1970) found no difference in nectaried strains in glabrous background. On the other hand, several workers have reported (or have cited earlier works) significant reduction of cotton fleahopper on nectariless cottons (Meredith, 1976; Schuster *et al.*, 1976; Schuster and Frazier, 1977). Liddell *et al.* (1986) showed that eight nectariless strains yielded only 47 to 73 percent as much lint at first harvest, and 76 to 86 percent as much at final harvest in heavily cotton fleahopper infested plots as in protected plots. In contrast, the most susceptible cultivar, 'Lankart LX 571', yielded 33 percent as much at first harvest and 66 percent as much total lint. Comparable figures for the most resistant strain, pilose, were 119 percent at first harvest and 91 percent total lint.

Lukefahr (1975) reported that two high gossypol strains had 70 percent fewer cotton fleahopper nymphs and 50 percent fewer total cotton fleahoppers than did

'Stoneville 7A'. Young *et al.* (1986) observed that a frego bract strain was preferred for oviposition over several normal-bract cultivars.

LEAFHOPPERS (JASSIDS)

Leafhoppers or jassids (*Empoasca* spp.) are widely distributed and a number of species occur as pests of cotton in many African countries, Australia, China, India, Pakistan, Philippines, United States and others (Painter, 1951). Certain species that occur in Africa, India, Pakistan and Australia are particularly destructive (Niles, 1980).

Fortunately, resistant germplasm is available and has been used extensively. In fact, host plant resistance is the major control strategy where leafhoppers are important economically. Cotton cultivars with dense leaf pubescence, especially on the adaxial (lower) surface, are highly resistant to leafhoppers (Bhat *et al.*, 1982). Hair density and hair length are both important. Leaf pubescence apparently interferes with oviposition. The highest level of resistance occurs when pubescence is high on both the midrib and the lamina.

Unfortunately, pubescent cultivars are undesirable for a number of reasons, including the occurrence of more trash in the lint and susceptibility to other insects such as whiteflies, aphids and bollworms (Bhat *et al.*, 1982; Butler and Wilson, 1984).

Bhat *et al.* (1982) crossed two densely pubescent, leafhopper-resistant cotton cultivars of *Gossypium hirsutum* with a less hairy, susceptible cultivar. In the two F_2 populations, 3 and 0.4 percent of the plants, respectively, combined a high level of leafhopper resistance with relatively sparse pubescence. Thus, it appears possible to separate leafhopper resistance from high levels of pubescence.

Bhat *et al.*, (1981a,b) found that two Asiatic strains of cotton (*Gossypium arboreum*) had the highest level of leafhopper resistance and the lowest amount of peroxidase activity and tannin, but not the lowest level of protein, in the leaves. Two resistant American cotton strains (*Gossypium hirsutum*) had the lowest enzyme activity and protein and tannin content, four moderately resistant strains had intermediate levels, and six susceptible strains had high levels.

Bailey (1982) showed in Mississippi that glabrous cottons had higher populations of leafhoppers (*Empoasca* spp., primarily) and *Lygus* spp., and lower lint yields than did hirsute cottons. Nectariless strains supported slightly lower leafhopper, plant bug, and predator populations; they yielded more lint than did nectaried strains.

WHITEFLIES

Two species of whitefly predominate as pests of cotton: they are the bandedwinged whitefly, *Trialeurodes abutilonea* (Haldeman), and the sweetpotato whitefly, *Bemisia tabaci* (Gennadius). However, there are others (Leigh, 1984). The bandedwinged whitefly is found throughout the Cotton Belt and is sometimes a pest of economic consequence in the Mid-South and Southeast (Clower, 1984; Jones *et al.*, 1975; Lambert, 1984; Lambert *et al.*, 1982b). The sweetpotato whitefly is widely distributed in warmer parts of the world and attacks many crops (Berlinger, 1986). In the United States, it is found mainly in the irrigated low-elevation deserts of Arizona and southern California.

Whiteflies secrete honeydew which results in sticky fiber and may also attract fungi which will discolor the fiber. In addition, the sweetpotato whitefly is the vector of a number of diseases of cotton and other crops (Butler *et al.*, 1985; Duffus and Flock, 1982).

Butler and Wilson (1984) observed significantly fewer bandedwinged whitefly on glabrous isolines, and on the semi-glabrous check cultivar, Deltapine 61, than on pubescent isolines. Lambert *et al.* (1982b) showed that less pubescent cultivars (among 35 total) generally supported smaller colonies of bandedwinged whitefly and allowed lower adult emergence, but there were some exceptions to this pattern.

The glabrous trait is the most important trait found thus far that reduces sweetpotato whitefly populations on cotton plants (Berlinger, 1986; Butler and Henneberry, 1984, 1986). Butler and Wilson (1984) found significantly fewer whitefly adults on sticky traps placed in glabrous isolines than in pubescent isolines in the AET-5 genetic background. Differences were not significant, however, between nectariless and nectaried isolines, and okra-leaf and normal leaf isolines. In another experiment planted in the same field, semi-glabrous isolines did not have lower whitefly populations than pubescent isolines. On the other hand, the semi-glabrous check cultivar, Deltapine 61, had lower mean numbers of whiteflies than all the other cottons in both experiments. In a commercial California cotton field, genetic background and level of pubescence both influenced adult whitefly populations. Two pubescent Deltapine cultivars averaged 914 adults per trap, two pubescent Stoneville cultivars averaged 691 per trap, and five semi-smoothleaf Deltapine cultivars averaged 493 per trap. H. M. Flint (Personal communication, USDA, ARS Western Cotton Research Laboratory, Phoenix, Arizona) found that the densely pubescent Stoneville 506 (85 trichomes per square centimeter on the sixth leaf from the apex) had fewer whitefly nymphs than expected, and the pubescent Centennial (42 trichomes per square centimeter) had more, based on the level of pubescence alone. Both pubescent cottons, as expected, had more nymphs than the semi-glabrous Deltapine 20 (0.2 trichomes per square centimeter). Butler *et al.* (1986) showed that, in 'Stoneville 825' genetic background, the pubescent isoline had the most adults and eggs, the semi-glabrous isoline had intermediate numbers, and the glabrous isoline had the lowest numbers. Also, number of whitefly adults and eggs were significantly lower on leaf halves that had been shaved with an electric razor than on the unshaven halves of leaves of the pubescent Stoneville 825.

Bindra (1985) reviewed the very serious whitefly problem in the Sudan. He concluded that damaging populations of whitefly (i.e., high enough to lower fiber grades through stickiness and discoloration) coincided with the introduction of the Lambert cultivars of extra long staple cotton, *Gossypium barbadense*, that had closed canopies and large leaf areas. The older, Sakel-type cultivars had open canopies and smaller leaf areas which had the advantage of permitting a less favorable (warmer, drier) microclimate within the canopy and which also allowed better penetration of insecticide. Also, the introduction of the closed canopy, large leaf area, Acala cottons (*Gossypium hirsutum*) aggravated the whitefly problem. A recent release of Sudac-K, a glabrous, super okra-leaf Acala cultivar, and anticipated releases of similar *Gossypium barbadense* cultivars should, in Bindra's opinion, reduce the whitefly problem significantly.

Berlinger (1986) stated that resistance to whitefly would be enhanced by glabrousness, a more open canopy (i.e., okra-leaf or super okra-leaf) and, based on Berlinger *et al.*, 1983 earlier work, a low pH in leaf sap.

In other studies, okra-leaf did not increase resistance to sweetpotato whitefly. Butler *et al.* (1986) studied six pairs of okra-leaf/normal-leaf isolines and found significantly fewer adult whiteflies only on 'Stoneville 7A' okra-leaf, significantly more on two others, and no differences on the other three. The okra-leaf cottons that Butler *et al.* (1988) and Khalifa and Gameel (1982) reported as having whitefly resistance were also glabrous.

The sweetpotato whitefly transmits a number of viruses, among them the cotton leaf crumple virus (Brown and Nelson, 1984). This disease has been present in the desert cotton growing areas of the United States for a number of years, but has increased within the past few years because of the increased incidence of whitefly. The commonly grown Deltapine cultivars are susceptible to cotton leaf crumple virus (Wilson *et al.*, 1989). Fortunately, the Cedix cultivar, developed in El Salvador, is highly resistant or immune to this virus. A nectariless cultivar (Conal) from Nicaragua also is apparently resistant, as are a number of other breeding lines from Nicaragua. A breeding program is underway to transfer the resistance into United States cultivars.

THRIPS

Lambert (1985) lists several species of thrips as economic pests of seedling cotton and five as economic pests of the mid-season and late-season crop. Several thrip species may be beneficial because they are predaceous (prey on) on other thrips and on mites. The western flower thrips, *Frankliniella occidentalis* (Pergande), shares this distinction, but can also be a pest of cotton throughout the season. The western flower thrips, long regarded as a cotton pest only in the western United States, apparently has now achieved pest status through the United States Cotton Belt.

Abdel-Bary *et al.* (1968) reviewed the literature up to that time on the response of cotton germplasm to onion thrips, *Thrips tabaci* Lindeman, attack and concluded that varietal differences existed. The 'Empire' cultivar (*Gossypium hirsutum*) and some of its derivatives seemed to have the most thrips resistance. Ballard (1951) attributed the resistance of Empire to the occurrence of dense pubescence on young leaves, and the susceptibility of 'Hi-Bred' to its glabrous leaves. Cultivars with intermediate pubescence varied widely in resistance, suggesting mechanisms other than pubescence.

In Egypt, 'Bahtim 101' and 'Menoufi', two extra long staple cultivars of *Gossypium barbadense*, had less seedling damage than another extra long staple cultivar, 'Bahtim 185', and an upland cultivar (*Gossypium hirsutum*), 'Coker 100' (Abdel-Bary *et al.*, 1968).

Abdel-Gawaad *et al.* (1973) measured the thickness of various cotyledon leaf-cell layers and counted numbers of onion thrips on sixteen cottons. Number of thrips was negatively correlated with the thickness of the lower epidermis. 'Giza 31', the exception, had thinner than average lower epidermis, but a lower than average population of thrips.

Rummel and Quisenberry (1979) showed that young plants, about 28, 35, and 42 days old, of 'Deltapine 14' pilose (densely pubescent) suffered no significant loss of leaf area caused by leaf feeding of thrips (several species, proportions of each not determined). However, leaf areas of the other five cottons—Tamcot SP-37, Tamcot SP-21, Deltapine 14 okra-leaf and Paymaster B8-3502—were reduced significantly. The pubescent Tamcot SP-37 did not suffer as much leaf area loss as the glabrous Tamcot SP-21.

Mauney *et al.* (1980) attributed one cause of shed of small squares to a soft rot caused by a bacteria that is presumably introduced into the square by thrips. Squares with abnormal numbers of involucral bracts (Wilson and Stapp, 1979), the so-called four-bract squares, apparently allow entrance of the thrips into the squares more readily than do normal, three-bract squares. Mauney and Henneberry (1984) observed that, over three seasons, thrips accounted for an average of 18 percent of the total square shed from early June to mid-July at Phoenix, Arizona, but only 4 percent from mid-July to early August.

Flint *et al.* (1989) determined causes of square shed in 'Deltapine 61' (a nectaried, semi-glabrous, normal-leaf shape cultivar) with those in WC-12NL (a nectariless, pubescent, okra-leaf shape germplasm line) (Wilson, 1987). Deltapine 61 had a significantly higher percentage of four-bract squares on the plant (10 percent) and on the ground (9 percent) than did WC-12NL (1 and 3 percent, respectively). Deltapine 61 also lost more squares due to thrips damage (30 percent of three-bract squares and 54 percent of four-bract squares shed were caused by thrips) than did WC-12NL (22 and 26 percent, respectively). In another experiment reported in Flint *et al.* (1989), Deltapine 61 and 'Deltapine 77' had higher percentages of four-bract squares, more total square shed, and more squares lost from thrips damage than did Stoneville 825. Percentages of three-bract squares lost due to thrips damage averaged 29 percent in the Deltapine cultivars and 21 percent in Stoneville 825. Percentages of four-bract squares lost due to thrips damage averaged 74 percent in the Deltapine cultivars and 30 percent in Stoneville 825.

SPIDER MITES

Relatively little research has been done on host plant resistance to spider mites, *Tetranychus* spp. The Acala and Pima cultivars seem to be more tolerant to spider mites than others. An extensive evaluation program indicated that 86 accessions of the 686 tested in the upland, *Gossypium hirsutum*, race collection, almost all 195 evaluated in the extra long staple, *Gossypium barbadense* collection, plus several species and interspecific hybrids were resistant (Table 20) (Schuster *et al.*, 1972a,b; Schuster *et al.*, 1973; Schuster and Maxwell, 1976). Cross resistance to twospotted spider mite *Tetranychus urticae* Koch and desert spider mite, *Tetranychus desertorum* Banks, exist in some cotton lines (Schuster and Cherry, 1975). Recent research indicates that strawberry spider mite, *Tetranychus turkestani* Ugarov & Nikolski produces a toxin induced injury in cotton (Brito *et al.*, 1986).

Table 20. Summary of selected evaluations for resistance in cotton to the twospotted spider mite.

Resistant source	Reference
Pima S-2, Pima S-4	Schuster *et al.*, 1972a,b,c
Gossypium barbadense, Gossypium australe, Gossypium lobatum, Pima S-1, S-2, S-3, S-4	Schuster *et al.*, 1972b
10 obsolete cultivars	Schuster *et al.*, 1973
86 *Gossypium hirsutum* race stocks (686 tested)	Schuster *et al.*, 1973 Schuster & Maxwell, 1976
184 *Gossypium barbadense* strains (195 tested)	Schuster *et al.*, 1973 Schuster & Maxwell, 1976
Gossypium hirsutum x Gossypium anomalum, Gossypium hirsutum x Gossypium raimondii	Schuster *et al.*, 1973

SUMMARY

We are at a threshold in the development of cotton cultivars (varieties) resistant to major pests. In the past several years, resistant, high yielding germplasms have been released and registered from public research programs (Tables 4, 14, 17). These germplasms are available to private seed companies for their use. The techniques for evaluating these germplasms have also been made available. Genetic engineering research to move the δ-endotoxin gene into cotton from *Bacillus thuringiensis* has progressed swiftly in the private sector. In the future, genetic engineering techniques will play an increasingly important role in broadening the germplasm base of resistance to pests. Field tests in 1990, 1991, and 1992 showed that the *B.t.* gene when inserted in cotton would provide significant levels of protection from damage by several lepidopterous insects.

Data from replicated field trials have shown that the nectariless trait provides a useful level of resistance to lepidopterous insects and plant bugs. The trend towards the development of early-maturing, fast fruiting cultivars will significantly reduce a number of insect problems now faced by growers. While the glabrous, okra-leaf, and frego bract traits confer resistance to some insects and susceptibility to others, breeders are combining traits that will help to ameliorate susceptibility. For example, frego bract confers resistance to boll weevil but susceptibility to tarnished plant bug. Germplasms that combine early maturity and the nectariless trait with frego bract are resistant to boll weevil but no more susceptible to tarnished plant bug than are normal-bract cottons.

The level of resistance to bollworm/tobacco budworm is high in several of the germplasms registered in the past few years. At least one major seed breeding firm in the United States is actively using these germplasms and techniques to develop bollworm/tobacco budworm-resistant cultivars. Three cultivars already on the market, DES 119, 'Stoneville 506' and 'Deltapine 50' have a useful level of tolerance to bollworm/tobacco budworm.

The appearance of early-maturing, rapid fruiting cultivars in the past several years signals the beginning of a concerted effort to breed cotton plants that evade pests and thus have effective field resistance to pests. In the next few years, new cultivars with resistance to bollworm/tobacco budworm, plant bugs and pink bollworm should appear on the market. Also, significant progress should be made in identifying resistant germplasm and management strategies that will help reduce problems from other major cotton pests. In fact, the new cultivars and resistant germplasms will form the foundation for even more successful methods of pest control. Control of cotton insects may not be possible without the continued use of insecticides to supplement other control methods. On the other hand, quantities of insecticides used with be reduced significantly as resistant germplasm and other alternative control methods are integrated into production systems.

SECTION IV

CONCEPTS OF POPULATION MANAGEMENT

Chapter 18

SUPPRESSION AND MANAGEMENT OF COTTON INSECT POPULATIONS ON AN AREAWIDE BASIS

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INTRODUCTION

COTTON INSECT PESTS AND COTTON PRODUCTION

Cotton, *Gossypium* spp, in the United States is grown annually in 15 to 17 southern states from the Atlantic to the Pacific Ocean under a variety of arid, tropical and subtropical habitats. The annual value of the crop over the five-year period 1987-91 averaged 5.2 billion dollars (USDA, 1992).

Insect and mite pests in most of the growing areas generally are accepted as factors that contribute to high costs of production and reduced quality and yields (Newsom and Brazzel, 1968; Schwartz, 1983). Major insect pests that occur in one or more production areas are the: boll weevil, *Anthonomus grandis grandis* Boheman; pink bollworm, *Pectinophora gossypiella* (Saunders); cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter); tobacco budworm, *Heliothis virescens* (Fabricius); bollworm, *Helicoverpa zea* (Boddie); *Lygus* spp.; and sweetpotato whitefly, *Bemisia tabaci* (Gennadius). Several other insect species and spider mites, *Tetranychus* spp., may also attack the crop in restricted and/or more localized areas.

Chemical control has been and continues to be of vital importance in the protection of the cotton crop and the production of profitable yields (Cooke *et al*., 1983). Chemicals are fast-acting, often control a complex of pests, may be used at the individual grower's discretion, and in most cases, are cost effective in relation to alternative control methods. In spite of these advantages, the peripheral problems (resistance, adverse effects on non-target organisms, secondary pests, etc.) associated with excessive use of chemicals has been of increasing concern to the scientific and public communities. These considerations, as well as our realization that a single factor unilateral insecticide-based focus on insect control will not provide long-term solutions to our key cotton insect pests have caused reassessments of approaches to insect control methodology. However, even though substantial progress has been made in developing autocidal approaches, resistant varieties, behavioral chemicals, methods of utilizing beneficial insects and pathogens, as well as cultural methods, none of these techniques are used on the same scale as chemical control. The need to facilitate implementation of these methods into integrated, multifaceted pest population suppression systems is urgent.

AREAWIDE INSECT SUPPRESSION OR MANAGEMENT

The concept of areawide suppression and management of target insect pest species has evolved with our increasing awareness of the limitations of attacking local infestations that represent only a small part of the total pest population. Moderate and consistent pressure applied each generation to the total population results in more effective pest population suppression than intensive pressure applied against small segments of the total population (Knipling, 1979).

Some of the tools that provide a strong base for the development of effective areawide cotton pest management systems are: (a) development of new cotton varieties with more manageable growth, fruiting characteristics and insect resistance; (b) increasing knowledge of insect population dynamics and the natural factors regulating insect populations; (c) identification and synthesis of insect pheromones and behavioral chemicals for detection, monitoring and control; (d) development of genetic methods of control, new and more effective chemicals, improved cultural technology; and (e) establishment of economic thresholds, improved sampling and more accurate descriptive and predictive modeling technology.

Areawide insect population suppression involves the coordinated efforts of many facets of an agricultural community cooperating to employ pest management strategies to reduce target species to levels that are below economic thresholds and/or to prevent target species from achieving economic levels. There are differences of opinion regarding the ultimate goals of such efforts, i.e., eradication or pest population management ("living with"). However, the fundamental ecological approach with regard to pest population regulation by natural factors and, if necessary, supplementary management practices (environmentally acceptable) remain the same. Ridgway and Lloyd (1983) suggested that the areawide insect management concept integrate eradication and pest management concepts with the view that areawide management could be a step in the direction of eradication of certain target species from defined areas.

GOALS AND OBJECTIVES OF AREAWIDE SUPPRESSION OR MANAGEMENT

The goals and objectives of pest management systems are not new. Briefly stated, they are to reduce losses in crop quality and yield caused by pests and to increase net profits to the grower. Methods are selected that cause minimal environmental damage and pose little or no risk to human health. During the late 18th and early 19th centuries, scientists stressed habitat modification and ecological approaches to insect control;

this formed the basis for modern integrated pest management approaches (Bottrell, 1979). Integrated pest management has been defined by a number of authors. Bottrell (1979) traced the origin of the terminology from integrated control (Bartlett, 1956; Stern *et al*., 1959) as broadened to become synonymous with integrated pest management (Smith and Reynolds, 1965; Smith and van den Bosch, 1967; Anonymous, 1975; Smith, 1978) and pest management (Geier and Clark, 1961). A widely accepted definition suggested by Rabb (1972) is as follows: "pest management is the selection, integration, and implementation of pest control actions on the basis of predicted economic, ecological, and sociological consequences". Lincoln and Parencia (1977) observed that these approaches have formed the basis of applied entomology since the beginning of the 20th century. Rabb (1972) described the evolvement of four principle types of control programs (strategies) after recognition and preliminary assessment of a pest situation: (a) emergency control methods; (b) management of local populations; (c) eradication; and (d) population management. Preventing the introduction and establishment of exotic pests through inspection, quarantine and regulatory action should be considered as a primary, preventative control strategy.

Almost none of our major complex and persistent insect problems have been satisfactorily managed on a local basis, and relatively few have been managed on an areawide basis. Current information indicates that the highest probability of success can be achieved when the focus is on a large area basis to affect a high percentage of the target pest population.

These programs can, but not necessarily, have the goals of eradication or total population management. Glass *et al*. (1975) suggested it to be unwise to argue that there are no circumstances in which eradication is desirable but proposed programs should be carefully evaluated as to cost benefits and probability of success. Rabb (1972) considered eradication (although incompatible with pest management) an appropriate strategy but he stressed that the decision to consider that option should be approached with considerable caution. It is not within the scope of this chapter to discuss the relative advantages and disadvantages of each of these two goals but the readers are referred to a series of papers from the symposium "Eradication of Plant Pests—Pros and Cons" for details (Eden, 1978; Knipling, 1978; Newsom, 1978; Rabb, 1978). Eradication and total population management approaches share in common the focus of their efforts on the total target insect population or at least a large proportion of it as opposed to treating local infestations, i.e., field by field. The most successful demonstration in recent years of the validity of this approach was the eradication of the screwworm, *Cochliomyia hominivorax* (Coquerel) from the southeastern United States (Baumhover, 1966) using the sterile insect release system (Knipling, 1955). This success was followed by a more extensive suppression program in the southwestern United States. While the program proved highly successful, the area under suppression was not large enough to prevent infiltration of screwworm flies each year from Mexico. Not until the program was expanded, through joint efforts with the Government of Mexico, to permit sterile fly releases in areas larger than the normal dispersal range of the flies, was progress made to achieve eradication. The pest has now been eliminated from all of the United States and Mexico as far south as the Isthmus of Tehuantepec. The history of the program was recently reviewed (Graham, 1985).

In this chapter we discuss areawide suppression of target pest species using the principles and concepts of pest management that prescribe the utilization of all suitable control methods in a compatible manner to reduce and maintain a target pest population below economic damage levels.

SOME BASIC CONSIDERATIONS FOR INSECT POPULATION SUPPRESSION IN AREAWIDE SYSTEMS

BASIC REQUIREMENTS

Essential in the development of an areawide cotton pest suppression program is a thorough understanding of: (a) crop production methodology; (b) the biology and ecology of the insect pest; (c) basic knowledge of its genetics, behavior and physiology; (d) relationships and interactions of the target pest with other organisms and other biological and physical components of the ecosystem; and (e) economic injury or treatment levels. This information is necessary to identify strategies, establish priorities and integrate control technologies as components of an effective suppression system that is compatible with crop production methodology as well as other segments of the ecosystem.

Knowledge of the farmland production potential, agronomic inputs, cotton plant growth, development and fruiting is essential in the development of insect management systems. Cultivar selection and planting date, as well as cultural practices (irrigation, fertilization and tillage) have a major influence on cotton phenology[1] as related to insect attack. Decisions on the need for control action must consider not only the pest insect population but also the stage of plant development and the number of susceptible cotton fruiting forms that could be damaged. There may be no justification for control action during low points in the cotton fruiting cycle because the potential loss does not exceed or equal the cost of the treatment in terms of projected boll set and maturity.

Bottrell (1979), in a review, presented the following important entomological considerations that should be addressed in formulating integrated pest management systems: (a) low levels of the target species may be desirable and do not necessarily indicate the need for control action; (b) manipulation of one component of the ecosystem may be useful in managing the target pest but may induce other pest problems or other undesirable effects; (c) natural control factors (weather, food, competition, etc.) and natural enemies must be considered and taken maximum advantage of; and (d) multi-disciplinary input is essential to consider all aspects of the ecosystem. Pest population levels that can be tolerated within a crop system can vary depending on a number of factors including crop management, harvesting schedules and inherent plant-insect tolerances. Also, reassessment of economic threshold levels may be nec-

[1]Phenology is a branch of science that is concerned with the relationship of climate and biological phenomena.

essary at periodic intervals in consideration of new cottons that fruit earlier and are more determinant.

ECONOMIC THRESHOLDS

The general principle of areawide management of a target species to maintain population levels below economic thresholds is in marked contrast to that of control based on prophylactic treatments applied to small segments of the population on a scheduled basis. The economic threshold is the population level below which the cost of taking control action exceeds the losses caused by the pest (Stern, 1973). Economic thresholds may vary from area to area, between different cultivars, between farms within the same area but under different management systems and under other circumstances. Even though economic thresholds must be flexible and are dynamic, their use and development in pest management systems is essential.

Pest and natural enemy population sampling is a vital component of pest suppression systems. Knowledge regarding the qualitative and quantitative distribution of pest and beneficial species is required to predict damage potential and the need for control action. Much progress has been made in establishing economic thresholds for cotton insects, in detection and survey methodology, and in systems management (Demichele and Bottrell, 1976; Hartstack *et al.*, 1976; Sterling, 1979; Brown *et al.*, 1979; Gutierrez *et al.*, 1980). These techniques play a vital role in cotton pest management systems. Decisions regarding the need for control action must be made on the basis of the pest population, presence of natural enemies and their potential for regulating the pest population, and the developmental stage of the cotton plant. Knipling and Stadelbacher (1983) suggest that, although the economic threshold concept is an integral part of current integrated pest management systems in cotton, it is a defensive strategy. Application of the economic threshold as a basis for the need for control action has, in most documented cases, reduced the number of insecticide applications and increased net profits to the individual grower. However, acceptance of the economic threshold strategy may result in some level of crop loss that, accumulatively, may amount to millions of dollars annually in the grower community.

The advantage of coordinated areawide pest management systems combined with the sound principles of integrated pest management is the potential for managing key pest insect populations over large areas at levels that do not approach "acceptable loss" as defined for economic thresholds. This avoids money expenditure for control action by individual growers on small local area basis.

SAMPLING

Direct sampling methods involve inspection of plants and recording of the presence or absence of pests and beneficials or damage to plant parts. These observations (measurements) are then expressed per unit of the crop measured. Indirect methods such as the use of various trapping techniques also are effective when relationships to crop infestations and damage thresholds can be established. Sampling methods vary greatly depending on the target species, but in most cases they are least efficient at low population densities. Sex pheromones (very sensitive at low population densities) of a number of species of cotton insect pests have been incorporated into trapping systems to provide improved sampling information for use in determining the need for control action (Beasley *et al.*, 1985; Rummel *et al.*, 1980; Benedict *et al.*, 1985). Additional research is needed to relate these trap indices to quantitative population levels.

MODELING

Models are being developed and/or are operational at various levels in developing pest management systems that interface with crop management and insect population management strategies (Gutierrez *et al.*, 1977; Baker *et al.*, 1983; Hartstack and Witz, 1983; Stone and Gutierrez, 1986a, 1986*b*; Stone *et al.*, 1986). These models can be useful particularly in describing crop and insect development and distribution. With refinement, they can be useful in predicting events that influence decision-making in crop-insect management systems that result in more effective, efficient production.

The integration of models into pest management programs can provide prediction capabilities that increase the probability of successful decision-making and provide explanations for fluctuating insect populations and cotton plant changes, as well as providing information that may make it possible to avoid adverse impacts that are identified by the model. Gutierrez *et al.* (1980) suggest that a most important use of a model in pest management systems is to define the validity and usefulness of available knowledge regarding the problem and identify information needed to explain differences that occur between the model simulation and field observations.

NATURAL MORTALITY AND NATURAL ENEMIES

The basic framework of an areawide pest suppression system that embodies the principles of integrated pest management must be constructed around natural mortality factors in the system that contribute to regulation of the pest population and development. These include, but are not restricted to weather, climate, food resources and natural enemies. Natural enemy complexes are of particular importance in most cotton ecosystems (Gaines, 1942; Ewing and Ivy, 1943; Newsom and Smith, 1949; Wille, 1951; van den Bosch *et al.*, 1956). Every effort must be made in cotton pest management systems to conserve (and possibly augment) the natural enemy complex with selective insecticides, modified application technology and/or substitution of alternative methods incorporated with sound cultural control systems.

The role of individual or groups of natural enemies in regulating cotton insect populations has been difficult to quantify because of the many species involved and their interactions, between the target species and their host plants. Their importance, however, has been universally accepted. Increased incidence of primary or secondary pests after mismanagement of insecticides that decimate natural enemy populations has been abundantly documented. The biological component of current cotton integrated pest management is focused on conservation of natural enemies that play a significant role in suppressing some pests, particularly bollworm/tobacco budworm, where entomophagous (insect feeding) arthropods are particularly effective (Ables *et al.*, 1983).

Although past efforts at developing biological control approaches for boll weevil, *Lygus* spp. and pink bollworm have been disappointing, recent studies indicate that potentially useful exotic and/or indigenous biotic agents may exist (Phillips *et al.*, 1980; Jackson, 1980). The potential impact of natural enemies on population regulation of these important cotton pests, as well as the opportunity to manipulate natural enemy populations for maximum benefit or introduce new exotic forms, will be improved with further refinement and implementation of emerging areawide pest management systems that minimize insecticide use or improve insecticide application methodology and selectivity.

ECOSYSTEM AND PEST COMPLEX

The ecosystem is extremely complex and it is unlikely that we will ever know and/or understand every absolute and biotic facet and its role in an ever-changing environment; in fact, it may be unnecessary to do so. Understanding and manipulating the interactions of the target species, their natural mortality factors, natural enemies, competitors, hosts, alternate hosts, farm management systems and the physical environment present a formidable challenge to the scientific community. Much progress has been made but much remains to be understood. Thus, the components of an areawide pest suppression system must be carefully considered and researched to assure their compatibility in the system.

In most cotton growing areas we are confronted with a pest complex not a single species. Experience has taught us that adoption of a single control measure for the target pest or the complex is predestined to fail at least occasionally. Joint use of multiple pest suppression techniques has the highest probability of success over the long-term in pest management programs. Areawide pest suppression systems involve many aspects of the agricultural community and require interdisciplinary cooperation in research and development and on the implementation of pest management programs (Bottrell, 1979).

MANAGEMENT AREAS

GEOGRAPHIC AREA

Areawide management systems that target the total pest insect population, in most cases, will involve large geographic areas that may extend across county and state, and, in some cases, national boundaries. Thus, in addition to the technical complexities of target pest suppression, a high degree of local, state, national and sometimes international cooperation will be essential to assure a high probability of success. The cohabitation of the target species and other species within the influence of the biological and physical environment in an area form the ecosystem management unit (Bottrell, 1979). The interaction of biotic (living) and abiotic (non-living) factors influencing the target insect and other components of the ecosystem become more complex as the boundaries of the management unit become larger and involve more diverse biological and environmental components.

IMPACT OF INSECT MIGRATION

Many insects, both beneficial and pest species, move short distances in expanding their distribution and/or travel long distances during their lifetime to new or similar habitats (Williams, 1957; Schneider, 1962; Johnson, 1966, 1969). Movement of insect pests and beneficial species is of particular importance in the areawide management system. Each species appears to exhibit unique and characteristic movement and migration behavior that is influenced by a broad spectrum of ecological, biological and physical stimuli. The boundaries of an areawide management unit may be delineated by natural factors such as climate or geographical barriers such as large bodies of water, mountain ranges, and/or by host distribution. In many cases, artificial barriers such as the release of sterile screwworms to isolate the native population in Florida during the Southeastern eradication programs (Knipling, 1955) or the buffer zone method used in the boll weevil eradication effort (Lloyd, 1972; Boyd, 1976; Ganyard *et al.*, 1981) may be required to effectively prevent movement of target insects into the management area. Other artificial systems such as the use of insect pheromones and/or other biological systems also may have potential as barriers to prevent insect movement into management areas (Lingren *et al.*, 1977).

Long distance movement of key cotton insect pests (pink bollworm, bollworm/tobacco budworm, boll weevil) is well documented (Davich *et al.*, 1970; Sparks, 1972; Stern and Sevacherian, 1978; Raulston, 1979). However, the relationship of the migrating insects to establishment, population development and dynamics is not well understood. Until this information is available, key issues in long-term areawide management programs include: (a) the potential for migrant populations to initiate new infestations where management programs have reduced populations to low or nondetectable levels, and (b) the potential for establishment of high-level infestations in excess of the capabilities of suppressive action used in the management system.

LONG TERM MAINTENANCE OF AREAWIDE SUPPRESSION OR MANAGEMENT AREAS

The principle of continual maintenance of barriers or buffer zones is highly controversial on the basis of the cost involved and the perception that when it is required it indicates that the suppression technology used in the management area was inadequate initially or has become less effective in some way during use in the program. The cost of maintaining an effective barrier is not likely to exceed a small percent of the losses the pest would cause if not eradicated. Also, if a maintenance program alleviates the need for intensive and extensive use of ecologically disruptive insecticides there would be added benefits (Personal communication, E. F. Knipling, USDA, ARS, Expert-Pest Management, Beltsville, MD). The matter is controversial but, when related to economic losses of a major pest species, the objections may be unjustified if areawide suppression or eradication is technically and operationally feasible and advantageous from economic and environmental standpoints. The need for technology to isolate or delineate a pest management area may not always exist. Phillips and Nicholson (1979) and Phillips *et al.* (1981) reported that bollworm migration was not a major factor contributing to outbreaks of the insect in a highly successful community areawide pest management program in Arkansas. In contrast, Knipling (1979) suggested that the effects of insect dispersal have been confounded in the results of several areawide insect population suppression experimental programs and prevented clear-cut analysis of the results of the studies.

These differences will be explained only with a more complete understanding of the factors affecting insect dispersal. It appears that major research efforts on key cotton insect pests are needed to identify and define migrating insect behavior; factors influencing migration; and the role of migrating populations in initiating new infestations and their contribution to the population development of established infestations.

POPULATION SUPPRESSION METHODOLOGY

TECHNOLOGY

Methods of insect control such as autocidal techniques, sex pheromones, attractants, exotic and indigenous biological agents, cultural controls, resistant varieties and improved, selective chemicals are being developed and continually improved. Combinations of these and other methods are being selected and integrated into compatible systems to develop efficient, effective population management of cotton pest complexes with full consideration for social, economic and environmental values. Knipling (1979) discussed the value and importance of combining two or more control methods for management of insect populations and stressed the need for compatibility of the methods used. He proposed that when two or more methods of control are applied concurrently or sequentially to an insect population, three types of suppressive action may occur: (a) the total level of suppression is less than the effect of each method alone, i.e., one method negates or partially negates effects of the other method; (b) the total level of suppression effect is the sum of two methods individually since they act independently; or (c) the total level of suppression is greater than the sum of the two methods alone since one of the methods potentiates the action of the other method. It is important to know and understand how the various control methods work alone and when integrated into a system to suppress an insect population.

The complexities of the biological and environmental factors and their interactions that determine the quantitative population development and distribution of target species in the ecosystem demand multi-disciplinary input to provide information and solutions essential in the formulation of an effective management system. The potential social, economic and environmental benefits accruing from implementation of systems to manage major key insect pests justify a high level of research, extension and technology transfer activities.

TARGET PESTS OF MAJOR CONCERN

Research to obtain essential information for developing management systems for the boll weevil, bollworm/tobacco budworm, *Lygus* spp. and the pink bollworm, as well as other insect and mite pests, is being conducted at a number of locations across the Cotton Belt by state, federal and industry scientists. Much progress has been made, but continuing research, extension activities and other educational efforts as well as support by administrators must be realized to accomplish extensive acceptance and implementation of areawide integrated pest management programs to suppress major cotton insect and mite pests.

SELECTED EXAMPLES OF PROGRESS IN DEVELOPING AREAWIDE COTTON INSECT SUPPRESSION PROGRAMS

BOLL WEEVIL

The boll weevil has caused serious damage to cotton in the United States since 1892 (Townsend, 1895). Although synthetic organic insecticides were initially highly effective for control, the peripheral problems of resistance, secondary pests and environmental concerns stimulated an emphasis on alternate control methods (Ridgway and Lloyd, 1983). Also, a renaissance of ecological approaches using cultural control methods occurred (Frisbie and Walker, 1981). The results of over ninety years of research and practical experience have led to the development of several effective areawide boll weevil management programs based on the biology, behavior and ecology of the insect. Cross (1983) summarized some of the fundamental biological and ecological boll weevil characteristics and how that knowledge may be used in management strategies. The limited boll weevil host range (surviving principally on cotton), low overwintering survival, knowledge of overwintering habitat, spring emergence patterns, reproductive biology and role of the aggregating pheromone have been important considerations. Studies of the overwintering stage of boll weevils have revealed that this time in its life cycle is a particularly vulnerable period. Diapause is associated with boll feeding, cool temperature and short days. In general, diapause weevils begin to occur in late August, or earlier, depending on host conditions, but some adults remain reproductive until frost. Reduction of late-season, reproductive-diapause boll weevil populations has been an important component in the development of boll weevil management systems (Brazzel *et al.*, 1961). Equally important was the pheromone trap index system for predicting the need for overwintered boll weevil control (Rummel *et al.*, 1980), and the adoption of early stalk destruction (Hunter and Hinds, 1905).

Mississippi Areawide Management Experiment — The first attempt to integrate several boll weevil control methods into a large areawide suppression program involved an area in Mississippi of more than 20,000 square miles and about 24,000 acres of cotton (Davich, 1976). The goal of the study was to demonstrate elimination of the insect from an area where it was well established with relatively high populations (Lloyd, 1972). This was not accomplished throughout the experimental area. However, the combination of suppression methods in the Mississippi program applied over a 3-year period to a high percentage of the population drastically reduced the numbers of boll weevils; demonstrating the effectiveness of an areawide multifaceted approach to boll weevil population suppression. The center of the 3-year experimental area was Columbia, Mississippi, and included all cotton (1,817 to 3,222 acres) grown within a 38-mile radius of that city. An additional contiguous area extended about 50 miles (3 concentric zones of 5, 15, and 30 miles) from the perimeter of the management area. The contiguous area served as a buffer zone to prevent or reduce boll weevil migration into the target management area since boll weevils have been known to move 45 miles to infest cotton (Davich *et al.*, 1970). The buffer or barrier zone technique was a critical factor in delineating the targeted eradication zone within the management area.

The suppression methods were: (a) trap crops; (b) pinhead square insecticide treatment; (c) pheromone traps; (d) in-season chemical control; (e) reproduction-diapause control; and (f) release of sexually sterile boll weevils. Cotton within the targeted eradication zone and first buffer area was defoliated when 60 percent of the mature bolls were open. Stalk destruction was accomplished as soon as possible after harvest to further enhance the effectiveness of the program.

Poor participation during the in-season chemical/control phase in the first year of the program (1971) and lack of early stalk destruction after harvest resulted in boll weevil populations so high that the reproduction-diapause insecticide applications were relatively ineffective. Thus, in 1972, 74 percent of the cotton fields had 8 percent oviposition (egg laying) square damage by the last week in June.

In-season insecticide efforts were much improved in 1972, and treatments were applied to all cotton in the eradication zone and first buffer zone. Also, trap crop and pheromone trapping components were included in the program to reduce overwintering populations. Oviposition damaged squares were 90 percent less than in 1971 and adults per acre were reduced 99.6 percent, indicating the dramatic effect of applying insecticide control, trap cropping and pheromone trapping pressure to a high percentage of the total population. Ground trash samples collected in the fall of 1972 and spring of 1973 revealed no boll weevils in the eradication or first buffer zone, and 380 and 143 per acre in the second and third buffer zones, respectively.

In 1973, populations were extremely low in the eradication zone, and from May 7 through August 10, only nine adult weevils (7 in June) were found in nine trap crops. Only nineteen native boll weevils were found in 15 cotton grower fields, and only 2,279 oviposition damaged squares were found in 183 collections from 77 fields. Of 236 fields (1,817 acres), boll weevil infestations were found in 34 fields (167 acres). Over two-thirds of the infested fields were in areas adjacent to a heavily infested area outside the eradication zone.

It was not possible to accurately and precisely determine the relative contributions to the boll weevil population suppression of each of the three major suppression components—insecticides and cultural measures on in-season and overwintering populations; use of grandlure pheromone traps to reduce weevil populations emerging in the spring; and sterile boll weevil releases.

The insecticide management component involved in-season applications to reduce the developing population coupled with late-season applications to reduce reproductive weevils that continued to produce diapause progeny as well as weevils already in diapause.

Grandlure® (boll weevil sex pheromone) was used to trap overwintering weevils before they entered the cotton fields and also to attract weevils to early-season systemic insecticide-treated cotton. The insecticide component was estimated to reduce the boll weevil population to about two per acre and the pheromone component was estimated to reduce the overwintering population an additional 80 percent (i.e., 80-90 percent of two per acre) (Knipling, 1979; Hardee and Boyd, 1976).

Sterile boll weevils were released at the rate of about 50 per acre per week. Taking into consideration the non-competitive nature of the released insects, Knipling (1979) estimated the effective ratio was 250 sterile to one native, and no reproduction of native weevils occurred. He also suggested that, since no evidence was found for reproduction in 170 fields that were more than 25 miles from infested cotton, some partially sterile-released females may have produced all the weevils found.

The results of the study clearly demonstrated the technical feasibility of reducing boll weevil populations to extremely low levels through a coordinated effort employing several management strategies that adversely impacted a high percentage of the boll weevil population over a large geographical area.

The effect on nontarget organisms in the eradication area was as expected (Harris *et al.*, 1976). Predator populations were reduced because of the heavy insecticide use (in-season and reproduction-diapause control), but increased dramatically when boll weevil populations were low as a result of population suppression measures that resulted in the need for little or no insecticide application. In contrast, bollworm/tobacco budworm populations were highest under extreme insecticide pressure for the boll weevil and the related low predator populations, but were low when predator populations increased and insecticide use decreased.

Mississippi Optimum Pest Management Study — A subsequent study was conducted during 1978 to 1980 in Panola County, Mississippi. It incorporated several additional boll weevil and other cotton insect management tactics into an areawide cotton insect management program (Andrews, 1981; Hamer *et al.*, 1983). The results were compared with cotton grown under standard boll weevil management practices in Pontotoc County, about five miles distant, and comparable in cotton production, boll weevil populations and crop management. The components of the pest management system were: (a) pheromone (boll weevil and bollworm/tobacco budworm) and blacklight traps (bollworm/tobacco budworm); (b) uniform planting dates; (c) pinhead square insecticide applications; (d) scouting; (e) in-season control of boll weevils, bollworms, plant bugs, spider mites and other pest species; (f) boll weevil reproduction-diapause control; and (g) early stalk destruction.

Grandlure®-baited traps were distributed at the rate of one trap per 20 acres of cotton in Panola County and in representative fields in Pontotoc County. The detection of five weevils per week in May alerted consultants and producers to the need for field surveys to determine the need for pinhead square treatment. Uniform planting dates were encouraged and all participating growers planted cotton as soon as soil temperatures were acceptable.

The first application of insecticide for reproduction-diapause boll weevil control was scheduled 10 days after the producers ended in-season control followed by the second, 10 days later. The third and fourth applications were at 15-day intervals. The initial applications were applied on September 10, September 20 and September 10 in 1978, 1979 and 1980, respectively. The number of per acre in-season insecticide applications in 1978, 1979 and 1980 was 3.3, 3.41 and 3.01, respectively. Up to 4 reproduction-diapause insecticide treatments were applied to most of the cotton acreages in the management area in the fall of 1978, 1979 and 1980. In the spring of 1979 and 1980, boll weevil captures were 78 and 94 percent less than occurred in Pontotoc County where standard in-season insect control practices were followed. Further, the need for pinhead square treatments was reduced because of the reproduction-diapause control program, and only 57 acres (105,000 total acres planted during a 3-year test) received insecticide applications in 1980. The effectiveness of the reproduction-diapause control program resulted in reduced insecticide use because boll weevil and bollworm populations rarely reached economic threshold levels. Yields were higher in Panola County than in the six surrounding counties where the number of in-season insecticide applications averaged 3 to 8 per acre.

Boll Weevil Management in the Lower Rio Grande Valley, Texas — Under subtropical conditions in the Lower Rio Grande Valley of Texas, cotton regrowth (resulting from inadequate stalk destruction after harvest) and volunteer cotton are serious problems in boll weevil management systems. The benefits of an areawide approach to early-season cotton stalk destruction and early crop plowdown management components have been effectively reemphasized recently. Summy *et al*. (1985, 1986a, b) estimated that more than 190,000 adult weevils per acre could be produced during fall and winter cotton regrowth under Lower Rio Grande Valley conditions. The authors suggested alternative cultural practices that result in nearly complete stalk destruction and use of herbicides to kill volunteer cotton seedlings (Summy *et al*., 1986b). An areawide surveillance system based on color infrared photography of more than 250,000 acres revealed large areas of cotton regrowth (Summy *et al*., 1984). The identification of the problem areas resulted in achieving 98 percent reduction in stalk destruction through the cooperative efforts of the entire agricultural community. Adult weevil populations were reduced to nondetectable levels where early plowdown was accomplished; in areas of poor to moderate stalk destruction, weevil populations remained at economically damaging levels. This demonstrated the efficiency of areawide stalk destruction as a boll weevil management component in the Lower Rio Grande Valley of Texas.

Areawide Boll Weevil Management in Arizona — One of the most recent community-wide IPM programs in Arizona was established in the area surrounding Laveen, Arizona. During the 1985 growing season about 75 percent of 10,000 acres of cotton were infested with boll weevils and growers applied up to 22 insecticide treatments (Farr and Lame, 1987.). For 1986, cooperating cotton growers adopted the University of Arizona's Cooperative Extension Service IPM program of: (a) uniform planting, March 25 to April 15; (b) pinhead square stage insecticide applications, three treatments at 5-day intervals initiated at 850 accumulated degree day heat units (55F base); (c) in-season insecticide treatments (5-day intervals) based on economic thresholds of 5-8 percent square infestations, or treatments at 3-day intervals when over 20 percent square infestation occurred; (d) irrigation termination by September 1; (e) plant growth regulator application by mid- to late-September to remove non-harvestable fruiting forms; and (f) stalk shredding immediately after harvest but no later than December 1, 1986. In the 1986 season, over 80 percent of the growers used fewer or the same number of insecticides compared to 1985, and most boll weevil field infestations were kept below 10 percent. Plant growth regulators to accelerate mature boll opening and accomplish defoliation were applied about one week earlier than in 1985, and crop plowdown by January 1 was considerably advanced as compared to previous years.

In 1987, trap cropping strategy was integrated into the program along with the previously-described management system (Moore and Watson, 1990). Trap crops (34 fields) planted 15 days ahead of the regular crop had as many as 16,000 boll weevil damaged plants per acre before insecticide applications. Five insecticide applications at 3-day intervals destroyed the weevils in the trap crop before it was plowed down prior to squaring of the current year's commercial crop. Average percent infested squares (20 fields) were 0.6 and 2.8 on July 8 and 29, respectively, as compared to 4.9 and 15.1 on the same dates in 1986. In 1987, percentages of infested squares ranged from 0 to 9.2 during July 1 to September 6 as compared to 4 to 23.4 percent in 1986 in 19 fields during the same sampling period.

In 1985, the year before the IPM program was initiated, the host-free period was 45 days compared to 105 and 120 days in 1986 and 1987, respectively, following initiation of the program. Cotton yields in 1985 were 840 pounds of lint per acre; they were 1200 and 1344 pounds of lint per acre in 1986 and 1987, respectively, with comparable (17-18) insecticide applications (Unpublished data, Marc L. Lame, Ombudsman, Arizona, Department of Environmental Quality, Phoenix, Arizona).

The results from the Laveen IPM project and two other boll weevil community-wide IPM projects near Phoenix resulted in an estimated gain of an average of $40/acre as a result of increased yield and reduced production input; a combined increase of $1.2 million for the approximately 80 growers involved (Personal communication, Leon Moore, Department of Entomology, The University of Arizona, Tucson, Arizona).

Other Boll Weevil Management Strategies — Prior to the advent of the organic insecticide era, scientists relied on knowledge of cotton crop development and the interaction with insect population development in efforts to manage insect populations and prevent losses. This was particularly true with the boll weevil. Hunter and Hinds (1905) recognized the value of early planting of early maturing varieties and early harvest followed by thorough stalk destruction in boll weevil population suppression. Scientists have expanded these principles and developed additional tools that form the basis for boll weevil management in many cotton production areas. For example, the development of early fruiting cottons with determinant growth characteristics have had a major impact on cotton production systems in the Rio Grande Valley of Texas. Short-season varieties (130 to 140 days from planting to maturity) with two early-season insecticide treatments for boll weevil control resulted in below economic threshold populations for an average of 59 days after the last insecticide application (Heilman *et al.*, 1977). Lint yields were equal to or greater in short-season systems with four less insecticide applications than lint yields from plants grown in conventional systems. An economic evaluation of the early-maturing varieties, selective insecticide use and efficient water management systems showed that the production cost advantage of the integrated short-season system was $0.18 per pound of cotton lint as compared with conventional long-season cotton-growing systems (Heilman *et al.*, 1978).

Considerable progress is being made in developing short-season cotton production methodology. Generally, less insect control input has been required because of the reduced opportunity for insect damage per unit of growing time, and because of the longer host-free period that reduces numbers of developing overwintering insects and increases natural winter and spring mortality. Integrating short-season production systems with resistant varieties, cultural methods—methods that include manipulation of planting dates to escape early-season emergence from overwintering or to enhance early maturity before economic infestations develop—and early harvest and plow-down are insect control components that should be incorporated in areawide insect management systems.

Sources of plant resistance such as frego bract, red plant color and male sterile characters have been demonstrated to have potential in boll weevil population suppression programs. Incorporation of the characters into cotton types that are agronomically acceptable has not been accomplished, but research progress is being made and it is highly probable that such varieties will be developed which will also include resistance characters to other cotton insects such as bollworm/tobacco budworm and plant bugs.

BOLLWORM AND TOBACCO BUDWORM

The cotton bollworm and the tobacco budworm have emerged in recent years as the cotton pest complex causing the highest losses in cotton yields and costs of control (Frisbie and Walker, 1981). A number of authors have documented the evolution of the bollworm/budworm complex and the associated peripheral problems—resistance, effect on nontarget organisms, pest resurgence, secondary pests and environmental considerations—across the Cotton Belt as a result of the unilateral reliance on insecticides for pink bollworm and boll weevil control (Newsom and Smith, 1949; Wille, 1951; Gaines, 1942, 1954, 1955; Ewing and Ivy, 1943; van den Bosch *et al.*, 1956; Van Steenwyk *et al.*, 1975). Insecticides will retain a vital role in cotton production systems but must be incorporated into a sound management system that utilizes an ecological approach incorporating effective natural and cultural control practices.

Bollworm/Tobacco Budworm Management Systems in Arkansas — The validity of effective pest management with coordinated areawide insecticide applications based on economic thresholds, bollworm/tobacco budworm population dynamics and cotton plant phenology was discussed by Phillips and Nicholson (1979) and Phillips *et al*. (1981). For the three years prior to the initiation of a bollworm/tobacco budworm management program, growers in a selected area in Arkansas averaged ten insecticide applications annually for control. A carefully designed research program revealed important information leading to effective areawide management strategies. The program was designed to: (a) evaluate sampling and surveillance techniques and economic thresholds; (b) develop modified life tables; (c) examine population dynamics; and (d) develop a forecasting program.

Examination of insecticide use patterns in the area indicated that mismanagement of control methods contributed significantly to the bollworm/ tobacco budworm problem. Analysis of the biology, ecology and population dynamics of the pest complex as affected by natural enemies and mortality factors showed that the magnitude of the July population was closely related to the density of the June population. When plant development approached 50,000 squares per acre, and populations of bollworm/tobacco budworm larvae reached 1,500 per acre, then control was initiated. Further, a treatment that induced areawide reduction of 50 percent of the population in June held July population development to levels below economic thresholds.

The bollworm/tobacco budworm management program in Arkansas was initiated in 1975, and expanded in 1976 to an area of approximately 50 square miles with 12,000 acres of cotton. The key strategy involved bollworm/tobacco budworm population suppression at a time during crop development when the need for square and boll production was less than occurs in mid- to late-season. This reduced population development results in fewer insects in the area during the critical crop development period.

Cotton crop scouting and treatment thresholds were based on the areawide community population levels as opposed to farm-to-farm evaluation. In the first year of the study, action thresholds, as determined by whole plant sampling at strategic locations over the entire community, were not reached until August. All cotton in the area was treated once within three days of the action threshold determination. This was followed by a second (and final) application on August 27. Careful management practices based on insect population thresholds and crop development reduced the use of insecticides 80 percent.

In the second year of the program, pest and beneficial insect scouting in relation to crop development showed that action thresholds (1,500 larvae per acre) were not reached in June (infestations were less than 500 larvae per acre). The resulting July population, as predicted, did not justify use of a hard pesticide but a microbial insecticide was incorporated into the management system. The total impact of the microbial insecticide (Elcar®) on population suppression was difficult to assess, but larval collections indicated that 25 percent mortality was virus-induced. Data taken for three years prior to the 1975 initiation of the pest management program showed a 15-fold July to August population increase; in contrast, the July to August increase after the communitywide microbial application was only 4-fold. Considerably higher population suppression may have occurred as a result of the use of the microbial insecticide than was indicated by the sampling technique used. Action thresholds again were not reached until August 12 when a final insecticide application was applied to all but 1,500 acres of late-planted cotton that required a third treatment.

The results of the third year of the study were confounded by drought conditions, low initial natural enemy populations and a large segment of the cotton grown in the management area that reverted to conventional insecticide application schedules. However, even under these adverse conditions, the pest management approach proved superior to conventional control tactics. It was clearly demonstrated that treatment on a field-by-field basis was less effective than treatment on a total areawide treatment basis. The areawide treatment program averaged 5 insecticide treatments and cotton in control areas required 11 insecticide treatments.

As a result of these research efforts, cotton farmers in Arkansas have voluntarily organized bollworm management communities in an attempt to manage bollworm and tobacco budworm populations over large land areas rather than by the more common field-by-field approaches. The intent is to coordinate control decisions so that all cotton fields in a bollworm management community are treated within a 3-day period. In 1988, there were approximately 150,000 acres in six bollworm management communities. Assessments of the economic impacts of the community approach have clearly demonstrated the benefits of the concept (Parvin *et al.*, 1984; Cochran *et al.*, 1985; Scott *et al.*, 1983).

Parvin *et al.* (1984) compared the performance of the bollworm management communities to control areas in adjacent counties to identify farm level benefits from participation in the community action approach. Significant differences in yields, insect control costs and net returns per acre were discovered. Yields were increased by 23 pounds of lint per acre; insect control costs were lowered by $1.85 per acre; and net revenue was increased by $18.57 per acre. Further, these data were used to estimate that the community program increased overall producers' incomes in 1984 by $1.5 million and reduced insecticide use by 92,000 pounds of active ingredients (Cochran *et al.*, 1985).

As an indirect benefit, it was hypothesized that the bollworm management communities also functioned as effective mechanisms for technology transfer and information dissemination. Scott *et al.* (1983) measured the effect that participation in a community program had on the adoption by the community of other Arkansas Cooperative Extension Service recommended production practices (not just pest management). The results showed that participation in a community program increased the percentage adoption of recommended practices by about 11 percent. Thus the intangible effects of community involvement provides, in addition to direct economic benefits, a forum for much needed communication leading to technology transfer.

Other Bollworm/Tobacco Budworm Management Strategies — The economic importance of the bollworm-tobacco budworm complex in cotton production systems has stimulated research efforts to develop the necessary information to supplement and improve existing management programs and to formulate new more effective, efficient management systems to prevent excessive losses. The large number of host plants, ecosystem diversity and variability of bollworm/ tobacco budworm host plant interactions make this a challenging and difficult goal to achieve. Agronomic practices of planting date, cultivation, fertilization and irrigation are intimately related to bollworm/tobacco budworm population dynamics and must be considered in management programs (Bradley *et al*., 1986; Luttrell *et al*., 1986; Rummel *et al*., 1986). Quantification of the impact of these factors on populations of these pests has been difficult because of the wide range of climatic influences and diversity of agricultural systems. Manipulation of planting date as well as cultural inputs and early-fruiting varieties can be used to avoid early-season insect infestations that are initiated by overwintering insects; this is accomplished by minimizing the amount of susceptible host material during peak occurrence of the overwintering population. The value of this approach is illustrated very well in South Texas where uniform early-planting is recommended to enhance crop maturity before insect populations reach damaging levels; and in North Texas where uniformly late planting is recommended to allow maximum overwintering and spring mortality of key insect species and suicidal boll weevil emergence (Frisbie and Walker, 1981). In West Texas, a bollworm forecasting model (Hartstack *et al*., 1976) is used to estimate bollworm oviposition (egg laying) and to manipulate irrigation scheduling to avoid lush cotton growth during peak oviposition periods. Early maturing cottons and associated cultural practices are used in South Texas to avoid late-season damaging insect infestations (Walker and Niles, 1971; Namken and Heilman, 1973; Walker *et al*., 1977). The potential value of modified crop production systems in bollworm/tobacco budworm management programs justifies the need for intensified research to define the interactions of these cultural practices and the potential for their manipulation as components of management systems (Ridgway, 1986).

Many sources of germplasm resistance to bollworm/tobacco budworm exist (Beck and Maxwell, 1976) and research is currently directed to incorporating these traits into acceptable, high-yielding and quality cotton backgrounds. The need for early-fruiting, high-quality cottons in cotton insect management systems was suggested by Walker and Niles (1971).

The role of indigenous natural enemies in regulating bollworm/tobacco budworm population development is well documented. Control strategies in management systems must be developed to conserve natural enemy populations and maximize their effectiveness. Long-range bollworm/tobacco budworm management plans should include: (a) manipulation of systems to maximize effectiveness of natural enemies; (b) provisions for augmentation of indigenous populations of natural enemies; and (c) importation of exotic forms of natural enemies.

PINK BOLLWORM

Pink Bollworm Management in Arizona — Integrated pest management (IPM) and communitywide participation systems have been important factors in cotton production in Arizona. The basis for IPM systems in cotton was established with the development of efficient cotton scouting programs (Unpublished report, Leon Moore *et al.*, Department of Entomology, The University of Arizona, Tucson, Arizona). The benefits of this approach were quickly realized in Graham County (Carruth and Moore, 1973). Growers in 1968 adopted scheduled insecticide applications at weekly intervals over a 6-weeks period for pink bollworm control. Treatments were made regardless of insect population density. This resulted in about 80,000 acre-treatments annually. After the initiation of a scouting program in 1969, acre-treatments were reduced 93 percent, 96 percent and 82 percent in 1969, 1970 and 1971, respectively. Costs of treatment per acre in 1968 was $15. This compares to $2.70, $2.54 and $5.00 per acre, respectively, in 1969, 1970 and 1971.

The success of the Graham County program stimulated a similar program in Pinal County where a Growers Pest Management Corporation was established. Economic evaluation of the Pinal County program for 1971 (Lawrance, 1972) and 1974 (Olmstead, 1976) showed that participants in the University of Arizona's IPM program spent $10.58 and $13.66 less per acre, respectively, on cotton insect control than did growers not participating in the program.

Areawide Management to Prevent Establishment in Uninfested Areas — An areawide pink bollworm population suppression program has been conducted since 1968 in the San Joaquin Valley of California to prevent establishment of migrating native pink bollworm populations from southern California and Arizona (USDA, 1977). The program has been improved continually and currently involves: (a) pink bollworm traps baited with the pheromone gossyplure to detect native migrant moths and to indicate areas in need of suppressive action as well as to establish ratios of released sterile to native male moths; (b) release of radiation-sterilized pink bollworm moths; (c) cotton plant destruction and plowdown to maintain a 90-day host-free period; and (d) most recently, the mating inhibition and/or male annihilation technique involving field application of gossyplure slow-release systems (Foote, 1988).

The pheromone trap system has proven to be an indispensable tool in the detection of low level migrating pink bollworm populations. Native moths have been caught each year since the initiation of the program, except for 1968. The numbers ranged from 5 in 1969 to 7,402 in 1977.

About 9 million sterile moths were released in 1968. The program has expanded each year; in 1988 over 754 million sterile pink bollworm moths were released. Releases have been made by air in areas ranging in size from 15 to 350 thousand acres of cotton where native moths were found or larvae detected in bolls. Annual ratios of steriles released to native moths as measured by captures in pheromone-baited traps have ranged from about 100:1 to 6,200:1 (USDA, 1977).

The mating inhibition technique as a supplementary suppression measure may be used when: (a) 20 or more native moths are caught in a one-mile section (prior to October); (b) there is evidence of a reproducing generation; (c) larvae are found; or (d) the native to sterile moth ratio is less than 1:50 (Foote, 1988). For example, in 1988 three areas met one or more of the criteria and were treated with gossyplure slow-release materials at 8- to 12-day intervals until defoliation. Treated areas involved: 200 acres treated four times beginning July 30; 700 acres treated three times beginning August 11; and 260 acres treated twice beginning September 1.

Native male moths have been trapped in the San Joaquin Valley each year of the program since 1969; larvae found in bolls in each of five years. Diapausing pink bollworm larvae have been observed to survive, pupate and emerge in the spring in the Bakersfield area of the San Joaquin Valley (Unpublished data, A. C. Bartlett, USDA, ARS, Western Cotton Research Laboratory, Phoenix, Arizona, and R. T. Staten, USDA, APHIS, Methods Development Laboratory, Pheonix, Arizona). It is difficult to conclude with scientific certainty that the program has been the total factor preventing the establishment of the pink bollworm in the San Joaquin Valley. However, the indirect evidence supports the premise that the pheromone-trap detection system, releases of the sterile moths, early crop destruction after harvest, and in recent years, supplementary behavioral control methodology, have successfully achieved that goal.

Other Potential Components in Pink Bollworm Areawide Management Systems — Large-scale coordinated areawide management systems using all available technology for pink bollworm population suppression of established infestations have not been implemented. However, the first steps have been taken toward managing the insect on a local basis. In all pink bollworm-infested cotton areas in Arizona and California, cotton scouting is practiced, and pheromone trapping and boll sampling are used to determine to a greater or lesser extent the need for control based on established economic thresholds. Further refinements in new technology can improve current management systems; additional management components can be incorporated; and acceptance of areawide systems for population suppression can be expanded.

Several aspects of pink bollworm biology and ecology contribute to natural population regulation. Early season pink bollworm population development is affected by a large number of natural factors such as: (a) suicidal emergence (Bariola, 1978, 1983; Fullerton *et al.*, 1975); (b) natural enemies (Noble, 1969; Orphanides *et al.*, 1971; Irwin *et al.*, 1974; Jackson, 1980; Henneberry and Clayton, 1982); and (c) soil temperature effects on larvae in early season (Fye, 1971; Butler and Henneberry, 1976; Clayton and Henneberry, 1982). The results are a low (50 to 150 percent) population increase during the first generation that infests the current year's cotton crop (Graham *et al.*, 1962; Slosser and Watson, 1972; Bariola, 1978). Consequently, supplementary early-season suppression technology such as: (a) resistant plant types (Wilson and Wilson, 1976; Wilson, 1982); (b) short-season varieties and modified cotton culture (Walhood *et al.*, 1981, 1983); (c) planting dates to increase suicidal emergence (Adkisson *et al.*, 1962; Henneberry *et al.*, 1982); and (d) behavioral control with the sex pheromone (Doane and Brooks, 1981; Butler *et al.*, 1983), have the potential to further reduce early-season population increase. These methods are effective particularly at low population densities and must be integrated with techniques to reduce overwintering populations.

Mid- to late-season control is heavily reliant on chemicals. Careful sampling with sex pheromone-baited traps (Beasley *et al.*, 1985) and examination of bolls (Watson and Fullerton, 1969; Toscano *et al.*, 1979; Toscano and Sevacherian, 1980) to determine application of insecticides on a "need" basis can reduce numbers of applications and cost of chemical control substantially. Sampling pink bollworm eggs laid on bolls is a relatively new technique that also can be used to time insecticide applications (Hutchison *et al.*, 1987). A treatment threshold of 6-8 percent egg-infested bolls resulted in a 35 percent reduction in insecticide use with no reduction in yield. The maximum number of susceptible bolls occurs about three weeks after peak flowering (Fry and Henneberry, 1983). When applying insecticides, consideration should be given to pink bollworm populations and plant development stages (Reynolds, 1980; Fry and Henneberry, 1983).

Development of insecticide resistance is one of the threatening problems to the cotton industry. Pink bollworm resistance to DDT (Lowry and Berger, 1965) and tolerances to pyrethroids (Bariola, 1985) have been documented, but not to organophosphates (Reynolds, 1980). At the moment, the only possible method to prolong the life of insecticides is to reduce selection pressure that results in the development of resistant strains. This may be accomplished by limiting the use of one class of insecticides to one generation per year. Monitoring insecticide resistance and managing insecticide use patterns should be incorporated into pink bollworm management systems to extend the longevity of existing chemicals. Haynes *et al.* (1986, 1987) have developed a reproducible and economical technique for monitoring insecticide resistance in pink bollworm field populations.

Late-season management systems to reduce development of the diapause pink bollworm generation by eliminating host material (Bariola *et al.*, 1976) and/or destroying diapaused larvae, using tillage and/or irrigation techniques (Watson, 1980), are the most powerful and economical methods of population suppression of this insect pest. They should be components of areawide pink bollworm management systems.

Stalk shredding to enhance uniform and deep burial of shredded plant debris, followed by disking and effective plowing and winter irrigation treatments, effectively induce additional mortality of overwintering pink bollworms (Watson, 1980). The most effective, practical tillage practice has been deep plowing that results in turning over the soil to a depth of 8 inches or more. The earlier that winter plowing is accomplished, the higher the larval mortality, with fewer moths emerging in the spring.

Presently, the use of early-season pheromone trap monitoring and field scouting to obtain estimates of infestation levels to determine the need for control action is standard practice in most growing areas. A careful analysis indicates that incorporating short-season methodology, resistant varieties and good cultural practices of early harvest, stalk shredding and plowdown into current management systems on an areawide basis could reduce the pink bollworm populations to noneconomic levels that would allow consideration of sterile release methodology as a low-density population management tool (Henneberry and Keaveny, 1985).

DISCUSSION

Areawide suppression or management of total cotton insect populations which have multifaceted control approaches and incorporate the principles and tactics of integrated pest management as an ecological approach to more socially, economically and environmentally acceptable methods of pest control have the highest probability of success. Research, extension and other teaching efforts dealing with most of our key cotton insect pests are making significant progress in development of the concept of coordinated large area, agricultural community involvement in pest population management. The areawide approach focuses suppressive measures on the total pest population as opposed to uncoordinated efforts focused on local or farm-by-farm or field-by-field attempts to control limited segments of the population. The farm-by-farm and field-by-field approaches have not provided effective solutions to our key insect pests. Areawide programs include producers as active participants in the program which is a facet that helps to ensure success. The producer is not a bystander nor are extension and private consultants. The entire community has an active part in the program.

The technology to manage many of our key pests on an areawide basis currently is not available; however, important progress is being made in developing methods that can be incorporated in management systems that are compatible within the ecosystem. Although considerable progress has been made, much additional research needs to be accomplished to supplement our incomplete understanding of the factors affecting population density, dynamics and behavior of the target species and the role of beneficial species and their interactions as they relate to the other biological and physical components of the ecosystem.

Areawide suppression programs for many of our key cotton insect pests are at various stages of development. Existing technology is being continually modified and improved and new technology developed. The most effective and efficient areawide insect management programs incorporate multifaceted, multidiscipline inputs to achieve the desired suppression of the target species population with little or minimal impact on other components of the management unit. The ultimate impact of suppression technology applied against one species must be weighed and measured as to potential effects on other biological and physical entities within the system. The complexities of the interaction of all components in an areawide population suppression unit make it impossible to predict long-range effects that may occur and modifications that may be required to maintain the suppression system in a viable and acceptable manner.

Chemical, biological, behavioral, genetic and cultural control methods, as well as development of resistant cotton variety technology, is advancing rapidly. All control methods must be considered in areawide management or suppression systems. No single method is totally acceptable. Combining all of the available technology offers the highest probability of success in suppression/management programs. The selection and integration of compatible control methods should be based on knowledge on how each of the methods function individually and when introduced separately or simultaneously as suppression methods to achieve population reduction. Further, suppressive action must be taken within the framework of detailed knowledge of the biology, ecology and population dynamics of the target species as well as crop development.

The implementation of areawide management systems for key cotton insect pests is a major undertaking that requires the cooperative efforts of research, extension, teaching and grower communities. The potential long-term benefits of pest population suppression on an areawide basis appear to justify the efforts in terms of reduced costs, more effective pest control, less environmental contamination, and other peripheral problems associated with local uncoordinated efforts which result in year-after-year economic pest populations.

SUMMARY

Community-involved areawide cotton pest management systems for population suppression of several major cotton insect pests have been successfully demonstrated. The systems were based firmly on technical information, theoretical analysis and demonstrated documented research achievements. The accomplishments have resulted from the coordinated efforts and input from many scientific disciplines, experiment station and extension staff, the cotton industry and the grower communities, as well as state and federal agencies. Commonality of interest to maintain and/or increase crop yield, quality and net profits within the framework of effective pest management systems that are socially and environmentally acceptable has contributed greatly to successful programs.

The scientific community has made outstanding progress leading to: (a) better understanding of the benefits of focusing control actions on total insect populations; and (b) exploiting the roles of natural mortality factors, including natural enemies, in regulating populations of many of the important insect pests. Much progress has been made in developing sampling methods, economic thresholds and insect-cotton plant models that are invaluable tools for determining the need for supplementary control actions to complement natural population regulating mechanisms. The most common current array of potential cotton pest population management methodology consists of, but is not limited to: (a) chemical insecticides; (b) host plant resistance; (c) biological agents; (d) autocidal methods; (e) behavioral chemicals (for sampling, detection and control); (f) and cultural controls. Continuing research will undoubtedly refine and improve the potential of these methods and identify additional ones that will expand our selection options. Much additional information needs to be gathered. It is doubtful that we will completely reveal every aspect of the complex biological and physical interactions of agricultural ecosystems. More importantly is the development of adequate information about a target species and the ecosystem that assures, with tools available, a reasonable chance of achieving a successful areawide integrated pest management system. The effectiveness of available control methods for achieving the desired impact on the target pest population will be greatly enhanced with increasing

knowledge of the ecological relationships and interactions of the pest and beneficial species, as well as other factors regulating pest population dynamics. Most importantly, but most difficult to attain, is a reasonable estimate of the absolute numbers and distribution of the target pest within the management area. The availability of such information allows analysis of the estimated impact of each potential population suppression component alone and in combination. Such an analysis would provide major guidelines for establishing priorities and selecting pest population suppression techniques with the highest probability of success. In most cases, this information and/or the methodology and expertise to obtain it has not been developed. The importance of having the capability to obtain this vital information justifies a concerted research effort in population ecology to elucidate factors affecting changes in spatial (space related) and temporal (time related) population magnitude. All pest management methods need to be examined, but each one may not be applicable or necessary in every cotton growing area for each target species. More likely, each agricultural area will have specific needs that can be satisfied by tailoring management programs through selection and integration of methodology to meet the highest priority requirements within the area. The selection and integration of technology into a pest management system that is compatible within a specific agricultural production area should be based on knowledge of the target insects and crop production methodology; it should be designed with considerations given to the agroecosystem within which the pest management system is imposed.

Several of the listed population suppression methods, but not all of them, have been combined in the areawide boll weevil management experiments in Mississippi, Texas and Arizona, bollworm/tobacco budworm management experiments in Arkansas, and pink bollworm management experiments in Arizona. These efforts clearly demonstrated that the combinations of suppression methods selected and applied over areas that encompassed a high percentage of the total target pest population significantly reduced their pest status more efficiently than "farm-by-farm" efforts previously practiced (localized control efforts). In each case, the programs provided economic benefits to the farmer and were more environmentally acceptable. Additionally, because of the experience gained, continuing research, technology transfer and extension-education efforts, the programs are being refined and continually improved.

Increasing concern over the environment, as expressed by the public and private sectors as well as the scientific community, places the challenge of providing the world with adequate food and fiber within the constraints of ecologically-based pest protection systems during and after production. Much progress has been made in providing the technology to accomplish these objectives through areawide pest management fundamentals stressing biological and ecological orientation.

Chapter 19

BOLL WEEVIL ERADICATION

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INTRODUCTION

The boll weevil, *Anthonomus grandis grandis* Boheman, was first reported in the United States in south Texas near Brownsville in 1892 by C. H. T. Townsend (1895). It established in the Lower Rio Grande Valley and dispersed north and east, becoming established in North Carolina and Virginia by 1921. Over a 30-year period, the boll weevil occupied most of the cotton acreage in the southeastern United States and became recognized as a "key" pest of cotton, wherever it occurred.

For about 30 years, the range of the boll weevil remained relatively static until it was found infesting irrigated cotton in the Presidio area of West Texas along the Rio Grande River. In the early 1960s, boll weevil population buildup occurred in the Rolling Plains of West Texas. Prior to this, the boll weevil was found in the area sporadically, in low numbers. These buildups coincided with the expansion of irrigated cotton acreage in the area.

Prior to these developments, entomologists believed the boll weevil could not become established in areas with an average rainfall of less than about 20 inches per year. These infestations indicated that the boll weevil could become established in arid areas where cotton is irrigated, including west Texas areas with only six to eight inches of rainfall per year.

During the 1960s and 1970s, reproducing populations of the boll weevil were detected in southwestern Arizona. These were associated with the grower practice of producing "socca" or "stub" cotton (i.e., ratoon cotton). Entomologists opposed this practice because cotton plants fruited continuously allowing pest populations to buildup earlier and to greater levels than where stalks were destroyed and plowed under each year.

Localized populations, which developed in the Arizona area prior to 1970, disappeared when the practice of "stub" cotton was discontinued. However, in the late 1970s, the practice of "stub" cotton was again allowed, and boll weevil infestations soon developed throughout the desert valleys of southwestern Arizona and southern California. These populations caused economic damage in localized areas along the Gila and Colorado Rivers and the Mexicali Valley in Mexico.

The prohibition of "stub" cotton and regulations for destruction of previous year cotton stalks by specified dates did not eliminate the boll weevil this time. In fact, it continued to increase in intensity and spread until cotton throughout the desert valleys from Phoenix westward was infested. Presently, the boll weevil occurs in all cotton areas of the United States with the exception of the High Plains of Texas, New Mexico, San Joaquin Valley of California, and the areas where eradication has been achieved in Virginia, North Carolina, South Carolina, and the western-most desert valleys of California and Arizona. Moreover, the boll weevil has been largely eliminated as an economic pest in Georgia, north Florida, and Alabama. And, the states of Mississippi, Arkansas, Louisiana, and Texas have passed legislation allowing for the establishment of eradication zones based on approval by grower referenda. Failure to continue the elimination of the boll weevil from the United States may result in reinfestation in eradicated areas.

EARLY HISTORY OF THE BOLL WEEVIL

Historically, it was not known that there was a boll weevil which attacked cotton before the 1890s (Cross, 1983). An adult specimen was found in a cotton, *Gossypium hirsutum* L., boll fragment from Oaxaca, Mexico, in diggings dated 900 A. D. If the boll weevil was a problem before the middle 1800s, no record was reported. The boll weevil was described by C. H. Boheman in 1843 as *Anthonomus grandis* from an adult collected 1831 to 1835, and labeled "Veracruz" with no host record.

The boll weevil adult is a small, hard shelled snout beetle, averaging about 1/4 inch long, gray to brown color, becoming nearly black with age. The slender snout is about 1/2 the length of the body; heavily sclerotized elytra (wing covers) fit closely over the abdomen. It overwinters as an adult in debris on the soil, such as in and around cotton fields and buildings. The adult emerges from spring to midseason; with most emerging about the time the crop begins to fruit. The adult feeds on squares (flower buds) and bolls. Eggs are laid in these feeding punctures which are then plugged with frass by the female. Thus, the three immature stages (egg, larva and pupa) are protected inside the cotton fruit until the adult forms and emerges. The female is capable of depositing 100 to 300 eggs. The life cycle varies from three to four weeks depending upon temperature. In cotton-growing areas there may be three to eight generations per year. In the presence of mid-summer temperatures, boll weevil populations may increase rapidly to extremely high densities and infest nearly all of the fruit, unless control measures are employed.

Growers in South Texas reported a new cotton pest, the damaged it caused, and requested assistance from the United States Department of Agriculture (USDA) in 1893. The USDA dispatched an entomologist to examine infested territories in this area and in adjacent areas in Mexico. Reports emphasized the dangers involved in allowing the boll weevil population to expand into the cotton-growing South.

The boll weevil was already causing serious damage to the cotton crop in parts of the Lower Rio Grande Valley by the time it was detected in 1892. Results of this investigation were reported by Townsend (1895) and included in a description of the infested area and life history and habits of the boll weevil. This report also included the first recommendations for control, i.e., destruction of cotton stalks in the fall to reduce overwintering weevil populations, and the need to establish non-cotton-growing zones around the infested areas to prevent further geographic expansion by the pest.

As the boll weevil spread into the United States, various remedies were suggested. The USDA recommended early stalk destruction during the fall to deprive the weevil of a food supply and oviposition sites. Weevil catching machines were proposed. Farmers tried to destroy the pest with ashes, lime, London purple, Paris green, and molasses baits containing a toxicant. Several communities in Texas promoted hand picking of weevils. Funds were established to pay for weevils, at rates of 10 to 50 cents per 100 weevils captured.

Entomologists thought that the boll weevil would eventually reach a northern limit. In 1903, a plan was promoted to establish a non-cotton belt along Louisiana's western boundary to prevent its expansion into the Mid-South. But, in 1904, weevils were discovered in Louisiana, and by then 32 percent of the United States Cotton Belt was infested. The boll weevil became the major pest of cotton. In 1903, demonstration programs to educate farmers on boll weevil control were established, serving as the genesis for the present-day Cooperative Extension Service.

Dispersal by the boll weevil expanded its geographic range to within a few miles of the western boundary of Mississippi by 1906. Some entomologists hypothesized that the Mississippi River was an adequate barrier to spread by the boll weevil, but, in 1907, a USDA entomologist found that the weevil had breached this barrier at a number of points. Weevil populations expanded to the northeasterly-most cotton-production area of the United States, Virginia, by 1922.

Hunter and Coad (1923) reported that after 1894 the boll weevil extended its range annually from 40 to 160 miles, although in several instances the winter conditions caused a steep population decrease. By 1922, 87 percent (producing 96 percent of the lint) of the Cotton Belt was infested by the weevil.

Land values decreased as the weevil dispersed throughout the South. Many areas did not return soon to pre-weevil levels of cotton production. Land values were slow to recover. Within the South, where cotton was the only cash crop for many farmers, there were recognized areas of high productivity. After the boll weevil spread across the South, some of the centers of production disappeared, while others were eclipsed by new areas. As the weevil migrated toward the Atlantic seaboard, the states to the east of the infestation at first benefited from reduced cotton production in the south-central states. The long-tended lands of the Carolinas and Georgia garnered greater profits for the farmers than the less depleted soils of the infested territory. The semi-arid portions of Texas and Oklahoma came to the forefront as major cotton-producing areas. There, the weevil was less destructive, and less labor was required to produce the crop. After the weevil had totally infested the South, the permanent adjustments became obvious. The developments were not at all encouraging to the older cotton states of the Southeast. While fertile soils and less weevil damage due to a drier climate were advantages in the West, the lower winter temperatures of the Cotton Belt's northern fringe suppressed weevil populations. For example, the Tennessee Valley in northern Alabama ranked ninth out of the ten farming areas in per-acre production for that state from 1904 to 1914, but ranked third during 1914 to 1924.

The intrastate shift in cotton production in Mississippi was even more pronounced than in Alabama. Twenty-seven delta and adjoining counties of northwestern Mississippi doubled their average production. Bales produced increased from 585 thousand bales during 1905–1909 to 1.2 million bales during 1943–1947. The state's remaining production decreased one-half, from 718 thousand to 350 thousand bales during the same period.

The center of cotton production in the United States probably would have shifted westward with time, but the weevil accelerated the process. From 1910 to 1930, cotton-production areas in Texas and Oklahoma doubled. There was a combined 40 percent increase in acreage in Mississippi, Arkansas and Louisiana. The acreage in Alabama, Georgia, South Carolina and North Carolina increased only five percent (Helms, 1977).

More recent extension of the boll weevil's range occurred in 1953, when the Presidio, Texas area was first reported infested by populations from Mexico, and in 1961, a notable spread into the Texas High Plains was observed. These latter reports indicated the weevil's possible adaptation to dryer western areas, which occurred during the early 1980s when infestations became established in the southwest desert valleys of Arizona, California and Mexico.

JUSTIFICATION FOR A BOLL WEEVIL ERADICATION PROGRAM

The boll weevil is responsible for losses and control costs to the cotton industry and to the nation's economy, ranging from \$200 to \$300 million each year, depending on the severity of the infestation, the acreage, and the price of cotton. The cost of control efforts each year is estimated to average \$75 million. Naturally occurring beneficial organisms are generally ineffective in keeping the boll weevil suppressed below economically damaging levels; consequently, broad-spectrum insecticides are applied to reduce damage. In absence of these insecticides, the boll weevil would inflict tremendous economic losses every year on millions of acres of cotton. In severely infested areas, when cotton is not protected with insecticides from attacks of the boll weevil, reductions in yield over a period of years averages about 50 percent. Because of the difficulty in controlling the boll weevil, it has long been the goal of the cotton industry to encourage the development of methods for eliminating the pest. Accordingly, the objective of much of the research effort since the 1950s has been toward that goal.

Efforts to develop satisfactory control measures for the boll weevil over the last 100 years closely follow the phases or actions described by Rabb (1972) on evolution of insect pest control actions. During the initial 30-year period (1892 to 1922), cultural control methods were relied upon as the boll weevil dispersed across the southeastern United States. Regardless, yield losses to the boll weevil ranged from 30 to 50 percent. Practices of early stalk destruction and early planting of early fruiting, short-season cotton varieties to reduce populations of overwintering weevils and avoid late-season buildup of populations were ecologically sound. Nevertheless, these practices alone did not provide satisfactory control.

In the early 1920s, formulation of calcium arsenate satisfactory for field applications were developed. This material provided good boll weevil control, but acceptance of the practice was poor because of adverse effects by the chemical on predators and parasites. Secondary pests were elevated to primary pest status in absence of these beneficials (natural enemies). In fact, these problems continue, leading entomologists to label the boll weevil as a "key" pest of cotton. ("Key" pests are defined as insects and mites annually requiring directed control action, often in the form of synthetic chemical pesticides.)

The sequence of events occurring with use of calcium arsenate were as follows:

(1) Treat the cotton with calcium arsenate for boll weevil control. This treatment controlled boll weevils but destroyed a major portion of the beneficial population.

(2) With the loss of naturally-occurring predators and parasites, aphid populations expanded exponentially; calcium arsenate did not control the aphids.

(3) Thus, another insecticide, nicotine sulfate, was developed to control aphid, but it was not widely accepted because it was noxious to formulate.

During the 25-year period beginning in the 1920s and ending after World War II, practices recommended for the control of the boll weevil were as follows:

(1) Cultural practices such as early destruction of cotton-plant residue after harvest to eliminate feeding, oviposition and potential overwintering sites;

(2) Early planting of fast maturing cotton varieties to escape mid and late-season buildup of boll weevil populations;

(3) Chemical control with calcium arsenate; and

(4) Use of other chemicals to control secondary pests that were elevated to primary pest status as a consequence of killing their natural enemies with the calcium arsenate.

This control program was reasonably effective and established the pattern as new chemical classes, viz., the organochlorines and organophosphates, were used for control of the boll weevil.

Immediately after World War II, the synthetic organic pesticides were made available for cotton pest control. There was a great variety of these materials, and many were toxic to most arthropod species inhabiting cotton fields. Cotton producers and most researchers were highly pleased with the results these new pesticides provided. Consequently, reliance on chemical pesticides to control cotton-arthropod pests was near complete.

The new insecticides possessed two qualities of great importance: (a) high initial toxicity to the cotton pest insects; and (b) sufficient persistence to control newly emerging insects or insects migrating from untreated to treated areas. The chlorinated hydrocarbon insecticides had a great impact on cotton production. For the first time, cotton producers were able to achieve highly effective control of all arthropod pests of the crop. The impact of these insecticides stimulated unprecedented demand by growers for almost complete control of pest arthropods. It then became profitable for producers to use fertilizer, irrigation, and long-growing, indeterminate cotton varieties to achieve maximum yields.

The chemicals used in mixtures for boll weevil control included organochlorine compounds such as BHC, dieldrin, aldrin and toxaphene. Then, in 1955, less than 10 years after use of organochlorines began, boll weevil populations resistant to organochlorines were selected (Roussel and Clower, 1955). Fortunately, organophosphate compounds such as methyl parathion and azinphosmethyl (Guthion®) were available as substitutes for boll weevil control. These materials were highly effective against boll weevils; and, they have continued to the present to be effective. Nevertheless, based on occurrence of resistance in other pest species to organophosphates, there remains the possibility that genotypes resistant to organophosphates may yet be selected. In fact, Teague *et al*., (1983) reported a 3- to 6-fold tolerance to azinphosmethyl (Guthion®) in a field strain obtained from the Lower Rio Grande Valley of Texas, but this report has not been confirmed by other researchers.

Resistance to the organochlorines created considerable concern among cotton producers and entomologists. The short (approximately eight years) effective life of the organochlorine materials led most growers and entomologists to the realization that they did not have the ultimate solution to controlling cotton pests.

In the early 1960s, the bollworm, *Helicoverpa zea* (Boddie), and tobacco budworm, *Heliothis virescens* (F.), developed high levels of resistance to the organochlorine, organophosphate and carbamate insecticides (Brazzel, 1963, 1964; Adkisson, 1969; Harris *et al*., 1972). So, pest control priorities in cotton reversed. The bollworm and tobacco budworm became more important pests than the boll weevil in many areas. The problem of bollworm and tobacco budworm resistance was temporarily solved by increasing the dosage of methyl parathion from 0.25 to 0.50 pounds per acre per application. Monocrotophos (Azodrin®) at 0.8 to 1.0 pounds per acre also was introduced as were mixtures containing 2.0 pounds of toxaphene, 1.0 pound of DDT, and 0.5 to 1.0 pound of methyl parathion.

An immediate effect of increasing chemical concentration rates was increased production costs; yields remained high, but profits decreased (Adkisson, 1969). This situation prevailed until the late 1960s when the tobacco budworm in the Lower Rio Grande Valley of Texas and northeastern Mexico became resistant even to high rates of the organophosphorus insecticides. Many Lower Rio Grande Valley producers treated fields with methyl parathion 15 to 18 times per year but still suffered great losses in yield. Others produced at relatively high levels, but made smaller profits because of the high costs incurred from intensive insecticidal treatment. Some cotton crops were destroyed in spite of intensive treatment with insecticides. Approximately 700,000 acres in northeastern Mexico were removed from cotton production because of damage by the tobacco budworm (Adkisson, 1969; Reynolds *et al*., 1975).

Organophosphate-resistant tobacco budworms occurred in Texas, Louisiana, Arkansas, Mississippi, and other states to the east as well as in the Imperial Valley of California. The pest developed such a high level of resistance that control remained difficult with any insecticide registered for use on cotton at that time.

Another drastic change in the pesticide usage pattern on cotton occurred in 1973 when the Environmental Protection Agency banned the use of DDT. DDT combined with toxaphene had provided satisfactory control of the boll weevil, bollworm, cotton fleahopper, and plant bugs in cotton producing areas in Texas. (Methyl parathion was frequently added at a low rate if weevils became extremely numerous.) Cotton producers in states east of Texas had not experienced severe pest resistance problems because toxaphene-DDT formulations controlled a broad spectrum of pests. Organophosphate resistance had developed slowly in these bollworm/tobacco budworm populations. However, the banning of DDT forced cotton producers to shift to high concentrations of organophosphate insecticides for pest insect control. These materials were typically applied in combination with toxaphene and, to a lesser extent, with endrin or chlordimeform (Galecron®, Fundal®). Thus, the banning of DDT increased selection pressure for the development of organophosphate-resistant pest strains. Cotton producers in the Mid-South and Southeast began to experience the same problems of decreasing effectiveness of insecticides, decreasing yield and increased cost that had been confined to Texas and Mexico.

When current advances in the technology of insect suppression are considered, an all-out elimination effort against relatively few insects can be justified when chances of success, and possible costs and benefits, are clearly favorable. Most experts on the boll weevil agree that such an effort is fully justified because of crop losses caused by this pest and the magnitude of insecticides applied to reduce and prevent its damage.

Many people recognize the adverse environmental effects on natural enemy complexes resulting from use of insecticides to control the boll weevil. The intensive use of insecticides in cotton during the last 50 years has posed questions as to the immediate and long-range hazards to fish and wildlife from insecticide residues. However, the adverse effects of their use on resources of beneficial insects — bees, parasites, and predators — are apparent and usually more acute.

Entomologists and other biologists agree that the use of boll weevil insecticides causes a drastic reduction in the beneficial insect complexes in cotton fields and often in adjacent crops. Depletion of these beneficials often has been proven responsible for the emergence of other insects and mites as important pests. It is well recognized by entomologists and most growers that bollworm and tobacco budworm problems are intensified when insecticides are applied for control of the boll weevil. Bollworms and tobacco budworms in recent years have rivaled the boll weevil in destruction of cotton in many areas, as well as causing extensive losses on a number of other crops.

A matter of real concern is the long-range dependability of currently registered insecticides for control of the boll weevil. The boll weevil and many other insects have demonstrated their ability to develop strains resistance to certain insecticides.

So, in the early 1960s the cotton industry and entomologists were faced with two major problems, which led to the events of the next 20 years. First was the possibility that boll weevils might develop resistance to available effective insecticides and constrain economical production of cotton throughout much of the Cotton Belt. This was in effect the realization that complete dependence upon pesticides was not a viable long-term option. The weevil problem must be handled by a management system, which did not produce the undesirable side effects upon secondary pests. Secondly, the solution to the key pest (boll weevil) must allow for a better management for bollworm/tobacco budworm populations and other secondary pests thereby allowing maximum use of natural control factors and less overall reliance upon pesticides.

DEVELOPMENT OF NEW BOLL WEEVIL CONTROL TECHNOLOGY

This state of affairs led to a series of events over the next 15 years resulting in the conduct of the first of two eradication trials. With the leadership of the National Cotton Council of America representing the cotton industry, representatives of the state experiment stations, USDA Agricultural Research Service (ARS) and USDA Animal and Plant Health Inspection Service (APHIS) developed a series of reports and recommendations on the state of boll weevil research and the feasibility of eradication. An excellent review of these events and the persons and agencies involved is given by Parencia (1976).

In 1958, the National Cotton Council passed a resolution that called for increased research and development to provide the technology for the eradication of the boll weevil from the United States. A working group was appointed by the USDA to review existing boll weevil research programs, need for a more comprehensive research effort, and the areas which should be supported by the USDA. This was done at the request of Agricultural Committees of the United States House of Representatives and Senate. As a result of the recommendations of this working group, Congress appropriated funds to establish the ARS Boll Weevil Research Laboratory on the Mississippi State University campus and to augment the funding level at other USDA stations as well as state experiment stations. The Boll Weevil Research Laboratory was dedicated in 1962 with the stated goal of developing technology that could be used to ultimately eradicate the boll weevil from the United States.

During the years prior to and after the establishment of the Boll Weevil Research Laboratory, significant findings were produced which influenced future boll weevil suppression and eradication strategies. These included:

(1) Mass rearing of boll weevils for research purposes and use in the sterile insect technique (Vanderzant and Davich, 1958);
(2) Identification of the diapause condition of overwintering boll weevils (Brazzel and Newsom, 1959);
(3) The significance of decreasing diapause populations just before and during the cotton harvest period, and the efficacy of organophosphorus compounds during this period of the cotton season (Brazzel, 1959; Lloyd *et al.*, 1967);
(4) Development of ultra-low-volume (ULV) aerial application of insecticides for control of the boll weevil (Brazzel *et al.*, 1968);
(5) Development of a highly effective pheromone trapping system for survey and detection of boll weevils with potential for suppression of low density populations, including the identification and synthesis of the four components of the pheromone and a suitable trap (Tumlinson *et al.*, 1971; Mitchell and Hardee, 1974; Hardee *et al.*, 1971); and,
(6) Development of the systemic insecticide aldicarb (Temik®), which controlled boll weevils feeding on treated cotton during early stages of cotton development.

The search for a better solution to the boll weevil problem began in 1958 when the National Cotton Council resolved to support an intensified research and development program on the boll weevil. As a result of this action, funds were made available to expand research directed toward this objective. By 1969, in view of research developments cited above and the urgency of a solution to the boll weevil, the National Cotton Council appointed a special study committee with a charge to (a) review current status of boll weevil suppression measures and (b) consider feasibility of actions with current technology to eliminate the boll weevil as a pest of cotton.

This committee concluded that adequate technology had been developed to expand to large-scale field testing. A subcommittee was appointed to survey the boll weevil-infested area of the Cotton Belt for test sites. The objectives of such tests were to determine if available technology applied in large-scale tests with 100 percent participation of growers in the test area could eradicate the weevil population.

ERADICATION TRIALS

The subcommittee recommended that a pilot Boll Weevil Eradication Experiment be conducted in South Mississippi and adjacent areas of Alabama and Louisiana in 1970. The objective of the experiment was to assess the technical and operational feasibility of boll weevil eradication. Funding difficulties delayed the initiation of the test in 1970. It was started in July 1971 and completed in August 1973. An experiment of this magnitude required the cooperation of many agencies and groups. The action agency of the USDA, APHIS, was assigned the lead role to execute the program components. The execution of regulatory requirements was the responsibility of the state regulatory agencies. The growers agreed to be part of the program. The state extension agencies handled information and education activities. The state experiment stations and ARS furnished research support.

Coordination of these agencies and activities was achieved by appointment of a Technical Guidance Committee consisting of members representing these groups. This committee was charged with (a) developing an operational plan for the project, (b) overall supervision of project execution; and (c) final evaluation. When the project was completed, two additional groups were appointed for evaluation by the Entomological Society of America and the National Academy of Sciences.

The pilot experiment was located in five counties in South Mississippi, five parishes in Louisiana, and two counties in Alabama. There were approximately 24,000 acres of cotton in 1971 and 19,000 acres in 1972 and 1973 in the experiment. The area was divided into zones with an outer buffer zone fifty miles in width to reduce immigration to the inner core zone where the evaluation was done. Program components in the first year, 1971, consisted of:

(1) In-season control by growers to reduce boll weevil population levels for production of an acceptable crop. Voluntary grower control was good on about 25 percent of the cotton and sporadic to none on the remaining acreage. As a result, very high weevil populations developed in almost all fields;
(2) Diapause control was the first action under program control and supervision. This tactic was designed to destroy potential overwintering populations by treating the fields periodically in the fall with organophosphate insecticides before weevils in diapause development achieved diapause, left the fields, and entered winter quarters. These treatments were continued until food and breeding sites on cotton were destroyed either by mechanical means or by cold weather; and,
(3) Defoliation and early harvest followed by stalk destruction to terminate diapause development. This was also a voluntary action on the part of the growers.

Program activities in 1972 consisted of:

(1) Pheromone traps were located in and around all fields to measure the effectiveness of action taken the previous year and to locate problem areas, which would require supplemental suppression measures;
(2) Trap crops were planted near potential hibernation sites, where diapause boll weevils were likely to emerge in the spring. These consisted of four rows of cotton planted across the field approximately two weeks before the grower planted the remainder of the field. The rationale was that weevils would colonize the older, fruiting cotton first, where they selectively could be killed with insecticides, yet restrict the treatments to only a fraction of the total field acreage;
(3) Weevils were reared in the Robert T. Gast Insect Rearing Laboratory, Starkville, Mississippi, sterilized by irradiation, and distributed over the cotton fields by aircraft. Releases were conducted during early- and mid-season. Sterile males mated with native females, thereby preventing reproduction;
(4) Insecticides were applied during the growing season when pheromone traps or visual surveys indicated a reproducing population of boll weevils in a field; and,
(5) Insecticides were applied in the fall in the fields where reproduction was occurring.

Program activities in 1973 consisted of:

(a) The same procedures used in 1972; and,

(b) Final evaluation by intensive survey by visual inspection, pheromone traps, and vacuum-type insect population samplers.

In addition to the technology described above, there was a need for a series of regulatory requirements to ensure the integrity of the trial area and that the suppression components were implemented on 100 percent of the cotton in the trial area. These regulatory requirements included the following:

(a) Authority to quarantine zones under treatment and zones where the boll weevil had been eliminated;

(b) Access and entry authority;

(c) Authority to require reporting of cotton acreage by the grower to ensure all acreage was included in the program;

(d) Authority to purchase and destroy cotton posing an undue hazard to program objectives because of difficulty in execution of the program;

(e) Authority to prohibit planting of noncommercial cotton in program operation areas; and,

(f) Authority to take necessary action to prevent volunteer cotton and alternate host plants from jeopardizing program objectives.

Funding for the trial was provided by APHIS, ARS, Cotton Incorporated, and the state of Mississippi. This trial was subjected to an intensive evaluation by: (a) the Technical Guidance Committee which had overview of all aspects of the trial during its 3-year course; and (b) a committee appointed by the Entomological Society of America.

It was recognized that this trial was located in an area of extreme boll weevil pressure and there was concern about the size of the area designed to prevent immigration of weevils from outside the area. It was known that the weevil could move up to 50 miles and in large numbers for 30 miles. The treatment series in the buffer zones was depended upon to protect the evaluation area. This did not prove to be the case, and weevils were found in the northern one-third of the eradication zone nearest to cotton outside the trial area.

Boll weevil reproduction was suppressed below detectable levels in 203 of 236 fields in the eradication zone. All of the infested fields were located in the northern one-third of the eradication zone and less than 25 miles from substantial populations farther north. In the southern two-thirds of the eradication zone no reproduction could be detected in any of the 170 fields (Committee on Appropriations, 1974).

Each of the 170 fields were regarded as a replicate. Taken together, these replicates indicated that the boll weevil suppressive system employed could eliminate isolated weevil populations and prevent reinfestation by occasional migrants. Experience with the screwworm fly convinced researchers that achievement of total elimination of all individuals from the target area following the first application of the pest suppressive system was not necessary to make a judgment on whether eradication is feasible. Eradication can be accomplished interatively. The first application of the suppressive system clears the pest from most of the target zone. Subsequently, surviving populations were delimited and suppressive measures applied to them. In this iterative fashion, the aggregate range occupied by the pest was progressively reduced toward zero.

The Technical Guidance Committee, after considerable debate, developed a report that the trial showed that it was "technically and operationally feasible to eliminate the boll weevil as an economic pest in the U.S. by the use of techniques that are environmentally acceptable." The other evaluation committee reported essentially the same. Both committees expressed reservations about initiation of a Beltwide eradication program until research led to improvement of techniques used in the trial.

The Technical Guidance Committee experienced difficulty drawing conclusions from the available data. Accordingly, the Committee stated that: "Based on the results and experiences gained in the Pilot Boll Weevil Eradication Experiment conducted in south Mississippi and adjacent areas in Alabama and Louisiana, and mindful that the experiment was conducted in an area representative of the most severe boll weevil conditions likely to be encountered in the boll weevil belt, the Technical Committee has reached the conclusion that it is technically and operationally feasible to eliminate the boll weevil as an economic pest in the United States by the use of techniques that are ecologically acceptable".

The Entomological Society of America Review Committee stated that: "Data available at the termination of the experiment indicate that eradication was not accomplished in the core area . . . The Committee is divided as to whether or not technical feasibility of eradication of boll weevil has been demonstrated, but unanimously expressed reservations concerning any massive eradication undertaking without further research to refine suppressive techniques."

The cautious position of the latter Committee may have been based in part on data provided by Hardee and Boyd (1976) indicating that 17 boll weevils had been trapped in the southern two-thirds of the eradication zone (see Perkins, 1982). However, weevils were captured during the normal F_2 emergence period. Whether they were progeny of mated females that moved into the southern two- thirds of the eradication zone from reinfested fields, or whether their parents had survived the eradicative treatments, was not ascertained.

None of the committees' reports reflected a belief that the experiment proved that eradication of boll weevil was technically and operationally feasible. Although no minority report was submitted, members of the Technical Guidance Committee were not unanimous in support of their report. Some felt that no consideration was given to the magnitude and distance the weevil was capable of moving during migration.

The major lesson learned in this experiment was that any future trials must be sufficiently isolated to prevent migration from outside the test area from confounding evaluation. Also learned was that while trap crops did aggregate large numbers of weevils early in the season, their value was questionable because of: (a) continued weevil emergence after grower cotton began fruiting; and (b) operational problems with getting them planted sufficiently in advance of normal planting operations. Most growers insisted on planting as early as weather permitted, a long-term practice to escape late-season buildup of weevil populations.

Following the completion of the experiment and evaluations, the status of the experiment was critiqued at a meeting in Memphis, Tennessee on February 13-15, 1974. The proceedings of this meeting revealed continued interest in pursuing eradication, particularly by the cotton industry. The cotton industry asked the USDA to conduct another eradication experiment because:

(1) It had not "conclusively" demonstrated the feasibility of eradication;
(2) Research findings, particularly use of the aggregation/sex pheromone in traps, must be fully utilized; and
(3) The evaluation area must be located a sufficient distance from non-test cotton to prevent weevil immigration from confounding results.

Following a series of meetings over the next year, it was decided to conduct an eradication trial with a concurrent optimum pest management trial. This decision was based on interest and willingness of the cooperating agencies and groups which would be involved in this endeavor including the USDA's ARS, APHIS, and Economic Research Service (ERS), as well as the state departments of agriculture, extension services, state experiment stations, The National Cotton Council of America, and growers in the trial areas.

It was decided to locate the eradication trial in northeastern North Carolina and southern Virginia. This was the eastern extremity of the Cotton Belt. Cotton fields outside the eradication zone were approximately 70 miles to the southwest. The area included 16,000 acres the first year and increased to 34,000 acres by the third and last year of the trial. About 20 percent of the cotton was located within the buffer zone between the evaluation zone and outside non-program cotton. The USDA's APHIS led in the eradication trial.

An areawide suppression trial was conducted simultaneously with the Eradication Trial. It, the Optimum Pest Management Trial, was located in Panola County, Mississippi; the lead agency was the Mississippi Cooperative Extension Service. The acreage of cotton ranged from 32,000 to 40,000 over the 3-year trial period. Results were compared with data collected in a conventional boll weevil control area in nearby Pontotoc County.

Grower, federal and state support was used to conduct both trials. In the eradication trial, the growers, by referendum, approved 50 percent support and mandatory participation. The states furnished 25 percent and the USDA 25 percent of the funding. The components of the Optimum Pest Management Trial included:

(1) Four fall diapause treatments at no expense to the grower;
(2) Pheromone traps to monitor populations;
(3) Pinhead square treatments in spring, if needed;
(4) Scouting of all cotton after fruiting began;
(5) In-season control by growers when economic thresholds were reached; and,
(6) Destruction of stalks when harvest was completed before frost.

The components of the Eradication Trial consisted of:

(1) Fall diapause treatments beginning when diapausing weevils were first detected and up to destruction and plowing of crop residue, with treatment intervals ranging from 7 days in September to 14 days as the weather became colder at season's end;
(2) Pheromone traps to monitor populations and determine if in-season treatments were needed;
(3) Diflubenzuron (Dimilin®) applied to pinhead square cotton as needed;
(4) Sterile weevil releases in early fruiting period;
(5) Defoliant applied to destroy food and breeding sites of the weevil prior to stalk destruction;
(6) Stalk destruction as soon as possible after harvest; and,
(7) Monitor insects (particularly the bollworm and tobacco budworm) other than boll weevil, and treat as needed.

These two trials were subjected to an in-depth biological, economic and environmental evaluation by special teams made up of members of the cooperating agencies and groups. Evaluation of both trials indicated successful demonstration of technical and operational feasibility for improving management of boll weevil through organized areawide programs without adverse effects on the environment.

The data for the eradication trial indicated eradication had been achieved by the second year of the 3-year trial. It was also found that the improved pheromone trap with the pheromone in a controlled release formulation could be used to "trap out" very low populations of boll weevil in early spring.

Carlson and Suguiyama (1985) reported on the economic returns growers could expect following eradication of boll weevil. Using four-year averages before and after eradication, pesticide costs to produce a crop decreased from $51 per acre to $17 per acre. Moreover, there was about 50 pounds of lint per acre yield increase following eradication. While difficult to quantify, environmental benefits were derived from the dramatic reduction in pesticide use in the area. This reduction in pesticide use on cotton was to some extent mirrored by a concurrent reduction in pesticide use on other crops in the area.

A review committee appointed by the National Academy of Sciences at the request of the USDA issued a report (National Academy of Sciences, 1981), which did not support the concepts of boll weevil eradication or optimum boll weevil management. Nevertheless, following the completion and evaluation of the trials, the USDA position on cotton management was given in a press release dated January 5, 1982. In part, this release stated:

(1) The technology to suppress or eradicate the boll weevil is available and further research will improve on this knowledge;
(2) The USDA holds the view that the future of cotton insect management is in the hands of the producers and the industry. Only they can determine what is best or most applicable under different sets of circumstances; and,
(3) The USDA is prepared to work closely with cotton producers and the industry in trying to achieve the most appropriate approach possible.

This in effect stated that areawide cooperative boll weevil programs in the future would have to be initiated by cotton growers. This policy was expanded to the extent that APHIS involvement in cooperative programs required passage of a referendum in which two-thirds of the growers voted for the program, and the growers must furnish 70 percent of the funding, with APHIS furnishing the remaining 30 percent.

ERADICATION PROGRAM

The eradication trial in North Carolina and Virginia was successfully completed in 1980. A containment program was conducted in 1981 and 1982 in the buffer zone to prevent reinfestation of the eradicated area during the extensive evaluation process. During this period, discussions within the cotton industry were held to determine the interest of producers in follow-up action programs against the boll weevil. As a result of these meetings, The National Cotton Council of America informed the USDA in late 1981, that producers were interested in expansion of the eradication program to include the remainder of cotton acreage in North Carolina and all of South Carolina. They also requested that APHIS organize an advisory committee to advise the industry on the feasibility and cost of such a program.

The USDA responded by arranging a public meeting in Fayetteville, North Carolina on January 15, 1982. The purpose of this meeting was to provide a forum for discussing program effectiveness, future plans, and to make the program more responsive to public needs. The persons present and statements submitted by persons in absentia supported expansion of the boll weevil eradication option to include all cotton acreage in North and South Carolina. A Technical Advisory Committee was appointed to provide a review of technology and cost estimates for the expanded program in preparation for a grower referendum.

The technical committee advised that the program could be expanded and that the cost would be approximately $100 per acre over a two and one-half year period. With this information the concerned agencies and groups entered into preparations for a grower referendum in each state. These referenda were passed in early 1983 with a program starting-date of July 1, 1983 through 1985. The passage of the referendum required two-thirds of the voters to favor the program and that all commercial cotton be included in the program. A cost share formula of 70 percent grower and 30 percent USDA participation was approved. (This cost-share formula has prevailed throughout the program to date.)

Shortly after the cotton industry met the requirements for a cooperative program, the second increment of the eradication program was expanded into the remainder of North Carolina and all of South Carolina during the period 1983 to 1985. In 1985 to 1986, eradication was expanded to include western Arizona, southern California, and northwestern Mexico. Eradication was successfully completed in these areas, and the program was expanded in 1987 into parts of Georgia, Alabama, and all of the cotton in Florida. In 1988, the remainder of the infestation in central Arizona was included, along with 5,000 acres in Mexico (Figure 1).

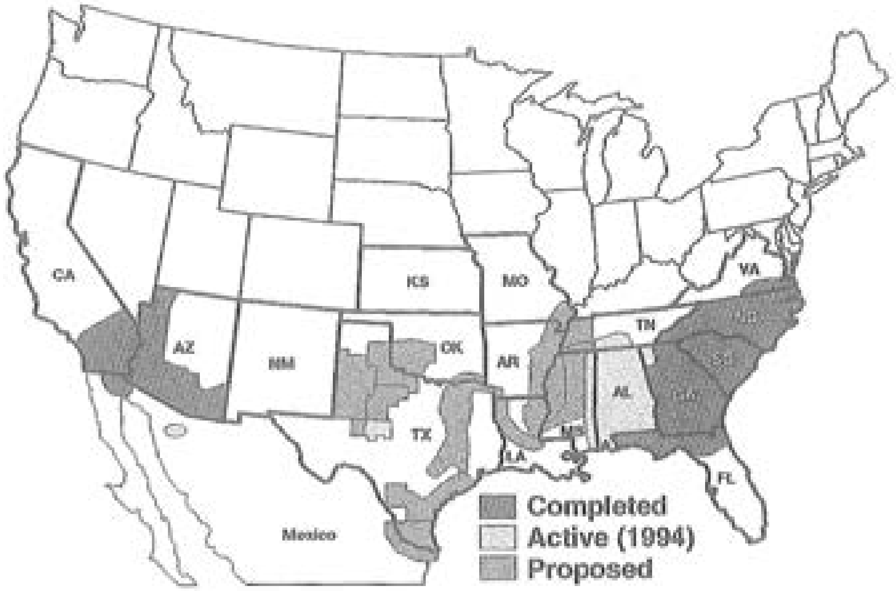

Figure 1. Increments of boll weevil eradication. Areas where boll weevil eradication is complete are heavily shaded. Areas where eradication is currently active are lightly shaded. Areas proposed for eradication (contingent on approval of grower referenda) are moderately shaded. (Figure provided courtesy of Bill Grefenstette, USDA, APHIS, PPQ, Hyattsville, Maryland.)

SOUTHEASTERN BOLL WEEVIL ERADICATION PROGRAM

The technology used in the Carolinas program was altered somewhat from that of the two trials because of experience gained and the greater magnitude of the program. Techniques used included:

(1) Growers were urged to maintain economic boll weevil control through August to lower population levels during the major diapause development period in September and October;

(2) Diapause control treatments were begun in late August and continued until cotton was destroyed;

(3) A rebate was paid to growers who met various deadline dates for stalk destruction to encourage early harvest and destruction of food and breeding sites for the boll weevil. This also led to a reduction of the acreage requiring diapause treatments;

(4) Pheromone traps were used at a rate of one trap per acre. Trap placement was oriented toward areas around fields likely to harbor diapause weevils. Data

from the traps were used to monitor progress of the program in overall population reduction and to time the initiation of pinhead square treatments wherever populations around fields indicated the likelihood that a field infestation might develop. Trapping data were used also to make decisions in treating on a field-by-field basis, and to detect early spot infestations, which could be treated and contained to prevent weevil dispersal to uninfested fields; and,

(5) Early destruction of standing cotton stalks; even when cold weather had killed them.

The program was initiated July 1, 1983 and included all of the cotton acreage in North and South Carolina infested by the boll weevil. This amounted to about 95,000 acres and included the buffer zone and southern portions of the original eradication trial area where immigration had occurred (Figure 1). During the six weeks between July 1 and mid-August, personnel were hired, equipment was purchased, fields were mapped, traps placed, and other logistical operations were readied for the start of the diapause control phase of the program. Practically all personnel were new to the operation, requiring intensive training.

Diapause treatments were begun on August 22, about two weeks before the projected starting date. This early start was necessary because the cotton was in severe drought stress and boll weevil diapause and migration were beginning earlier than normal. Diapause treatments were made at 5-, 7-, and 10-day intervals as the season progressed and weather became cooler. Traps were placed at approximately one per ten acres of cotton to monitor weevil populations during the fall diapause treatment phase.

The first plant-killing frost occurred in mid-November, about two weeks later than the average frost date for the area. Thus, the early start and late completion resulted in about four more treatments for diapause control than estimated earlier. A total of 11 to 13 treatments were made during the August 22 to mid-November period.

Excellent weather prevailed during the diapause treatment period, and treatments were on schedule. Trap records indicated a population reduction in excess of 90 percent in most fields. More importantly, the treatment interval was such that all weevils were subjected to two treatments before they had time to complete feeding and enter diapause. Also, the traps indicated the fields where control was less than desired. Special attention was given to these fields the following year. Such fields were small in size (up to 10 acres) and typically had obstacles interfering with aerial application. Border treatments with mist blowers were made, but these trouble spots persisted. In 1984, ground application was utilized in these sites to the extent possible.

During 1984, fields were trapped at the rate of one or more traps per acre of cotton. Acreage in the program area in 1984 was about 145 thousand acres. Traps were placed around 1983 production year fields in April and serviced until July. Traps were placed in new 1984 production year fields in June. All cotton fields were monitored at this trapping rate until the cotton was killed by frost in early November.

Data collected from the traps were used to determine control measures during the 1984 season. Three periods during the year are identified, and criteria for control measures were developed as follows:

(1) Early season or pinhead square stage of growth. This included the period from just before squares were large enough for oviposition (mid-June) to early July. This was the last chance to attack the surviving diapause population of the previous year. About 25 percent of the acres were estimated to require some control during this period. Eighteen percent of the acres were treated using the following criteria, based on trap catches three to four weeks prior to the eighth leaf stage: (a) 0 to 0.1 weevils per acre (up to 1 weevil per 10 acres of cotton) - no treatment - depend on traps to eliminate (trap out) the low population; and (b) 0.2 or more (2 or more weevils per 10 acres) - treat with diflubenzuron (Dimilin®) or organophosphate insecticide at seven-day intervals until trap catches were below the "trigger" level.

(2) In-season. This covered the period from early July to September. During this period, searches were made for reproducing aggregations of weevils. This was expected to occur either from weevils missed in the early season control period or from the few diapause weevils still emerging from hibernation quarters. Because some diapause weevils emerged into late August when abundant fruit was available, reproduction was expected. The strategy during this period was to locate areas of reproduction and treat them with insecticide to prevent further geographic expansion. The goal was not to eliminate these aggregations of weevils during the mid-season, but to contain them within a local area so they could be targeted as a diapause population later in the fall. During the period of July to early August when an occasional weevil was caught in a trap, the immediate area was visually surveyed to determine if reproduction had occurred. In August, as reproduction sites were found, they were treated at four to five day intervals. In all cases, the area of reproduction was localized to one to two acres and appeared to be the progeny of a single female. Accordingly, treatment was made to a localized area of five to ten acres from criteria used to initiate in-season treatments. These treatments were highly effective in containing weevils in localized areas until late September when defoliation began.

(3) Diapause Control. This covered the period of September 10 to frost on November 9-10. This was about three weeks later than diapause initiation in 1983. The reasons include the fact that it was a wet season with plenty of fruiting into September, very few weevils could be found and dissection of collected weevils indicated no evidence of diapause development until cotton began to "cut-out" in mid-September. Treatment during this period differed from the in-season regimen primarily in that buffer fields up to one mile from the reproduction site (based upon the numbers caught in traps) were treated. This was necessary to prevent weevils from the reproduction site from dispersing into nearby fields and attaining diapause status. Diapause treatments were made at seven to ten-day intervals from September 10 until a killing frost on November 9-10.

It was estimated that ten percent of the acreage would require diapause treatment in the fall of 1984. This estimate was considerably lower than actual treatments. On

September 10, when diapause treatments began, the in-season acreage being treated, plus buffer fields around these areas, amounted to approximately 20 percent of the program acres. The continued boll weevil dispersal during September and October resulted in a weekly increase of acreage treated to approximately 60 percent by November 10.

Based upon trap captures, boll weevil reproduction was estimated as occurring in less than five percent of the fields by September 1. By October 1, this infestation of fields had reached 21 percent. Also, during September, small terminal bolls were infested in these localized infestations as squaring decreased with crop termination. These weevils which were developing prior to October 1 were of great concern. A boll weevil egg deposited after October 1 would not have time to develop and attain diapause condition before the food supply was destroyed. Migration became more evident during late September and early October because crop termination and defoliation practically eliminated fruiting forms suitable for weevil food and reproduction. All diapause treatments during this period were to localized infested areas. It was decided to treat the total acreage once in mid-October, even fields where no weevils had been trapped, to prevent diapause development of scattered weevils on the sparse food available. Following this overall treatment, only the localized populations which were identified, were treated. The first crop year (1984) is summarized as follows:

(1) Data developed from trapping records indicated that only 0.45 percent as many weevils per trap were captured in the spring of 1984 as were captured in the fall of 1983 in the eradication area. This compares favorably with the level of suppression obtained in the eradication trial. All indications were that the diapause program in 1983 and natural mortality during winter, and pinhead square treatments in spring resulted in a population suppression in excess of 99 percent;

(2) No reproduction was detected (intensive trap and visual survey) until August 1984;

(3) Even with the late season buildup and spread of weevils, trap captures were zero for many fields. On September 9, 63 percent (2,706) of the fields showed no evidence of boll weevils. On October 9, 31 percent (1,344) of the fields showed no evidence of weevils and by the time of frost (November 9) 23 percent of the fields were free of weevils; and,

(4) In 1984, the surviving population was aggressively attacked in early- and mid-season and in the diapause period. This was a tighter and more intensive program than in 1983, primarily because personnel were better trained, understood the program better, and had more interest in doing the job correctly.

In 1985, the same procedures were employed as in 1984 and the program was successfully completed. Eradication was achieved with the exception of a few scattered fields in the eradication area and the buffer zone (between South Carolina and Georgia outside the program area). These populations were routinely treated during the holding period until the next increment of the program could be initiated.

During 1986 to 1987, the cotton industry worked with growers in Georgia, Florida and portions of Alabama to expand the program. The necessary referenda were passed by the growers and the program began with the initiation of the fall diapause treatments in early September 1987, and continued on the same acreage into December, depending on the condition of the cotton. All cotton containing fruiting forms suitable for food for diapause development was treated in this phase of the program, since boll weevils were present in all fields. The program acreage in this phase was approximately 400,000 acres and the treatments averaged slightly over eight treatments per acre. The treatment interval increased as the season progressed. There was a 5-day interval between the first two treatments in September and it was expanded to 7-day intervals in late September and most of October. A 10-day interval was used in late October until mid-November followed by 14-day intervals into December. The rationale for these expanded treatment intervals was as follows:

(1) The objective was to destroy incipient diapausing boll weevils in the field before they attained firm diapause and left the field for overwintering quarters;

(2) Data showed that most boll weevils which survived the winter go into diapause during late September and October; and,

(3) As the season progresses in the fall, the cooler weather and deteriorating food supply increased the time required for boll weevils to attain firm diapause.

The bid for the chemical for the diapause program was won by Mobay Chemical Corporation (now Bayer) and azinphosmethyl (Guthion®) was used. The use of this chemical caused considerable controversy, even though it often was used routinely by many growers for in-season control programs.

The fall diapause control program can be characterized by the following:

(1) Treatment schedules were met satisfactorily due to excellent weather during the fall;

(2) The new operational team was necessarily recruited on short notice and training was less than desirable;

(3) Adequate equipment for field border treatments was not available until near the end of the program because of delivery delays;

(4) Lack of field border treatments in much of the area was further magnified by constraints placed upon the program by the Environmental Assessment, which set up buffer zones around sensitive areas that could not be treated by aircraft. This resulted in many field borders not being treated properly;

(5) During 1987, substantial amounts of the cotton were planted late, resulting in early planted cotton, which had terminated and was opening, alongside late-planted fields which were fruiting vigorously in September. The late-planted cotton produced large populations of boll weevils late into the season; and,

(6) Overwintering boll weevils continued to emerge for about a month later than usual. In isolated cotton fields not planted in 1988, weevils continued to emerge in large numbers until well into July. This placed severe pressure on the pinhead square phase of the program. It was estimated that peak emergence occurred at least three weeks later than usual.

Therefore, even though problems were experienced resulting in a surviving diapause population greater than in previous program years, results were acceptable. This was borne out by 1978 trap captures, where some historical trap data were available. In fact, it was well into the growing season (July and August) before growers detected boll weevils in their fields.

The first crop year (1988) was divided into three periods based upon the strategy to be employed. These were the (a) pinhead square stage in early season; (b) the mid-season containment stage; and (c) the fall diapause stage which extends to the end of the crop year, when food and breeding sites are destroyed. These periods were approximate and vary from area to area.

All treatments during these three phases were based upon the trap data from individual fields. No areawide or automatic treatments were made except in the buffer zone adjacent to cotton outside the program area during the fall diapause phase.

Treatments were based upon the numbers of boll weevils caught in traps around each field. A field was designated as up to 40 acres in size. Approximately one trap per acre trapping density was used with traps arrayed around field borders with more used near suspected hibernation sites. The number of boll weevils trapped to "trigger" insecticide treatment varied with the phase of the program.

(1) Pinhead Square Phase. This was the last opportunity to destroy the overwintering population and the success was dependent upon the precision of the trapping effort. A trap catch (all traps around a field) of two to three weevils triggered treatment. Two treatments were made at 7-day intervals beginning at the eight-leaf stage of cotton development. If the trap captures continued to trigger treatments, treatments continued until trap captures were below the trigger level. This situation occurred in many fields due to the prolonged emergence of the 1987 diapause population.

(2) Mid-season Containment Phase. Treatments made in this phase (July and August) were designed to prevent boll weevil spread from isolated, established population to adjacent uninfested fields, and to prevent population buildup in mid-season causing economic loss to growers. The trap capture per field to trigger treatment was five boll weevils per field. Fields were treated on 7-day intervals. Again the attempt was not to eradicate during mid-season but to trigger treatments at a very low level to contain them to the infested field. If trap captures began to increase, the interval between treatments was shortened to five days and, in a few cases, to three days.

(3) Fall Diapause Phase. By this time of the season, boll weevil migration had begun from the earlier fields which were nearing harvest. Movement of migrating weevils occurred from fields at the time of defoliation, harvest, and again during stalk destruction. These migrating populations were not of serious consequence, particularly during November and later. The main diapause population develops in late September and October and primarily in fields where populations developed during mid-season. Because this was the phase of most concern, the "trigger" for treatment was set at 10 weevils per field. Also, the treatment interval was gradually increased (14 to 21 days) as the season progressed.

During the course of the 1988 season, the program area consisted of 473,000 acres of cotton. These fields were treated on a field-by-field basis according to the trap capture trigger cited above. Average applications per acre ranged from 3.8 in the South Carolina buffer zone to 11.2 in the Eufaula, Alabama area. For the program as a whole, an average of 8.6 applications per acre were made through October 29, 1988. This was more than anticipated but it was felt necessary to compensate for the less than ideal fall diapause program in 1987 and the emergence pattern of the 1988 overwintering population. No "firm" diapause boll weevils were found from samples dissected that fall. The first crop year of the program appeared to be on schedule.

SOUTHWESTERN BOLL WEEVIL ERADICATION PROGRAM

A major difference between the Southeastern and Southwestern Eradication Programs was that the areawide fall diapause phase conducted as the first step in the Southeast was not done in the Southwest. This in effect eliminated one-half year of the program, except for cultural control measures. Elimination of the areawide diapause treatments to begin the program was adopted in the successful 1985 to 1986 program, and was used in the 1988 to 1989 program to complete the eradication in the southwestern United States.

Two basic reasons led to the elimination of the initial, areawide diapause treatments for the southwestern program. First, trap surveys before program commencement revealed that while boll weevils were widespread and found in most fields in the fall after migration began, they were found in the spring in localized areas near suitable hibernation sites. These sites included embankments by rivers and base irrigation canals as well as residential areas near cotton fields. Secondly, boll weevil populations (with some exceptions) were relatively low in the spring compared to those in fields in the southeastern United States.

It was deemed reasonable to conduct the program in the first increment in 1985 to 1986 and not have to treat more than 20 percent of the acreage, even though some of that acreage would need several treatments. This proved to be the case with the following strategy based upon trap capture of boll weevils:

(1) Begin 7-day interval pinhead square treatments at the 8-leaf stage of cotton, where two to three boll weevils have been captured. This treatment interval was continued until spring emergence of the weevil was complete. This treatment regimen greatly reduced reproducing populations in the field;

(2) Mid-season treatments at 7-day intervals where infestations did develop, were "triggered" by five boll weevils captured in traps. This prevented dispersal into uninfested, nearby fields (containment) and prevented economic loss to growers; and,

(3) Diapause treatments in the fall at 7- to 21-day intervals, triggered by 10 boll weevils trapped per field. This was designed to reduce the potential overwintering diapause populations.

This approach worked well in the 1985 to 1986 increment and continued to work well during the 1988 to 1989 program. This program encompassed 380,000 acres of cotton. During the year, 875,000 cumulative acres were treated for an average of 2.3

treatments per acre. Obviously, this approach has resulted in great savings in the cost of the program. Only areas where weevils are found are treated with insecticide. This was, in part, made possible by the highly effective pheromone trap.

The Southwestern Eradication Program was on schedule for the first year, even though some localized problems were encountered in Pima cotton. In 1991, only 56 weevils had been captured as of October and only 798 cumulative acres had been treated.

CURRENT STATUS OF BOLL WEEVIL ERADICATION PROGRAMS

By 1993, boll weevil eradication had been achieved in the western portion of the Cotton Belt, including California, Arizona and Northwest Mexico. Also eradicated in the southeastern portion of the Cotton Belt were populations in Virginia, North Carolina and South Carolina (Figure 1). The areas in Georgia, Alabama and Florida shown in Figure 1 had been eradicated with the exception of less than 1 percent of the acreage. These localized spots were included in the surveillance area and are expected to be cleared up in the near future. Also, some reinvasion has occurred in the buffer zone in the eradication areas adjacent to the outside areas not included in the program at present.

An occasional boll weevil has been found in the eradicated areas. Intensive trapping and visual surveys indicate these are "hitch hikers" and are not progeny of local reproducing populations. These isolated detections are always found and in greater numbers in those areas closer to outside untreated infestations.

The buffer zones between the eradication increment and outside increment are necessary to prevent reinvasion of the eradicated areas. These zones extend from 20 to 40 miles of cotton inside the eradicated increment. These zones must receive the eradication operations during the additions of new increments as the program expands.

There is also a network of traps in a surveillance program for all acreage of cotton which has been eradicated. The number of traps in the surveillance program varies downward in number per acre of cotton as the distance from established weevil populations increases.

It has been possible to reduce the amount of pesticides to produce cotton by 50 to 90 percent in the eradicated areas. Also, there is evidence of increased cotton yields in the boll weevil eradicated areas. These benefits have resulted from two primary events: (a) the ability to rely to a greater extent on enhanced beneficial arthropods populations for control of secondary pests of cotton in the absence of boll weevil treatments; and (b) an increase in cotton yields due to the absence of boll weevils, even though effective chemicals for control of boll weevil are available and are used by growers (Carlson & Suguiyama, 1985).

It is expected that this eradication program will continue to expand to include the entire Cotton Belt of the United States and adjacent areas of Mexico. This assumption is based upon: (a) The success of the program in the most difficult boll weevil areas of the Southeast; and (b) the increasing interest and action of cotton producers in the currently infested areas.

SUGGESTED PLAN FOR ERADICATION IN THE REMAINDER OF THE COTTON BELT

It is proposed that, in future expansions of the eradication program, the areawide fall diapause phase should be eliminated, except where trap surveys indicate a need. The diapause treatments will still be made on a selective basis during the two full crop years of the program. In this scheme, data collected during the season will be the basis for treatment of any field. It is expected that localized, high populations will be encountered in all areas. This was the case in the southwestern United States program.

This change in program strategy can and should be done for the following reasons:

(1) Weevils were successfully eradicated in the Southwest without using the areawide fall diapause treatments at the beginning of the program;

(2) Suppression measures of populations at their source protects these areas until late season when a selective diapause program was conducted;

(3) This places major program actions in the field when growers traditionally fight boll weevil, resulting in immediate benefits to the growers; and,

(4) The Southwestern Eradication Program cost less than in the Southeastern.

The period of program action covered two and one-half years in each increment. Other potential eradication areas more closely resemble the Southwestern Eradication Program. The sequence of Program actions are projected, as follows:

(1) Extension services in the states involved should conduct an extensive information and education program on all aspects of the program and how they fit into the scheme of eradication. Emphasis should be placed upon those actions the grower can do to make eradication programs more efficient. These include such things as early harvest and stalk destruction and locating cotton fields, to the extent possible, away from environmentally-sensitive sites (ponds, streams, dwellings, near wildlife refuges, schools, and obstacles interfering with aerial and ground treatments).

(2) The period July 1 to January 1 of the first one-half year should be used for program preparation. Inadequate time for organizational and logistical matters has been a major problem in all previous programs. This period should be used for such actions as field mapping, moving key personnel into the area, survey trapping and personnel training. Program personnel should monitor stalk destruction and certify fields meeting the requirements for a rebate.

(3) The first full year of the program should begin January 1. Such activities as hiring local personnel for area and work unit supervisors, trappers and personnel training should be conducted pre-planting.

(4) Pre-crop infestation activities should include mapping of rotation fields, placement of traps around fields and commencement of trapping.

(5) Activities in early season, and in some cases mid season, primarily should be concerned with trapping and field treatments where trap data indicate necessity. Early season or "pinhead square" treatments should be more extensive than conventional pinhead square treatments. This should be the first attack on the dia-

pause weevil population, except for the cultural measures made the previous fall and selective diapause treatments. It is designed to prevent the overwintering weevils from becoming established. Criteria for numbers of weevils caught in traps around each field will "trigger" treatments. Once triggered, fields should be treated twice on a 7-day interval; treatment should continue until weevil trap captures decrease below the "trigger" level. Thus, since no areawide fall diapause treatments are conducted initially, many fields may require two to four or more treatments.

(6) During July and August, the "containment" or "mid-season" phase of the program begins. This phase is designed to prevent population buildup and movement of weevils, which earlier evaded control measures. Again, the objective is not to eradicate the population at this phase; populations should be contained in identified fields and these weevil populations treated during the diapause phase to attain eradication. Thus, this phase of the program is designed to prevent population spread into uninfested fields and to prevent economic damage to growers' crops.

(7) From late season until harvest represents the "diapause" phase of the program. Weevils begin to disperse when cotton begins to "cut-out", and defoliation, harvest, and stalk destruction is conducted. Criteria are based upon trap captures allowing selective treatment of those fields which are most likely to produce diapausing weevils. These will be primarily those fields in which reproduction occurred during mid-season and those that earlier had migrating populations. Also, the suppression measures taken earlier in the year greatly reduce the diapause population merely by the reduction in overall weevil population.

(8) The second crop year should be the same as the first crop year and the program should have covered a period of two and one-half years.

(9) In mid-season of the second crop year, key personnel should begin the preparations described above for moving into a new increment.

CONCLUDING COMMENTS ON THE FUNDAMENTAL PRINCIPLES OF BOLL WEEVIL POPULATION SUPPRESSION

The ability to eradicate isolated boll weevil populations has been amply demonstrated in the several trial and operational programs that have been discussed. Advocates of boll weevil eradication from specific areas as a viable option for dealing with this costly and ecologically disruptive pest fully appreciate, however, that eradication programs are difficult and demanding undertakings. Programs must be well organized and executed by persons who understand the pest, the technology, and the basic principles of pest population suppression. Complete cooperation of all growers is essential. The suppression measures must be directed against total populations in areas large enough to virtually eliminate normal boll weevil dispersal as a major deterrent to success. The movement of boll weevils from high density populations within flight range of areas under eradication heretofore has been a major problem in the execution of experimental and operational programs.

When total populations consist of billions of boll weevils, it may seem technically and operationally unfeasible to eliminate the last reproducing insects. In practice, however, weevil numbers are finite, ranging from less than one to a few thousand per acre. By taking full advantage of the fundamental principles of insect population suppression and natural control factors, populations can systematically be reduced to zero on a field-by-field basis.

The availability of grandlure, the highly effective boll weevil attractant, is a vital component of available boll weevil eradication technology. When populations have been reduced to near elimination in cotton fields, the use of survey traps makes it possible to determine where localized populations have been eradicated or where populations continue to exist. The use of the traps also contributes to further suppression.

As noted earlier, it is not necessary that suppressive measures be applied with such intensity that complete elimination of the populations be achieved during a single generation or even during a single season. Instead, if populations in all cotton fields are attacked in a systematic manner, taking full advantage of the knowledge gained on the biology, behavior and dynamics of the boll weevil, it is possible to eliminate populations largely by attrition. As pointed out by Knipling (1979), moderate suppressive procedures (i.e., 90 percent or better) applied against total populations for several successive generations reduces the surviving insects to a lower level in a pest ecosystem than intensive control efforts that result in near 100 percent kill of the insects each cycle in 99 percent of the habitats, if the insects in the remaining one percent of the habitats are permitted to develop in the normal manner.

Natural control factors make major contributions to boll weevil eradication. The boll weevil has the potential of increasing from overwintering populations numbering as few as 10 to 100 per acre to 1000s per acre during a single cotton growing season. However, the weevil is highly vulnerable to natural hazards from the termination of one growing season to the beginning of the next season in areas where cotton is not permitted to grow during the winter. Weevil mortality during the winter in most areas is typically about 95 percent or higher. Natural mortality due to such factors as severe winters, unfavorable hibernating sites, general predation and agricultural practices act largely independent of the boll weevil density.

In view of the significance of moderate but uniform suppression pressure during the growing season and natural mortality between seasons, a series of simple population models are presented in Table 1. These depict, in numerical terms, boll weevil population trends from different numbers per acre, if merely enough suppressive pressure is applied to prevent increases in the boll weevil populations during the growing season. It is essential, however, that all cotton fields be monitored and that suppressive pressures be applied as needed to achieve the objective. The technology and knowledge are available to accomplish the objective. It is largely a matter of applying available technology in the most expeditious manner.

Table 1. The contribution that natural winter mortality can make to boll weevil eradication. Enough control is achieved in all fields during the growing season to prevent increases of overwintered boll weevil populations.[1]

Parameters (one acre)	High density areas[2]			Moderate density areas[2]			Low density areas[3]		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Overwintered boll weevils	1,000	50	2.5	200	10	0.5	20	1	
Population at the end of the growing season	1,000	50	2.5	200	10		20	1	
Precent natural mortality before the next season	95	95	95	95	95		95	95	
Overwintered boll weevils the next year	50	2.5	.125	10	.5		1	.05	

[1]When populations decline to very low levels, several options for further suppression can be employed, including the release of sterile boll weevils. However, the use of pheromone traps will not only identify where reproduction is likely to occur, the traps contribute to further control.

[2]Grower practices for boll weevil control are generally based on the application of control measures as needed to permit optimum cotton yields at minimum costs. This practice, however, permits enough boll weevils to reproduce after the main crop matures to result in comparable overwintered populations each year. For eradication, the minimum objective would be to prevent an increase in populations in all fields until the end of the cotton growing season.

[3]In low density areas, severe winter weather and/or limited favorable hibernating habitats are likely to result in much higher than 95 percent mortality.

In many cotton growing areas, unfavorable hibernation sites and/or adverse winter climate reduce diapause weevil populations to very low levels. Most of the survivors are likely to be concentrated near the most favorable overwintering habitats. Control measures involving several early season treatments, limited in-season treatments, or timely diapause applications in the most critical areas may result in near elimination after one year, if migrating boll weevils from high density populations are avoided. Even in high boll weevil density areas, populations will decline to near elimination within two to three years by applying minimal but consistent suppression during the growing season and relying on natural control during the winter months. On the other hand, cultural control tactics, such as stalk destruction and plowdown of cotton stalks after harvest will have to be relied upon in South Texas, since overwintering weevil adults are not exposed typically to freezing temperatures.

The boll weevil exists under a wide range of ecological conditions. Cotton growing practices vary. The basic approach to eradication may differ depending on the behavior of the pest, the conditions under which it exists, and the experience gained as programs are executed. But in all areas it is essential that suppressive measures be directed against total populations in an organized and coordinated manner and in areas large enough to minimize the influence of boll weevil movement. The boll weevil continues to thrive as a costly and ecologically disruptive pest in many areas. This condition exists not because of the absence of suitable suppression technology, but rather because of failure to apply sound principles of boll weevil population suppression in a fully coordinated and systematic manner.

SECTION V

IMPLEMENTATION OF INSECT AND MITE PEST MANAGEMENT PROGRAMS

Chapter 20

INSECT AND MITE PEST MANAGEMENT IN THE SOUTHEAST

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INTRODUCTION

The economy, indeed the history, of the Southeast (Alabama, Florida, Georgia, North Carolina, South Carolina and Virginia) has been intimately tied to the production of cotton. Insects and mites have been major factors affecting the success of cotton culture, and as such, have influenced the history of the region.

Although wild cottons were discovered in 1528 growing in the territory that is now the states of Louisiana and Texas, the first commercial United States production occurred in the Jamestown settlement of Virginia in approximately 1621. North Carolina traces its cotton production back to 1664 when colonists from Barbados planted cottonseed at Cape Fear. South Carolina started producing cotton early in its colonial history, and became an early exporter, shipping the first boatload from Charleston in 1754. Cotton was soon produced in every county, and until 1825, South Carolina was the leading cotton-producing state (Frank, 1985).

Georgia's cotton history parallels that of other southeastern states. The first cotton in Georgia was grown in Trustees Garden, Savannah, in 1733. Cultivated commercial cotton was introduced in 1734 by Philip Miller. Seven years later, a sample of Georgia grown cotton was sent to England where it became known as "Georgia Cotton" and in France, as "Sea Island Cotton." Until slavery was allowed in the Georgia Colony in 1749, most cotton was consumed domestically. But with the advent of slave labor, production increased and cotton became a major export (Linden, 1954). By 1825, Georgia passed South Carolina as the nation's leading producer. Production increased in Georgia until 1911 when nearly five million acres were planted to cotton.

Florida, historically, has never been a major producer of cotton, although cotton was cultivated as early as 1765 along the St. Johns River. Alabama traces its cotton production back to pre-Revolutionary War years when cotton was planted along the Tensas and Tombigbee Rivers and in French settlements near Mobile. Cotton acreage increased until Alabama rivaled Mississippi in production by 1840 (Frank, 1985).

The boll weevil entered the United States from Mexico in 1892, and spread at the rate of 40 to 160 miles per year entering Alabama about 1910 (Howard, 1895; Gaines, 1952; Metcalf *et al.*, 1962). The boll weevil invaded Georgia in 1916, and by 1923 was causing considerable damage. Yield dropped to 90 pounds per acre in 1921 in Georgia compared to 314 pounds in North Carolina, a state only lightly infested at that time (Brown, 1938).

Although many factors were involved, a single insect pest, the boll weevil, contributed significantly to the decline of cotton in the Southeast. Georgia, for example, grew five million acres in 1911, prior to infestation by the pest. By 1978, only 115,000 acres were devoted to the crop (Snipes and Hammer, 1984). But improved pest management practices in the late 1970s and 1980s—including the use of pyrethroids, faster fruiting cotton varieties and production practices designed to shorten the fruiting season—stimulated new interest in cotton. Elimination of the boll weevil contributed to increased plantings in the Carolinas in the early- to mid-1980s, and increasing yields and improved profitability caused Georgia's acreage to triple by the late 1980s.

The Southeast is in a transition period because of the boll weevil eradication program. Elimination of the boll weevil has been and will continue to be the dominant factor determining overall cotton insect management strategies. This chapter traces cotton insect control technology from the early 1900s through the 1980s, and emphasizes the role of the boll weevil and eradication efforts now and in the future. The authors hope that our experience may serve as a guide to those who may yet become involved in similar eradication programs and the changes they inevitably cause.

EVOLUTION OF CONTROL TECHNOLOGY

EARLY CONTROL EFFORTS

Cotton insect control really began in the Southeast with the arrival of the boll weevil into southwestern Alabama in 1909. By this time reports indicated that the boll weevil was already causing at least $200 million in damage annually in the remainder of the United States. Within nine years the weevil had completed its trek across

Alabama and was advancing through Georgia and into the Carolinas. By 1922 the weevil had infested the entire cotton producing area of the eastern United States.

All this took place despite monumental efforts by farm leaders of that day to halt the weevil's advance. Yet, the transition from quarantines to mechanical and cultural devices to poisons is a dramatic story that involved entomologists, agronomists, chemists and engineers.

The first move by Alabama was passage of a quarantine law in 1903. It was intended to prevent the weevil from hitching rides to fresh territory in seed cotton, old pick sacks, cottonseed, Spanish moss, and even household goods. Transport of such items from infested to weevil-free territory was prohibited.

But the weevil was no respecter of law. Under favorable weather conditions it enveloped 75 to 100 mile strips of "new territory" in a year.

Forefront in the fight were farmers, bankers, businessmen and personnel of the Alabama Polytechnic Institute's Agricultural Experiment Station. Beginning in 1904, the Alabama Station produced many publications concerning the boll weevil, methods of combating the pest and even one on "Heading Off Boll Weevil Panic".

With no known insecticide effective against the weevil, the logical attack was to cut off its food supply. Destruction of green cotton at least three to four weeks before usual killing frost was recommended. This was said to be the most important single step in a cultural system under boll weevil conditions. There were those that predicted that in the presence of weevils there could never be late-cotton. In addition to planting early, various mechanical contraptions were devised. Two such devices used were chain drags to sweep fallen, infested squares into middles for exposure to the hot sun; and a long sack fastened to a sugar-barrel hoop for collecting overwintered weevils and infested squares on young cotton.

Before the boll weevil migrated across the Rio Grande River into Texas in 1892, very little insect and spider mite damage occurred to cotton. Occasionally there would be outbreaks of armyworm or the cotton leafworm (many current growers, consultants and entomologists have never seen these pests). The arsenical insecticides were about all that was available to control these pests. These insecticides were commonly known as Paris Green, London Purple, lead arsenate and calcium arsenate. Another sporadic pest was the cotton aphid. Nicotine sulfate dust was sometimes used to control this insect. Buildups of aphids occurred as far back as the late 1800s when weather conditions were abnormal or when the good and harmful insects got out of balance.

However, the boll weevil changed much of this balance since it had few natural enemies. It has been very difficult to profitably produce cotton in the United States with a natural biological balance since the invasion of the weevil. Once insecticides were used for weevils, artificial man-made balances between insects in cotton fields were established.

THE ARSENICAL ERA

The first insecticide recommended for controlling the boll weevil was a mixture using Paris Green, London Purple or lead arsenate in combination with molasses.

These combinations were used in the late 1800s and early 1900s. Lack of adequate formulations and application technologies were major problems with these insecticides.

The first Alabama experiments involving calcium arsenate were in 1918 at Auburn, Hartford and Smyrna, Alabama. In 1923, improved weevil control was obtained by applying undiluted calcium arsenate dust by airplane. This technique had been used the previous year to control the cotton leafworm. Dusting with calcium arsenate from airplanes proved to be very successful in Georgia and Texas during the period 1925 to 1927. Aerial dusting became the primary method of applying insecticides for the boll weevil on large acreages of cotton until the early 1950s. Between 1919 and 1925, the use of calcium arsenate increased from 3 million to 15 million pounds. This is in sharp contrast with today's rates of pyrethroids where both weevils and bollworms can be controlled on many acres within the Cotton Belt with less than one pound of insecticide per acre per season. The production of calcium arsenate had increased to 84 million pounds by 1942. During the period from 1919 to 1948, it has been estimated that United States cotton fields received a total of about 850 million pounds of calcium arsenate.

Unfortunately, calcium arsenate was toxic to the beneficial insects which served as enemies for the cotton aphid. As a result the aphid became a serious problem and nicotine sulfate had to be added to the arsenical dust. About one million pounds of nicotine sulfate were produced between 1928 and 1940. Most of this was used on cotton and by 1945 growers were applying about 1.5 million pounds annually. It was during this period that the bollworm became a significant pest of cotton. As was the case with the cotton aphid, this was caused by the destruction of the beneficial insects by calcium arsenate. However, adequate control of the bollworm was maintained because the larvae were fairly susceptible to calcium arsenate.

Calcium arsenate also had an effect on the natural enemies of the cotton fleahopper and the tarnished plant bug, and sulfur dusts were added to control these pests and outbreaks of "red" spider mites. However, during the arsenical era of cotton insect control, most insecticides were applied for the boll weevil.

ARRIVAL OF ORGANIC INSECTICIDES

Calcium arsenate was to remain for almost 30 years as the standard insecticide for boll weevil control. Following World War II came new organic compounds—the chlorinated hydrocarbons (DDT, BHC, toxaphene, heptachlor, dieldrin and endrin) and the organic phosphates (parathion, malathion, methyl-parathion, and Guthion®).

Control of the boll weevil and other cotton pests shifted from an ecological (management) or cultural to a chemical approach. However, over the following ten to fifteen years, problems developed such as insecticide resistance, secondary pest outbreaks, environmental damage and increased insect control costs.

Chlorinated Hydrocarbons — In 1945 the chlorinated hydrocarbon (or organochlorine) insecticide DDT became available for grower use. DDT brought about a revolution in cotton insect control. DDT was a long-lasting contact insecticide which was oil-soluble and could be applied as a spray. Applications by plane with low volume sprays almost totally replaced dust applications. Later BHC and toxaphene also became widely used cotton insecticides. They were followed by aldrin, dieldrin, endrin, heptachlor and DDD (TDE).

The United States production of DDT increased to 164 million pounds by 1960. In addition, almost 200 million pounds of BHC and aldrin-toxaphene were being used annually by 1960. Some estimates indicate that up to one-third of all the organochlorine insecticides produced between 1945 and 1960 were applied to cotton.

These insecticides provided two important advantages. First, they were highly effective against a wide variety of pests. Second, they were very persistent or had long residual pesticidal activity which made it possible to control newly emerging insects or insects migrating into treated areas.

Spectacular yield increases were obtained for many years, and growers were producing cotton at a high profit level. At this time it appeared that all our cotton pest problems were solved forever. However, these insecticides also killed the parasites and predators of the damaging cotton insects and often resulted in "red" spider mite buildups. In addition, environmental problems began developing. This long residual activity also proved to be a disadvantage. Some of these insecticides were also shown to build up or magnify as they passed up food chains to higher animals.

Most growers know the "rest of the story" about the DDT related insecticides. All are now gone as insecticides in United States agricultural production. Perhaps the evidence against them was not always presented accurately, but that is all history now.

Organic Phosphates — In 1955, boll weevil resistance to DDT, toxaphene, endrin and related compounds was discovered. This resulted in a gradual but significant shift to organophosphorus insecticides such as parathion, methyl-parathion, Guthion®, malathion and EPN.

These materials were effective against the boll weevil at lower rates than the DDT-related chemicals. However, the parathions were not as effective in controlling bollworms and tobacco budworms, which became major pests about that time.

To control all the major pests, growers then began applying mixtures of DDT, toxaphene, endrin, methyl parathion, Guthion®, malathion, and EPN. Many can still remember the old days when the standard insecticide was 4-2-1 (toxaphene, DDT and methyl parathion). It was used at one gallon per two acres.

At first these mixtures gave good control of boll weevils, bollworms and budworms, aphids, fleahoppers, plant bugs, armyworms and spider mites. During this period of the late 1950s growers expected, and essentially obtained, cotton fields that were sterile of all insects.

SCOUTING AND IPM

Cotton "scouting" began in the late 1950s in the Southeast. Arkansas and Mississippi in the Mid-South and Alabama in the Southeast were the first three southern states to train and promote extension scouts to growers. In Alabama, for example, one scout was employed in 1959 and the program expanded slowly through the 1960s. By 1968, 26 scouts were employed and the number increased to 87 in 1972, the first year of the intensified scout promotion that was to usher in the decade of the 1970s. Between 1972 and 1987, over 4,000 persons attended scout training shortcourses in Alabama alone. In recent years over 95 percent of all cotton acres in Alabama have been scouted by extension service trained scouts, private consultants or trained growers. Other southeastern states have followed similar patterns.

In the late 1960s, budworms developed a resistance to DDT in the Southeast. Within a few years, budworm resistance increased in other southeastern states and in Arkansas and Mississippi. Resistance reached such high levels that it was nearly impossible to control budworms with any insecticide.

In the late 1960s and the early 1970s, it was obvious that growers would need insect control strategies other than insecticide applications. It was at that point that the idea of integrated pest management (IPM) was brought back into being. Management practices taught and used in the early 1900s had been left behind when new, effective insecticides became available. In the early 1970s, those management strategies, such as cultural practices, gained new educational emphasis under the term "IPM". Additional persons were employed in pest management positions. Scout training, sampling techniques, life cycles and the use of treatment thresholds were emphasized.

In December 1972, EPA banned the use of DDT on cotton. The ban resulted in a shift to a more intensive use of the organophosphate insecticides in combination with toxaphene or endrin. Insect control became more costly and the application of the chemicals became more dangerous to loaders, mixers and applicators. At the same time, the chemicals became less effective, despite the development and widespread use of the first ovicide, chlordimeform (Fundal®, Galecron®).

ARRIVAL OF THE PYRETHROIDS

Since 1977, cotton growers in the Southeast have utilized pyrethroids as the foundation of their cotton insect control programs. Organophosphate insecticides were tank-mixed for control of boll weevils and occasional secondary pests. Some carbamates were used for armyworm outbreaks.

Growers experienced another period of excellent insect control in the earlier years of pyrethroid use. However, after five to seven years, secondary pests began emerging as problems.

During the early and mid-1970s, the greatest problem facing cotton producers was delayed maturity. With very few exceptions, delayed maturity has not been a problem since the pyrethroids became available in the late 1970s for widespread use. Since the type of insecticide was the only production practice that changed distinctly during the late 1970s, it is possible that the use of pyrethroids had more to do with eliminating delayed maturity than any other factor.

When looking at yields since the pyrethroids entered the marketplace, a significant upward trend can be observed. When the extremely hot and dry years of the 1980s are considered, this trend strongly suggests that improved insect control has been a major factor in increased yields.

DEVELOPMENT OF RESISTANCE TO PYRETHROIDS

Due to development of resistance to the pyrethroids, by the late 1980s the greatest single concern of cotton entomologists was how to most effectively extend the life of this important group of insecticides. Concern among some entomologists about resistance actually began about the time the pyrethroids entered the market. This was probably due to several reasons. Problems associated with tobacco budworm resistance to organophosphate insecticides were still fresh on the minds of entomologists. Additionally, the pyrethroids have a similar mode-of-action (killing mechanism) as some of our earlier organochlorine insecticides against which resistance had developed. Finally, pyrethroids were extremely effective. This meant that the selection pressure for resistance was high.

Pyrethroid use on cotton in the United States was going along quite smoothly through the 1983 season. Growers, consultants and many entomologists paid little attention to the potential for development of resistance. Other than a few areas in the western states where budworms changed their tolerance to pyrethroids from year to year, little evidence for increasing resistance was present.

However, this changed suddenly with a report from Australia in January of 1984. This report confirmed what a few entomologists had been fearful of—the Australian bollworm had developed resistance to all the pyrethroids. This same bollworm had previously developed resistance to earlier insecticides such as DDT, parathion and others.

Several factors involved in the Australian cotton production situation were different than most of the United States Cotton Belt. First of all, it was a dry, arid location where the cotton was irrigated. All other crops grown in this area, such as sorghum, were also irrigated and treated with pyrethroids. This means that there were few alternate crops or wild hosts for bollworms where they were not being exposed to pyrethroids. Therefore, the selection pressure was heavy. The Australians quickly determined that other insecticides such as Bolstar®, Curacron®, Thiodan®, Galecron®, Fundal®, Lannate® and Nudrin®, were still effective against their bollworms. A spray strategy using these materials was developed for the 1984 crop year. Indications at this time are that this strategy has bought some time, but may not offer a long-term solution to the problem. Resistance levels fall after each crop season, but not to levels of the previous season.

However, during the 1984 crop year, several countries around the world reported pyrethroid resistance by their bollworm species. Then, in late- season 1985, late maturing cotton fields near Uvalde, Texas had high numbers of tobacco budworms. Pyrethroid insecticides were applied and all failed to give acceptable control. In 1986, additional pockets of control problems began occurring. The College Station area of Texas, Louisiana, the Mississippi Delta and even the Tennessee Valley area of northern Alabama had control failures with all pyrethroid insecticides. In the meantime, researchers monitoring budworm larvae confirmed resistance. Therefore, entomologists began developing plans of action to delay the spread of this resistance and prolong the life of pyrethroid insecticides. A basic part of this plan for the United States was to produce the earliest crop of cotton possible and to not use pyrethroids against the late May-early June generation of tobacco budworms.

In summary, it appears that the resistance of tobacco budworms to pyrethroids is present. There are those that feel that the ultimate fate of all insecticides is resistance. History supports this thinking. The question that no one has an answer for is " how much time do we have?" Growers and consultants control part of the answer to this question. How pyrethroids are used will likely have a major impact on how long they are effective.

At this time the pyrethroids continue to do an excellent job on bollworm-budworm control in most areas of the Southeast. One disadvantage of certain pyrethroids is that they do not control secondary pests such as spider mites and aphids. Also, most pyrethroids are rather ineffective on armyworms. Third, they are not as effective as organophosphates on boll weevils when used on longer intervals common with bollworm schedules. Some of the new pyrethroids currently under development may initially overcome some of these disadvantages.

History must ultimately evaluate the manner in which this remarkable class of insecticides was employed. Thankfully this era is not over.

BOLL WEEVIL ERADICATION: A SUMMARY OF PROGRAM EVENTS AND EXPANSIONS IN THE SOUTHEAST

THE BOLL WEEVIL ERADICATION TRIAL

The current Southeastern Boll Weevil Eradication Program evolved from The Boll Weevil Eradication Trial which was conducted from 1978 to 1980 in northeastern North Carolina and southeastern Virginia. The Eradication Trial was accompanied by an Optimum Pest Management Trial conducted simultaneously in Panola County, Mississippi. The objective of the Optimum Pest Management Trial was to test and demonstrate the ability to manage the boll weevil and other cotton insects on an area-wide basis. The objective of the Boll Weevil Eradication Trial was to test and demonstrate the technological and operational capability to eradicate the boll weevil from a geographically specified area.

The Boll Weevil Eradication Trial was conducted under the authority of the North Carolina Uniform Boll Weevil Eradication Act passed by the North Carolina General Assembly in 1975 as amended in 1977 (Chapter 106, Article 4F of the North Carolina General Statues). Subsequently, a grower referendum was conducted and received the required two thirds support for passage. Funding for the Eradication Trial was provided by the growers (50 percent), states of North Carolina and Virginia (25 percent) and the federal government (25 percent). The grower cost of the three-year Trial Program was estimated to be $100.00 per acre. Actual grower cost was $89.86 per acre. The Trial Program began in the spring of 1978 and concluded in December, 1980. Components of the program included both border and infield pheromone traps; pinhead square, in-season and diapause applications of insecticides, including diflubenzuron (Dimilin®); and the release of sexually sterile insects in 1979. During 1978 only, the control of all cotton insects after June 30 was the responsibility of Program personnel and was included in the cost of the Boll Weevil Eradication Program. The Biological Evaluation Team reported that, with a probability of at least 0.9983[1], the boll weevil was eradicated from the Trial Program Area (Anonymous, 1981).

Operational details of this Trial Program, including boll weevil captures, are discussed by Ganyard *et al.* (1981). A comprehensive review of the results of the Eradication and Pest Management Trials is provided by Lloyd *et al.* (1981) and Parencia *et al.* (1981), respectively. The economic impact of eradicating the boll weevil from the Trial Program Area is discussed by Carlson and Suguiyama (1983).

Upon completion of the Eradication Trial in 1980, a Boll Weevil Containment Program was initiated to prevent the reinfestation of the Trial Eradication Zone; concurrently, the results of the Trial Program were being evaluated. The Containment Program was funded by the North Carolina and United States Departments of Agriculture. In the spring of 1982, cotton producers in the Trial Area voted 90 percent in favor of assessing themselves a $10.00 per acre fee to support containment activities. These activities included: (a) monitoring of all cotton in the Trial Area with boll weevil pheromone traps; (b) suppression of boll weevil populations to below economic levels in the Buffer Zone; and (c) elimination of any reinfestations in the Eradication Zone.

Boll weevil populations outside the Trial Area increased substantially during the period 1981-1983. Dispersing weevils from these populations threatened to reinfest the southern portion of the Eradication Zone in 1982 and 1983. Intensive trapping followed by selected insecticide applications prevented this threat from materializing. Pheromone trap captures of boll weevils and chemical treatments during this period are presented by Ridgway *et al.* (1985).

ERADICATION EXPANSION INTO THE CAROLINAS

By the end of 1981 the evaluation of the Boll Weevil Eradication Trial was nearing completion and USDA policy regarding possible expansion of this Program began to be expressed. In January of 1982, in a speech to members of the National Cotton Council, H. C. Mussman, the Administrator of the USDA Animal and Plant Health Inspection Service (APHIS), stated, ". . . the Department holds the view that the future of cotton insect management is in the hands of the producers and the industry. They and only they can determine what is best or most applicable under different sets of circumstances — one or another of a combination of program options may be chosen in any area. USDA stands ready to contribute its skill and backup to producer-industry initiatives on boll weevil suppression or eradication."

A letter of May 24, 1982, from the USDA Boll Weevil Policy Group to, and concurred with by, Secretary of Agriculture John Block, included the following recommendations: "1. Postpone implementation of beltwide boll weevil programs because

[1]From a statistical standpoint, they were 99.8 percent sure of eradication.

of budget constraints, lack of appropriate regulatory authority to implement the eradication options in several states, and uncertainties associated with economic and operational feasibility of beltwide programs. 2. Assist short-term maintenance of the boll weevil containment area in North Carolina and evaluate the longterm cost effectiveness of containment technology to provide a better basis for evolving management and/or eradication strategies. 3. Facilitate testing and expansion of areawide cotton insect management trials and programs throughout the cotton belt, including possible future expansion of boll weevil eradication in the southeastern United States. Federal support should be determined on a case-by-case basis, through evaluation of state and producer proposals. 4. Continue to provide leadership in the decision making process and in the coordination of program activities. A Departmental position on program direction should include discussions with State Departments of Agriculture, State Agriculture Experiment Stations, Cooperative Extension Services, and grower organizations."

In response to grower and industry requests for possible expansion of the Eradication Program, the USDA and grower leadership established a general funding formula of 70 percent grower and 30 percent Federal. This formula combined with the contents of the speech by APHIS Administrator H. C. Mussman, and the four recommendations from the USDA Boll Weevil Policy Group provides the general framework of federal participation in boll weevil eradication/suppression programs.

Based on this understanding of federal support, cotton producers in the remainder of North Carolina not included in the Trial Area and all of South Carolina, conducted a referendum February 26 to March 5, 1982, to provide grower funding and mandatory participation for the expansion of the Eradication Program into those areas. This referendum passed in North Carolina but was narrowly defeated in South Carolina. Due to the improved cotton harvest and the dramatic resurgence of the boll weevil in these two states in 1982, an additional referendum was held January 21 - 28, 1983. This referendum was approved by 79.2 percent in North Carolina and 72 percent in South Carolina. This Expanded Boll Weevil Eradication Program was initiated with the application of a series of insecticide treatments to prevent boll weevils from entering diapause. The first of these treatments was applied the last week of August, 1983. This Expanded Program differed from the Trial Program in that release of sterile boll weevils, scouting and control of other cotton insects, and extensive use of diflubenzuron (Dimilin®) were not included. Operational components of this Expanded Program consisted of intensive trapping for both detection and suppression and timing of insecticide treatments to prevent weevils from entering diapause and those overwintered weevils that do survive from infesting the pinhead square stage of cotton. A more detailed discussion of the application of this technology is provided by Dickerson (1986). Program status for 1983-1986 as documented by weevil captures in pheromone traps is reviewed by Dickerson *et al.* (1986, 1987). The eradication of the boll weevil as an economic pest from Virginia, North Carolina and South Carolina is reported by Carlson and Suguiyama (1985). They reported that the profitability of cotton production in those states increased by $50 to $70 per acre. To emphasize the importance of the absence of the boll weevil, a funeral service was conducted in North Carolina in March of 1987 to celebrate the weevil's demise.

The expansion of the Boll Weevil Eradication Program to include all cotton grown in Virginia, North Carolina and South Carolina resulted in the establishment of the Southeastern Boll Weevil Eradication Foundation. Each participating state organized a state foundation consisting of appointed or elected grower representatives and a state regulatory official. Two grower representatives and the state regulatory official from each participating state Foundation serves as the Board of Directors of the Southeastern Foundation. A common cooperative agreement is signed by all participating state foundations. This agreement allows for funds to be collected and spent irrespective of state boundaries. The Foundation also provides for expeditious and efficient purchasing and contracting of needed supplies and services and the hiring of employees.

ERADICATION EXPANSION INTO GEORGIA, FLORIDA AND ALABAMA

As the success of this Expanded Program in the Carolinas became apparent, cotton producers in Georgia, Florida and Alabama expressed interest in expanding the Program into their areas. A series of cotton producer referenda was conducted between the fall of 1985 and early summer 1987. A referendum was held in 13 southeastern Alabama counties during December 5-12, 1985; it received a 67.17 percent favorable vote. An additional referendum was held during July 6-10, 1987, in eight adjoining Alabama counties; approval was by a 78 percent margin. The inclusion of these additional Alabama counties allowed all cotton in the Florida Panhandle to be included in this phase of expansion. The Florida referendum held June 30, 1987, received 77 percent approval. The Georgia referendum, conducted from November 15 - December 15, 1985, included the total state except for 23 northwestern counties. This referendum received 45 percent of the necessary 50 percent grower participation. Of those voting, 66 percent favored participating in the Eradication Program. An additional referendum was conducted from October 1 to November 1, 1986, with 68 percent of eligible voters voting. This referendum was approved by a margin of 89 percent.

This series of successful referenda coupled with the availability of 30 percent federal funding in July of 1987 allowed the Southeastern Boll Weevil Eradication Program to expand in August of 1987 from Virginia and the Carolinas into Georgia, Florida and southeastern Alabama. The lateness of federal funding allowed marginal time for program startup. Grower leadership decided a late start in 1987 was preferable to delaying expansion until the fall of 1988.

The intensive eradication phase of the Georgia, Florida and southeastern Alabama Program was anticipated to be completed in 1990.

COTTON INSECT MANAGEMENT FOLLOWING BOLL WEEVIL ERADICATION

NORTH CAROLINA

The start of the Boll Weevil Eradication Trial in 1978 also signaled the beginning of profound shifts in the dynamics of cotton insects in northeastern North Carolina and adjacent Virginia. A change as drastic as the removal of a key pest from an insect-susceptible crop such as cotton, with its annual protective blanket of insecticides, was bound to also greatly influence, both positively and negatively, the interaction of that host crop with other associated pest species. A decade of post-eradication research and survey information in northeastern North Carolina suggests that the benefits of reducing boll weevils to subeconomic levels and the present ease of bollworm/ tobacco budworm control thus far outweigh the negative impact of species such as the European corn borer, *Ostrinia nubilalis* (Hübner) and the green stink bug, *Acrosternum hilare* (Say) which have increased their population levels following "eradication".

Assuming that the boll weevil can be kept out of this and other regions in the coming decades, the relative contributions of boll weevil eradication in other cotton production regions will likely vary and await quantification. However, the dynamics of insect-related changes in the various regional cotton agroecosystems induced by the elimination of the boll weevil likely share some similarities. A look at the North Carolina-Virginia experience documents the impact of eradication on insect management in a selected area.

Bollworms/Tobacco Budworms — For most of the past two decades, the bollworm/tobacco budworm complex, primarily bollworm, has constituted North Carolina's most economically important cotton insect pest (Neunzig, 1969). After undergoing two larval generations in field corn, high numbers of bollworm moths invade cotton fields in late July to early August, usually overwhelming beneficial insect populations. Remedial treatment is, almost without exception, a necessity. Collectively, boll weevil eradication and the introduction of the pyrethroid insecticides greatly enhanced producers' ability to effectively and economically control this major bollworm generation. Attempts to control this generation with biological insecticides, primarily *Bacillus thuringiensis* both with and without chlordimeform (Fundal®, Galecron®), were generally futile when compared with the new synthetic pyrethroids. The microbial treatments typically resulted in more applications, higher costs, greater boll damage and lower yields even under light pressure (1 to 2 applications) (Bacheler, 1984). Research comparing various bollworm/tobacco budworm action thresholds has consistently pointed toward action based on an egg threshold as the most economical approach to bollworm control in North Carolina in the post-eradication era. This protective approach (as opposed to waiting for a specified larval population) places a premium upon the virtual elimination of the initial larvae of the major flight, resulting in significant yield increases without increasing the total number of applications. Three years of producer experience and extensive fall-damaged boll surveys confirmed that this post-eradication approach to controlling predictably moderate to high bollworm levels, particularly when coupled with maturity-enhancing crop production tactics, has resulted in a bollworm management scheme unique in the Southeast.

Stink Bugs — The elevation of the green stink bug, and to a lesser degree the brown stink bug, *Euschistus servus* (Say), and the European corn borer to legitimate pest status has been due in no small measure to the boll weevil's demise. Multiple applications of organophosphate insecticide directed against boll weevils and bollworms up through the late 1970s coincidentally tended to keep both green stink bugs and European corn borers at acceptably low levels. Of these two "new" post-eradication pests, the green stink bug relationship with eradication is the more easily understood.

Green stink bugs damage cotton by injecting their stylets through the carpal wall of medium-sized bolls and feeding upon the developing seeds (Glover, 1855); they often inject a hardlock-inducing pathogen, primarily *Nematospora coryli*, which is expressed at boll opening (James D. Barbour, Dept. Entomology, Louisiana State University; personal communication). Multiple feeding upon very young bolls (about 1 week old or less) sometimes either "freezes" the dead boll on the plant or results in the shedding of the damaged boll. This species is usually present in most North Carolina cotton fields in low numbers in June through mid July. In late July or early August, immigration into cotton fields from senescing wild hosts, such as wild cherry, augments the typically low infested population. The subsequent appearance of nymphs, indicating successful reproduction, marks the beginning of a potentially damaging population. In situations where bollworm does not reach treatable levels or where biological insecticides are employed, stink bugs have accounted for over 30 percent boll losses in some fields (personal observation). In these low bollworm situations, stink bugs must now be managed in their own right. Fortunately, due to the usual parallel appearance of bollworm moths along with increasing stink bug populations, employment of the bollworm egg threshold (Bacheler, 1988) for initiating bollworm/tobacco budworm control (2-5 applications) usually suppresses stink bugs to low, tolerable levels. The green stink bug in particular appears to be a consistent post-eradication cotton pest in North Carolina; it accounted for higher levels of boll damage in 1987 than either the bollworm or the European corn borer as documented in extensive late season surveys (King *et al.*, 1988).

European Corn Borer — The European corn borer's rise as an economic pest of cotton in North Carolina (King *et al.*, 1986; Gourd and Gouger, 1983; Savinelli *et al.*, 1986) following boll weevil eradication appears to be multi-causal. Although reported to have over 100 hosts in the southeastern United States, field corn is the predominant host of the European corn borer for its first two generations in North Carolina (Anderson, 1984). Like the corn earworm, the major, damaging third generation of European corn borer adult flies to cotton and to other cultivated and wild hosts such as cocklebur in late July to early August. Unlike bollworm adults, European corn borer female moths deposit egg masses deep within the plant canopy on the undersides of leaves (Savinelli, 1988). Neonate (very young) larvae feed briefly (only 24 hours on occasion) upon leaves and petioles before seeking out medium-to-large bolls (Savinelli, 1984, 1986). With their propensity to feed within large, lower bolls as second through last instars, these larvae are virtually impossible to control once they are established.

In North Carolina, the European corn borer has risen gradually in economic status throughout the 1980s to the point where it is now regarded as almost co-equal to the bollworm as the most significant insect pest of cotton (Jack S. Bacheler, personal observation). One factor in this species' elevation, as was the case with the green stink bug, is the absence of insecticides formerly directed against the boll weevil. Although the insecticides usually selected for boll weevil control, such as methyl parathion and Guthion®, are only marginally effective against European corn borer, their multiple usage patterns undoubtedly suppressed European corn borer larvae to a degree. This species is also becoming a more widely recognized pest of field corn, both due to a gradual appreciation of the physiological damage to corn caused by second generation larvae and to the noted greater mean level of abundance of this species in corn (John Van Duyn, V. G. James Research and Extension Center, Plymouth, North Carolina; personal communication). This rise in field corn translates into a spillover into other crops such as cotton, also explaining some of the changing status of the European corn borer on this crop.

Because the European corn borer and corn earworm adults often annually migrate into cotton fields from field corn at approximately the same time, insecticides applied against the bollworm egg stage (presently recommended in North Carolina) often result in residue of one or two applications being on the cotton plants at the time that European corn borer eggs hatch. This phenomenon appears to help explain the relatively high percent control of European corn borers in screening tests where treatments have been applied at egg threshold for corn earworms. Earlier tests conducted in 1984, primarily against the European corn borer larval stage, yielded controls varying from 2 to 48 percent after four applications (J. R. Bradley, Jr., Dept. Entomology, North Carolina State University, Raleigh, North Carolina; personal communication). Although the effect of boll weevil eradication on European corn borer damage to cotton is difficult to accurately quantify and will likely vary greatly from one region to the next, higher boll damage by the European corn borer in the southeastern United States is a likely prospect following boll weevil eradication wherever significant corn acreage occurs.

Other Cotton Insect Pests — Boll weevil eradication's long term impact on less significant, more sporadic, North Carolina cotton insect pests—such as aphids, spider mites and beet and fall armyworms—is largely speculative. The switch to synthetic pyrethroids was thought by many entomologists in the late 1970s to inevitably lead to higher mite populations on cotton. Mite numbers here have not increased with greater pyrethroid use and apparently have not been significantly affected by boll weevil eradication. Evidence suggests that with the cotton aphid, however, pyrethroid applications have been followed by the establishment of numerous small aphid colonies annually in many cotton fields.

The post-eradication lack of boll weevil insecticides such as Guthion® and methyl parathion (both active against the cotton aphid) in mid-season and in diapause programs appears to have exacerbated aphid problems in general; this, in turn, may be related to the present increase in honeydew-induced sooty mold and sticky cotton problems, in opening cotton in particular. Beet and fall armyworms are such infrequent pests of cotton in North Carolina that the impact of boll weevil eradication on these and other lepidopterous pests must await evaluation in other regions where their damage is more significant.

As has been well documented throughout the Southeast, cultural practices which hasten cotton crop maturity also generally render the cotton crop less attractive and less susceptible to many damaging mid- and late-season insect pests, especially corn earworms and tobacco budworms (Bradley *et al.*, 1986; Bradley, 1988). This also appears to be the case in North Carolina with the European corn borer and the green stink bug, as shown in both research plots (Savinelli, 1986; Barbour, 1988) and in statewide damaged boll surveys where late maturing, rank cotton is particularly attractive and/or susceptible to the European corn borer. Although difficult to forecast with certainty, early crop maturity and cut-out will probably offer a significant moderating influence on the potential destructiveness of some of the emerging cotton pests which will inevitably follow eradication in the southern United States.

SOUTH CAROLINA

Since the Eradication Program was expanded in 1983 to include South Carolina cotton, fields have been relatively free of boll weevils. A small percentage of fields has been infested with weevils during the program, but for the most part there has been no economic damage. Cotton farmers didn't have to worry about either scouting for boll weevils or controlling them from 1984 through 1988. This has presented a unique opportunity to re-evaluate management strategies for other cotton insect pests free from constraints inherent in a boll weevil control program.

Bollworms/Tobacco Budworms — The bollworm/tobacco budworm complex constitutes the most important cotton insect pest problem in South Carolina. Second generation larvae of both species attack cotton in June. In most years 15 to 25 percent of the cotton acreage in the Coastal Plain is treated one or more times with an insecticide between June 15 and July 1 for bollworm/tobacco budworm control. Infestations in July and August are generally bollworms.

Prior to the Boll Weevil Eradication Program, control efforts targeted at boll weevils in late June and early July often contributed to early-season bollworm/tobacco budworm problems by depleting populations of beneficial arthropods (A. R. Hopkins, USDA, ARS, Florence, South Carolina; personal communication). In the majority of cotton fields, beneficials will provide adequate control of second generation bollworms/tobacco budworms in most years if their populations are not drastically reduced by insecticides.

Following a cotton season with intense boll weevil pressure it was a common practice to apply organophosphate insecticides from late June to early July. Two or three applications were made five days apart beginning at the 8-leaf stage of cotton growth and ending about July 1. This coincided with the movement of beneficial arthropods into cotton. Disruptions of beneficial populations by insecticides applied during that time often flared bollworm/ tobacco budworm infestations.

After boll weevil populations were reduced to levels no longer causing economic damage to cotton, cotton growers were in a better position to manage infestations of bollworm/tobacco budworm. This was substantiated by Carlson (1985) who reported that in the Eradication Zone in North Carolina, following the Eradication Trial that began in 1978, the average number of insecticide treatments for bollworm/boll weevil and bollworm alone was 7.78. In 1978, the first year of the Trial, growers applied a total of 4.4 insecticide treatments for bollworms. The average number of treatments applied in the same area from 1979 to 1982 was 1.86.

From 1979 through 1982, USDA, APHIS entomologists investigated a biological approach to bollworm/tobacco budworm management in Chowan County, North Carolina (Robert G. Jones, USDA, APHIS, Mississippi State, Mississippi; personal communication). They utilized *Bacillus thuringiensis* (Bt) in combination with chlordimeform (Fundal®, Galecron®) to control bollworm/tobacco budworm infestations in cotton. Since both materials were easy on beneficial arthropods, populations of beneficials were maintained in treated fields to augment bollworm/tobacco budworm control. The cotton growers who utilized this strategy achieved bollworm/tobacco budworm control with an average of about two treatments per season.

After the eradication program expanded to include South Carolina in 1983, bollworm/tobacco budworm management was investigated in the absence of economic infestations of boll weevils. The objective of this study was to determine if bollworm/tobacco budworm in cotton could be economically controlled full season with Bt plus chlordimeform.

From 1985 to 1987 a bollworm/tobacco budworm management strategy with Bt plus chlordimeform (4 to 12 BIU's + 0.125 pounds of active ingredient per acre) was compared with a standard approach utilizing cypermethrin (Ammo®, Cymbush®) + chlordimeform (0.50 + 0.125 pounds of active ingredient per acre). This comparison was made at 19 on-farm locations in the following counties: Lee, Marlboro, Sumter, Darlington and Dillon. Yield comparisons for the two treatments are shown in Table 1 (Mitchell Roof and Robert Jones, unpublished data). At nine of the locations, lint yields under the biological approach were as good or better than the standard treatment over the three year study. There was no significant difference between treatments within years or when averaged over years. Populations of beneficial arthropods were higher where the biological approach was used.

When the bollworm/tobacco budworm management program was begun in 1985, Bt plus chlordimeform was tested as a full-season alternative to the pyrethroids (yield data presented for 1985 were based on full-season control). Then, reports began to surface in the Mid-South concerning tobacco budworms that were resistant to the pyrethroids. Development of early-season alternatives to pyrethroids was becoming increasingly important. Thereafter, Bt plus chlordimeform was viewed as a possible resistance management tool. In 1986 and 1987, Bt plus chlordimeform was used successfully in an early season control program.

Clemson University then included Bt plus chlordimeform as a recommendation for early-season control of bollworm/tobacco budworm on cotton (Roof, 1988). (Editors'

Table 1. Control of bollworm/tobacco budworm in cotton in South Carolina in the absence of boll weevils.

Year	Number of on-farm locations	Cotton lint yield	
		Biological[1] treatment	Standard[2] treatment
		lbs./acre	lbs./acre
1985	7	1030 a	1186 a
1986	7	637 a	681 a
1987	5	665 a	697 a

[1]Bt + chlordimeform

[2]Cypermethrin + chlordimeform

Means in rows followed by the same letter are not significantly different ($P < 0.05$; ANOVA).

note: Chlordimeform is no longer available.) The use of bollworm/tobacco budworm control alternatives such as this will be encouraged and the use of pyrethroids discouraged prior to July 1. Hopefully, this management philosophy will forestall the development of pyrethroid resistance in tobacco budworm. Extending the useful life of the pyrethroids could be an important spin-off of boll weevil eradication.

Other Cotton Insect Pests — Elimination of economic infestations of boll weevils may alter the importance of insect pests other than the bollworm/ tobacco budworm complex. Applications of organophosphate insecticides that were detrimental to beneficial arthropods may have also kept some potential pests under control.

Stink bugs were a pest in South Carolina cotton from 1985 to 1987, but no economic problems were observed in 1988. The green stink bug appears to be the major species involved. Whether or not this phenomenon is attributed to the eradication program remains to be seen. Three consecutive mild winters may have contributed as much or more to the problem. Furthermore, there have been similar reports of stink bug damage in cotton from other states, such as Tennessee, that were not involved in a boll weevil eradication program.

Cotton fleahoppers, *Pseudatomoscelis seriatus* (Reuter), have been more abundant in cotton since 1984. Prior to 1984, it was rare to see a cotton fleahopper in a cotton field. There also appear to be more tarnished plant bugs, *Lygus lineolaris* (Palisot de Beauvois). These insects are not causing widespread economic problems at this time, but the situation will bear watching.

Problems with cotton aphids, *Aphis gossypii* Glover, also appear to be increasing. Most infestations are occurring in late July and early to mid August. Aphid infestations may be more related to the use of pyrethroid insecticides for bollworm/tobacco budworm control than to eradication of the boll weevil.

THE FUTURE

The future for cotton production in the Southeast looks brighter because of the eradication program. Interest in producing cotton has increased where boll weevils no longer pose an economic threat. Acreage has increased in both North Carolina and South Carolina as a result of the program. There is every indication that this trend will continue as other states become involved in the expanded program.

Eliminating the boll weevil as an economic pest will provide farmers a method of reducing their cost of cotton production. Insect pest management will be vastly different without a pest that generally requires the disruptive application of an insecticide. Scouts won't have to concentrate on scouting for weevils; consequently they will be able to key on bollworm/tobacco budworm and other pests. Farmers won't have to tank-mix insecticides for weevils and worms—nor will they have to sandwich insecticides for weevils between bollworm/tobacco budworm sprays. There will be no insecticide costs for boll weevil control, and there will be no weevil-damaged cotton resulting in reduced yields and quality.

For the foreseeable future, the use of insecticides will continue to be an essential part of producing cotton. At the same time, concern for the environment, clean air, clean water and preservation of wildlife will intensify. The demand for food and fiber free of insecticide residues will increase. Eradicating boll weevils will put cotton production agriculture in a position to comply with these demands.

When the boll weevil is no longer an economic pest of cotton, the use of organophosphate insecticides will be drastically reduced. In terms of total quantity of insecticides (pounds of active ingredient per acre) applied to cotton, a considerable reduction should be expected. Where no insecticides are applied for boll weevil control there will be more opportunities to utilize beneficial arthropods to control bollworm/tobacco budworm and other cotton insect pests. This could provide further avenues for reducing insecticide use. Reducing our dependence on chemical insecticides is certainly a worthwhile goal from an economic as well as an environmental point of view.

Entomologists involved in cotton insect pest management have learned the rules well by observing infestations in the field year after year. Many have been involved in the development of economic thresholds for the different insect pests. Eradication of the boll weevil, however, will change some of the rules and alter some of the economic thresholds that have become so familiar to us. It is possible that certain secondary insect pests will attain more economic importance—others may become less important.

Following eradication of the boll weevil the responsibility of re-evaluating cotton insect pest management systems will fall on the shoulders of state and federal entomologists as well as consultants and others in the private sector. The potential for developing innovative approaches to assist farmers in managing insect pest problems in cotton is great.

Chapter 21

INSECT AND MITE PEST MANAGEMENT IN THE MID-SOUTH

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INTRODUCTION

The success of cotton insect management in the Mid-South region (Arkansas, Louisiana, Mississippi, Missouri and Tennessee) is easily seen by the presence of the multitude of cotton scouts, consultants and advertisements by commercial companies on the role of products in pest management. However, the development of insect pest management has not been easy and has often been wrought with controversy when new management practices were implemented. The broad based insect management system has resulted from years of research, experience, observation, and often trial and error on controlling cotton insects. The insect management system has evolved into a successful strategy that considers several biological factors in insect control with the ultimate objective of achieving optimum profits for the cotton producer. The overall management system will be discussed in detail in this chapter with special emphasis on each insect that occurs in this region.

HISTORICAL ASPECTS OF INSECT AND MITE MANAGEMENT IN THE MID-SOUTH

The cotton plant seems to have been designed by nature to attract insects. It has large succulent leaves, many large, open flowers, nectaries on every leaf and flower and abundant fruit. It is a ready-made haven for insects, some beneficial to man and some — the cotton leafworm, bollworm, tobacco budworm, boll weevil, cotton aphid, pink bollworm, cotton fleahoppers, tarnished plant bug, rapid plant bug, thrips, southern green and green stink bug, spider mites, and grasshoppers — very destructive.

Records from the eighteenth century show that the cotton leafworm was the first insect of major importance to the early cotton grower. In some years it destroyed 25 to 90 percent of the cotton.

In the early nineteenth century, the bollworm entered the picture. The biological differences between the bollworm and the tobacco budworm were not yet recognized, thus damage estimates attributable to either of these species are imprecise.

The chief source of cotton-insect research information was the individual cotton grower during the first half of the nineteenth century. In fact, it was a grower who first reported that the bollworm and the corn earworm were the same insect. This type of information was disseminated by letters, newspapers, and word of mouth.

Growers often found it unprofitable to grow cotton because of insects. As the country grew and cotton production increased, other insect pests made their presence known. In 1855, stink bugs and aphids were serious pests of cotton. It soon became evident that the federal government must aid cotton growers, so the Congress directed an investigation of cotton insects in 1878. These studies were directed at life histories, habits of destructive species, effects of natural enemies and cultural control methods. These studies provided much of the background information for later control efforts.

In 1892, the boll weevil crossed the Rio Grande River near Brownsville, Texas, and by 1894 had spread to six counties in southern Texas. It continued to advance at a rate of 40 to 160 miles a year and by 1922 had infested 85 percent of the Cotton Belt. Damage by the boll weevil varied greatly. Most farmers continued to grow cotton because about 95 percent of the hibernating boll weevils died and many that survived the winter died before cotton produced squares. Hot, dry weather, insect parasites and predators and birds also helped reduce populations.

The use of cultural control methods was recognized as a valuable aid in the control of insects and is still used even today. The use of early fruiting cotton varieties, early planting, frequent cultivation, clean culture, cleaning up debris in fence rows around fields and fall and winter plowing were utilized to lessen the damage caused by insects.

Artificial methods of control were attempted with varying degrees of success. Some of the methods used by both professional and lay research workers were attractants and repellents, poisoned baits, fires in fields at night to attract insects, mechanical devices for dislodging and collecting insects and hand-picking insects off of cotton.

Plant breeders played a vital role in the control of cotton insects during the early 1900s. They developed fast growing and early maturing varieties so that the cotton could be produced and matured before insects had time to build up to maximum numbers. They undertook studies to develop varieties that could better withstand insect attack and could produce additional fruit after insect damage had occurred.

Research on controlling cotton insects using various chemicals applied as sprays began in the early 1900s. As early as 1905, Paris Green was recommended as a spray to combat some insects. London Purple and arsenate of lead also came into general use. However, methods of application were crude and probably accounted for much of the ineffective control.

In 1908, lead arsenate was first used in dust form for insect control. From 1908-1916, dusts of lead arsenate, Paris Green, and London Purple were used against cotton leafworm. In 1916, calcium arsenate dust was found to be highly effective against some cotton insects. For the next three decades, research on control of cotton insects was largely devoted to developing dusts, dust mixtures and methods of application.

In 1917, the pink bollworm was discovered in Texas. Research efforts to control this pest were doubled in the areas of biology, ecology and control. This research provided the basis for the successful prevention of its spread to the Mid-South cotton producing areas through quarantine regulations and control efforts.

By 1920, calcium arsenate was a proven effective insecticide against the boll weevil, bollworm and cotton leafworm. Ground machines and airplanes were used to apply millions of pounds of calcium arsenate annually. Nicotine sulfate was used to control the aphid. Sulfur was proven effective against the cotton fleahopper, other plant bugs and spider mites.

In response to a shortage of cotton after World War I, acreage expanded. Intensive cultivation created new insect problems. Insects that previously were thought to be confined to other hosts were found in cotton. During this time, the cotton fleahopper, plant bugs, aphids, thrips, spider mites and stink bugs were all recognized as serious pests.

After World War II, new and more active organic insecticides entered the scene. DDT was the first to be tested extensively, followed by benzene hexachloride, toxaphene and chlordane. Although many of these were effective against certain insect pests of cotton, none individually controlled all the major pests. In the late 1940s and early 1950s, aldrin, dieldrin, parathion, methyl parathion, heptachlor and EPN became vital parts of the arsenal of available pesticides.

Following widespread use of the chlorinated hydrocarbon insecticides (DDT, benzene hexachloride, aldrin, dieldrin, heptachlor, toxaphene, chlordane and endrin), resistance of cotton pests to insecticides developed quickly. Since 1947, more than 25 species of cotton insects and mites are known to have developed resistance. Each new class of insecticide gave way to resistant insects in only a few years. These include (in chronological order of their appearance) chlorinated hydrocarbons, organic phosphorus compounds, carbamates and the most recent pyrethroid compounds.

BOLLWORM AND TOBACCO BUDWORM RESISTANCE

The two species of "Heliothis", *Helicoverpa zea* (Boddie) and *Heliothis virescens* (Fabricius), the bollworm and the tobacco budworm, respectively, are the most widely distributed major pests of cotton. Before the 1940s, management of bollworm/tobacco budworm populations consisted largely of avoiding problems when possible and living with them when necessary. Crops were planted at times and in areas where bollworm/tobacco budworm damage would be less and a certain amount of damage was tolerated. Control of cotton insects with insecticides was moderately successful prior to World War II using natural or elemental compounds such as rotenone, pyrethrin, and the arsenic and fluorine containing insecticides.

By the mid-forties, these compounds were largely replaced by organochlorine (chlorinated hydrocarbons) insecticides. DDT was the most widely used compound; other insecticides used were endrin, toxaphene and aldrin. These insecticides, especially DDT, were cheap and highly effective in controlling bollworms/tobacco budworms. This led to the widespread and heavy use of organochlorines. By the late 1950s, control failures were reported by growers using DDT. This decrease in susceptibility was well documented in the early 1960s. Resistance in bollworms was reported in Mississippi (Pate and Brazzel, 1964), Arkansas (Lincoln *et al.*, 1967) and Louisiana (Bradley *et al.*, 1966).

Widespread resistance in tobacco budworm to organochlorines was reported in Mississippi (Snow and Brazzel, 1965) and Louisiana (Graves *et al.*, 1967). By 1970, DDT resistance had been documented in twelve states for bollworm and eight states for tobacco budworm (Sparks, 1981); five states had reported bollworm resistance to endrin and three states to carbaryl (Sevin®). By 1980, tobacco budworm resistance to endrin was reported in twelve states, to carbaryl in eleven states and to toxaphene in four states (Sparks, 1981).

Organophosphate insecticides were used extensively during the 1950s, in part due to the widespread resistance to organochlorine and carbamate insecticides. The organophosphate methyl parathion was the most commonly used insecticide to control bollworms; it was cheap, plentiful and highly efficacious. However, by 1967, bollworms had developed resistance to methyl parathion after ten generations of selection in the laboratory (Carter and Phillips, 1968). Resistance to methyl parathion was reported in Louisiana (Graves and Clower, 1971; Graves *et al.*, 1973), and Mississippi (Harris, 1972). Other organophosphate insecticides to which resistance was reported were monocrotophos (Azodrin®), EPN and parathion; resistance to carbamate insecticides was also reported. Bollworm and tobacco budworm had developed resistance to all three of the major classes of insecticides before 1970 (Mullins and Pieters, 1981). By the late 1970s these two species had developed resistance to most organophosphate insecticides in all cotton producing states (Sparks, 1981).

During the late 1970s, pyrethroids were brought into full scale use, in part due to the widespread occurrence of resistance in the bollworm/tobacco budworm complex. Pyrethroids quickly became the most widely used group of insecticides in the United

States. By 1984, laboratory tests showed increasing tolerances to pyrethroids (Crowder *et al.*, 1984). Field control failures were reported in 1985 and increased reports of failures occurred through 1993. Extensive monitoring of pyrethroid resistance using an adult moth vial-testing technique was carried out in most cotton producing states and resistance was shown to be increasing (Graves *et al.*, 1988).

Pyrethroid resistance monitoring in Louisiana from 1987 through 1992 indicated a gradual increase in the survival of tobacco budworm moths at the ten microgram discriminating dose (Graves *et al.*, 1993). The tests showed overall survival increasing from 15 percent in 1987 to 40 percent in 1992. Similar trends were observed in Arkansas and Mississippi during the same time period. The overall field performance of pyrethroid insecticides for control of tobacco budworm has declined with increased reports of failures throughout the Mid-South cotton producing region.

BOLL WEEVIL RESISTANCE

Boll weevils require frequent application of insecticides to maintain control. DDT was the first effective organic insecticide used to control boll weevils and, as in the case of bollworm control, was widely used in large quantities. Organochlorine (DDT, others) resistance in the boll weevil developed first in Louisiana and Mississippi in 1954 (Roussel and Clower, 1955), but the problem soon spread to other states. By 1960, all areas of the Mid-South and Southeast infested by boll weevil had reported the development of organochlorine resistant weevils (Brazzel, 1961).

The organophosphate insecticides replaced organochlorines after the occurrence of widespread resistance. Methyl parathion, one of the more widely used insecticides, is still a very effective insecticide when used for boll weevil control. In addition, another organophosphate insecticide, azinphosmethyl (Guthion®) still provides good control.

BEGINNING OF COTTON PEST MANAGEMENT IN THE MID-SOUTH

Cotton grower's limited knowledge concerning insect pest problems and lack of expert personnel to advise on the proper use of insecticides resulted in growers using insecticides excessively when first introduced. Broad spectrum insecticides and insecticide mixtures were applied as many as 16 to 18 times during the growing season. By 1955, excessive use of insecticide had selected populations of boll weevils that were resistant to several insecticides and secondary pest problems had increased.

The need to determine when and how to use the synthetic organic insecticides was recognized almost as soon as they became available. Entomologists such as Dr. Dwight Isely and Dr. Charles Lincoln in Arkansas, Dr. Leo Dale Newsom, Dr. John S. Roussel and Dr. Dan Clower in Louisiana, and Dr. Ted Pfrimmer and Dr. James R. Brazzel in Mississippi were instrumental in researching insect scouting techniques and economic thresholds.

Pioneers in the area of private insect consulting emerged in 1947 and 1948. In Louisiana they were Ralph Penneull and Ray Young, who did so with the encouragement of Dan Logan, a cotton grower near Shreveport. In Mississippi, insect consulting services were being offered to growers in the early 1950s by Tom Edwards, Douglas Simms and others.

Scouting, as a basis for control has been the foundation of cotton insect control in Arkansas since the first scouting was done in connection with early research programs (Boyer *et al.*, 1962; Isely, 1926). A University of Arkansas sponsored program was initiated in 1949 with two scouts employed in Little River and Lafayette Counties. The scouting program was expanded to seven scouts in 1950 and 25 scouts in 1951. A similar program was started in Missouri in 1955 with Extension hiring scouts for growers. From 1962 to 1967, between 94 and 132 scouts were employed in the Arkansas program each year, with 130 to 180 thousand acres of cotton involved (Lincoln, 1978; Lincoln *et al.*, 1970). Since that time, cotton scouting in Arkansas has become a basic part of the production program and virtually all of the cotton is scouted by extension scouts, consultants, or individual growers.

In memorandum number 1666 (October 23, 1969), the Secretary of Agriculture outlined the USDA policy regarding pesticides. The policy memorandum encouraged the use of those means of effective pest control least hazardous to man, animals, wildlife and the environment, and encouraged restriction on the use of persistent pesticides. Most notable was a statement that nonchemical methods of pest control, biological or cultural, should be used and recommended whenever such methods are available for effective control of target pests. Integrated control systems were to be used and recommended in the interest of maximum effectiveness and safety.

Recognition of the need for more sensible use of insecticides resulted in the launching of an expanded pesticide safety program by the Extension Service, USDA in 1964. This funding provided support for additional professionals in state extension services to conduct educational programs for various audiences who used, sold, recommended or applied pesticides.

Through the efforts of Dr. James R. Brazzel of USDA's Animal and Plant Health Inspection Service (APHIS) and Dr. Roy Ledbetter of Extension Service, USDA, pilot pest management programs in cotton were funded by federal grants in 1972 at the state level. By 1973, pilot cotton pest management programs had been initiated in fourteen cotton producing states. Through efforts of the National Cotton Council of America, funding was approved by Congress in 1975 and made available through the state extension services to continue the development of pest management programs in cotton.

INSECT MANAGEMENT PRACTICES IN THE MID-SOUTH

The major insect pests of the Mid-South include thrips, tarnished plant bug, clouded plant bug, cotton fleahopper, boll weevil, bollworm and tobacco budworm (Reynolds *et al.*, 1982; Young, 1969b). Other insects that occasionally attack cotton include several species of cutworms, aphids, spider mites, whiteflies, fall armyworm, beet armyworm and cabbage looper. The management practices for these insects vary depending on the species and the management recommendations made by the individual states. In general, the state-to-state philosophies on individual species management are similar but vary because of local needs and research interpretation differences.

THRIPS

Thrips injure cotton plants shortly after plant emergence by attacking the terminal bud and the first two-to-four true leaves. Thrips cause economic injury to cotton by reducing stands, retarding growth, adversely affecting post-directed herbicide applications that may result in stunted plant growth (Lambert, 1984), and delayed optimal fruiting (Lambert, 1985). High infestations may kill terminal buds and cause severe plant abnormalities (Carter *et al.*, 1982; Young, 1969b). Clower (1984) cited four reasons for growing concern about thrips damage: (a) increased numbers of soybean thrips in cotton; (b) increased wheat acreage from which thrips may move to cotton; (c) recent cool springs detrimental to cotton vigor; and (d) less concern about bollworm/tobacco budworm outbreaks (following thrips control practices) since effective bollworm/tobacco budworm insecticides were available.

Experimental evidence of direct cotton yield loss due to thrips damage often has been controversial among scientists. Beckham (1970) and Watson (1965) reported no significant yield loss due to thrips damage although yields were lower in untreated checks. However, Watts (1938) reported a 41 percent yield reduction due to thrips injury. More recently, Johnson *et al.* (1988) reported a significant yield increase in a three-year study on irrigated and dryland cotton when thrips were controlled with foliar and in-furrow insecticides. The yield increase ranged from 14 percent using foliar sprays to 26 percent using aldicarb (Temik®) in-furrow on irrigated cotton compared to an 8 percent increase using foliar sprays and 17 percent using aldicarb on dryland cotton.

Systemic insecticides applied as in-furrow granules and sprays, seed treatments (e.g., acephate [Orthene®]) and foliar sprays are recommended in the Mid-South region for thrips control. Systemic granular insecticides (e.g., aldicarb [Temik®], acephate [Payload®], disulfoton [Di-Syston®], carbofuran [Furadan®], and phorate [Thimet®]) are applied in the seed furrow with a gravity-flow, granular applicator or applied as directed in-furrow sprays (primarily acephate) mounted on planters. Systemic granular insecticides are considered to give longer lasting control for thrips than insecticides applied as seed treatments. In-furrow insecticides usually are used in conjunction with a fungicide formulation for seedling disease control and to lessen the phytotoxic nature of the insecticides under cold, wet conditions. Granular fungicides are available in combination with systemic granular insecticides or may be applied concurrently using split-box granule applicators. In addition to thrips, systemic insecticides used at planting will suppress aphids and spider mites.

Foliar sprays for thrips control include several contact or contact-systemic organophosphate insecticides. Thrips control with foliar insecticide applications is recommended generally at the time of seedling emergence based on injury or population levels. Population levels requiring control measures recommended by various states are one or more thrips per plant in Mississippi and Tennessee. In Arkansas and Missouri, it is one or more thrips per plant at the cotyledonary stage and two or more thrips per plant from the cotyledonary stage to four-leaf stage.

TARNISHED PLANT BUG, COTTON FLEAHOPPER, AND CLOUDED PLANT BUG

The tarnished plant bug injures cotton primarily by feeding on pinhead squares and terminal buds. Tarnished plant bug feeding causes young squares to shed (Cherry, 1974; Tugwell *et al.*, 1976), while terminal bud injury results in multiple branched plants or "crazy cotton" (Tugwell *et al.*, 1976; Young, 1969b). The clouded plant bug causes injury to cotton similar to the tarnished plant bug (Tugwell *et al.*, 1976). Cotton fleahopper occurrence is well synchronized with the early fruiting stage of cotton growth (Young, 1969b). Cotton fleahopper feeding on young squares also results in square shedding and cotton plants may grow abnormally due to fleahopper injury to terminals (Pfadt, 1971).

The tarnished plant bug is more important in the Mid-South than the cotton fleahopper (Luttrell, 1985). Yield loss due to tarnished plant bug may be observed when extremely high and season-long infestations occur (Schuster, 1977). Scott *et al.* (1985) demonstrated that the tarnished plant bug can be a key pest in the Mississippi Delta based upon yield reductions.

Responses to a survey indicated that the importance of tarnished plant bug in cotton remains controversial (Luttrell, 1985). The importance of tarnished plant bug in cotton production is related to variations in annual populations (Gilliland, 1981; Oakman, 1981). However, severity of damage often extends beyond pure population estimates. Oakman (1981) cited cultivated and weed hosts, cotton variety, stage of cotton development, soil type, seedling disease, predators, other early-season pest insects and other factors that influence control decisions in the field. Delays in the fruiting of the cotton plant have been shown to increase the probability of tarnished plant bug attacks (Gilliland, 1981). Such delays may be caused by late planting or replanting, use of overtop arsenical herbicides, excessively high cotton plant populations and excessive nitrogen fertilizations.

Using a recently developed square slicing technique, Williams *et al.* (1987) were able to distinguish between plant bug, bollworm/tobacco budworm, and physiologically induced pinhead square shed. They demonstrated that their technique would be valuable in identifying cotton fields damaged primarily by plant bugs and/or bollworms/tobacco budworms and in making subsequent control decisions. Pack and Tugwell (1976) reported that small squares less than three millimeter in diameter frequently were shed when fed upon by either the clouded plant bug or the tarnished plant bug.

The management of plant bugs is highly dependent upon timely scouting and the use of threshold treatment levels. Research in Arkansas indicates that scouting at least twice weekly is needed to provide timely detection of damaging populations of plant bugs (Johnson and Tugwell, 1988). Scouting methods for plant bugs include visual observations, using a drop cloth or using a sweep net. The treatment level for plant bugs is similar throughout the Mid-South region. Treatment levels in Mississippi and Tennessee are: (a) one plant bug per six row feet the first two weeks of squaring; (b) one per three row feet during the third week squaring until first bloom; and (c) two per three row feet after first bloom (Head, 1993; Roberts and Lentz, 1993). Louisiana recommends treatment for 25 plant bugs per 100 plant terminals or 100 sweeps (Baldwin *et al.*, 1993). Missouri's thresholds are (a) 10 bugs per 100 terminals during the first three weeks of squaring; (b) 15-20 bugs through peak squaring; and (c) 20-25 clouded plant bugs per 100 plants during late season boll set (Jones and Nabors, 1988). Arkansas controls plant bugs when populations reach one per row foot in normal fruiting fields and one per three row feet in fields that are late or having problems setting fruit (Johnson *et al.*, 1993). In addition, Arkansas recommends using percent square set as an indicator of plant bug injury or plant conditions that may cause fruit shed. The major cause of fruit shed on irrigated cotton in Arkansas during early fruit set has been shown to be the plant bug complex (Johnson and Tugwell, 1988). As a result, treatment for plant bug is recommended when square retention is 75 percent or less before approximately July 1 (date varies depending on area of state) or 85 percent after that date if the loss is due to plant bugs (Johnson *et al.*, 1993). A square slicer and color diagnostic key is used to diagnose the cause of square loss (Williams *et al.*, 1987; Johnson *et al.*, 1985) and these treatment levels are used only when losses are caused by plant bugs.

BOLLWORM AND TOBACCO BUDWORM

Bollworm/tobacco budworm population management is affected directly by production practices applied to individual fields and also on a community basis. These insect pests should be managed through the conservation of beneficial insects, utilization of economic injury levels, thorough scouting and careful selection of insecticides. Utilization of a total pest management approach will insure the best production of cotton and avoid, as much as possible, outbreaks of secondary pests.

The natural control of bollworm/tobacco budworm populations by predators is well recognized (Whitecomb and Bell, 1964; van den Bosh and Hagen, 1966; Lingren *et al.*, 1968) and conservation of beneficial insects is vital to their control and management. Insecticide treatments for the control of cotton fleahopper (Newsom and Smith, 1949) and tarnished plant bug (Johnson and Tugwell, 1988) have resulted in outbreaks of bollworm/tobacco budworm. The destruction of parasites, predators, and other beneficial arthropods by insecticides applied to cotton has been well documented by several researchers (Lingren *et al.*, 1968; Newsom and Smith, 1949; Pfrimmer, 1964). Beneficial insect populations also will be reduced and bollworm/tobacco budworm populations increased by use of systemic insecticide applied at planting (Rummel and Reeves, 1971; Ridgway *et al.*, 1967; Cowan and Davis, 1967). The lowest rate possible of systemic insecticide to achieve thrips control should be used in order to lessen the impact on the beneficial insect populations. In addition, treatments for the tarnished plant bug or other pests should be applied only when scouting reports indicates a need based on the use of economic injury levels.

Bollworm/tobacco budworm larvae infest pre-bloom cotton, other cultivated crops and various weed species in early-season (Harris and Phillips, 1986; Lincoln, 1972; Neunzig, 1969). Early-season bollworm/tobacco budworm populations on cotton are generally considered to be sub-economic as compared to mid- and late-season populations on cotton. Bollworms and tobacco budworms feed on terminal buds, tender young leaves, pinhead to large squares and blooms in early stage cotton (Hopkins *et al.*, 1982; Young, 1969b). Bollworms and tobacco budworms are capable of destroying squares, blooms (Young, 1969b) and terminal buds (Hopkins *et al.*, 1982). Cleveland *et al.*, (1981) described tobacco budworm damage to greenhouse-grown cotton terminal buds as resulting in "crazy cotton" symptoms.

Bollworm/tobacco budworm larvae are capable of delaying cotton maturity or causing yield loss as a result of early-season damage. Hopkins *et al.* (1982) found that naturally occurring terminal bud destruction by bollworm/tobacco budworm larvae resulted in yield loss when 20 to 30 percent of the terminals were damaged in seedling cotton. Bollworm/tobacco budworm larvae damage pinhead squares and induce square shedding (Williams *et al.*, 1987).

In most cases, the cotton plant is able to withstand early-season square loss by bollworm/tobacco budworm larvae through compensation (Graham *et al.*, 1972). Schneider *et al.* (1986) reported five to sixty percent yield loss and one to ten days increased delay in cotton maturity due to early-season (1/3 grown square stage) bollworm damage. In their studies the plants were artificially infested.

The relationship between bollworm/tobacco budworm populations and the damage to the cotton crop determines the economic injury level and when treatments should begin. Adkisson *et al.* (1964a,b) estimated that an average of 2,000 to 2,500 larvae per acre (approximately one and one-half to two per 10 feet of row) are required to cause significant yield losses to cotton.

The recommended treatment levels for states in the Mid-South region of the Cotton Belt vary slightly from state-to-state. Mississippi recommends treatment for four small larvae per 100 plants at first bloom to August 15 and 8 larvae per 100 plants after August 15 (Head, 1993); Tennessee for four or more small larvae per 100 terminals, or five percent square damage and bollworms present (Roberts and Lentz, 1993); and Louisiana recommends treatment when five live worms are found per 100 plants plus eggs when squares are at least one-third grown (Baldwin *et al.*, 1993). Missouri begins treatment for six to eight larvae per 100 plants on previously untreated fields and four to six larvae on subsequent treatments (Jones and Nabors, 1988). Arkansas recommends treatment based on the point sample method of scouting; bollworm treatments are made when 7,000 newly hatched larvae are found per acre or when 3,500 larvae that are one-fourth inch in size or larger are found per acre (Johnson *et al.*, 1993). The use of ovicides for control of the egg stage has been recommended in all states in this region. They usually are applied in combination with an insecticide, for the management of bollworms/tobacco budworms.

The termination of the use of insecticide treatments for bollworm/tobacco budworm control usually is based on the maturity of the cotton crop, but the exact time to stop applying treatments is difficult to determine. A decision process for determining when cotton is not susceptible to bollworm/tobacco budworm damage has not been developed or adopted in most cotton producing states. Insecticide treatments are usually terminated when the cotton is obviously mature and not susceptible. One method to estimate maturity and susceptibility to larval feeding is boll slicing. Bernhardt *et al.* (1986) proposed another method of estimating the maturity of the cotton crop; their method involves counting the number of nodes between the uppermost bloom and the first leaf that is not fully expanded (node above white bloom). They suggest that, when the average node count drops below five, the need for insecticide treatments will cease after 10-16 days. The number of harvestable bolls expected in the remainder of the season is relatively low and their overall contribution to yield was projected to be less than one percent of total yield. The decision to terminate insecticide treatments should be based on the crop maturity, pest densities and potential yield and profit.

Tobacco Budworm/Bollworm Resistance Management Plan—The increasing incidence of insecticide resistance problems in the Mid-South region brought scientists together in 1987 to develop a regional approach to insecticide resistance management. The plan was developed and adopted by university extension, research and USDA-ARS entomologists.

The resistance management plan and strategy was divided into three time frames, each directed toward different field generations of tobacco budworms. The overall objective of the plan was to delay the development of the resistance in the tobacco budworm and recommend practices to aid the grower in producing a cotton crop. During the initial portion of the production year, the emphasis was placed on managing the crop for earliness by variety selection, prevention of thrips injury and avoiding late planting as much as possible to decrease exposure to late season insect populations.

From planting to late June, recommendations include applying insecticides only as needed, avoiding the use of organophosphate and pyrethroid insecticides and advocating the use of *Bacillus thuringiensis* formulations plus carbamate ovicides or carbamate insecticides alone. The objective is to avoid selection for pyrethroid or organophosphate resistance in the tobacco budworm population during early season. Scouting was recommended a minimum of twice per week to detect egg populations and small larvae in fields. Control strategies for tobacco budworm are most successful when directed toward newly hatched larvae.

During the period of early July through mid August, control strategies are oriented around the use of mid-rate pyrethroids plus carbamate ovicides for the control of tobacco budworms and bollworm. The decisions should be based on information gathered by twice-per-week scouting and directing control efforts toward eggs and one to two day old larvae. Pheromone traps should be used to determine the species composition in the area and if the tobacco budworm is a threat. A minimum of two applications of insecticides will be needed to manage moderate to heavy infestations of tobacco budworm larvae. Pyrethroid insecticides are recommended during this period because they are effective against a wide spectrum of cotton insect pests including the boll weevil and the cotton aphid. The larvicidal rates of carbamate and organophosphate insecticides should not be used unless field failures are occurring in the area. A full rate of the carbamate and organophosphate insecticides alone or in mixtures should be used if resistant tobacco budworms are found.

From mid August until crop maturity, the objective is to protect the bolls until the crop is mature. Control strategies are directed toward the third field generation of tobacco budworm and when resistance is at its peak. The insecticides of choice are the organophosphates at full rates or organophosphate plus carbamate ovicides. The level of resistance appears to be lowest to these products at this point because of the non use policy during the earlier part of the year, thus conserving this class of insecticides for maturing the crop. Pyrethroid insecticides should not be used during this period of time against tobacco budworm populations. Pyrethroid resistance levels and population densities are highest during this period of time which increases the chances of unsatisfactory control with this class of insecticides.

Bollworm and Tobacco Budworm Pheromone Traps — The pheromone traps for bollworm and tobacco budworm are used primarily for detection of population shifts and species composition in insect management programs. Pheromone trap catches have been used in certain areas of the Mississippi Delta as input to a bollworm/tobacco budworm population model, MOTHZV, along with appropriate climate and crop phenology to predict the timing of future generations (Hartstack *et al.*, 1983). The population trends of bollworm/tobacco budworm are related to the quantitative number of moths caught (Johnson, 1983). Most moth traps used in the Mississippi Delta are utilized to detect population shifts. This information is important to cotton pest management programs. The bollworm management communities in Arkansas rely heavily on pheromone traps to provide information that aids in decisions to determine community bollworm control treatments (Nicholson *et al.*, 1984).

The traps used in most programs to monitor bollworm/tobacco budworm follow the construction guidelines provided by Hartstack *et al.* (1979). The bollworm pheromone is formulated as a 2.5 milligram per square inch bait. The tobacco budworm pheromone is a 16 to one ratio of Z-11 hexadecenal and Z-nine tetradecenal formulated at 80 milligrams per square inch. The laminated plastic baits have produced good results in trials comparing the baits to virgin bollworm/tobacco budworm females (Zvirgzdins and Henneberry, 1983).

BOLL WEEVIL

The boll weevil has been the most serious pest of cotton production since its introduction to the Mid-South area in the early 1900s. Isely (1933) reported that the weevil was often the most important limiting factor in Arkansas cotton production. Since those early control problems, the boll weevil has continued to be a major problem even with the development of effective insecticides.

The primary economic damage to early-season cotton by boll weevils is development of the F_1 generation during early fruit set. Reproduction by overwintered weevils results in square damage, shedding and subsequent delay in cotton maturity. In a case study, Cross (1983) reported one and one-half to three percent square infestation by overwintered weevils and seven to nine percent infestation by the F_1 generation. Lloyd and Merkl (1966) found that 0, 14, 25, 50 and 100 boll weevils per acre produced F_1 generation weevils that damaged 0, 28, 46, 66 and 83 percent of the squares, respectively, in field cage tests.

Overwintering adult boll weevils feed upon the base of leaf petioles and in plant terminals prior to initiation of squaring (Cross, 1983; Young, 1969); they also feed on, and reproduce in, squares once cotton fruiting begins (Cross, 1983). Weevil reproduction in squares results in square flaring and shedding. Weevils in the resultant F_1 generation will emerge 17-21 days later and will cause increased square loss.

Pheromone Traps and Early-Season Control of Boll Weevils — The discovery and development of the male boll weevil pheromone (Hardee *et al.*, 1967; Tumlinson *et al.*, 1969) has led to improved management in cotton. In 1968, the first attempt was made to influence developing populations of boll weevils and measure the potential of using male baited traps (Cross *et al.*, 1969) in surveys and suppression of boll weevils. Since this early study, Rummel *et al.* (1980) developed a pheromone trap index system to predict the need for overwintered boll weevil control at the pinhead square stage. This work has been further validated by Johnson and Gilreath (1982) and Benedict *et al.* (1985). The use of properly timed insecticides to suppress the development of boll weevil populations by preventing significant egg lay has proved to greatly reduce or sometimes eliminate the need for in-season control (Ewing and Parencia, 1950; Taft and Hopkins, 1963; Walker and Bottrell, 1970). The usage of the pheromone trap system to determine the need for insecticide applications at pinhead square stage has been adopted by most cotton producing states.

The movement of overwintered boll weevil populations into cotton is closely related to plant phenology (White and Rummel, 1978). Only a small percentage of the overwintered weevil population which infests cotton enters prior to the onset of squaring. Boll weevil infestations increase as square size and density increase with major colonization occurring after the appearance of 1/3 grown squares (White and Rummel, 1978; Walker and Bottrell, 1970; Roach *et al.*, 1971; Rummel and Bottrell, 1976). To monitor this movement, boll weevil pheromone traps should be placed in the fields shortly after the emergence of cotton or at about the second or third true leaf stage. The traps should be placed around fields near overwintered sites such as woodland, old homes, barns or similar areas known to harbor overwintered weevils.

The need to apply insecticides is determined by the average number of weevils captured in traps around the field prior to square initiation. Rummel *et al.* (1980) reported using a treatment threshold called the Trap Index to determine the need for insecticide treatment. The Trap Index is the average catch of several traps placed around the field. The data indicated that Trap Index thresholds could be used as a guide in determining the need to treat for overwintered boll weevils. The treatment threshold was divided into three distinct groups based on their research: (a) do not treat if the Trap Index is less than one; (b) if the Trap Index is between 1.0 and 2.5, treatment may or may not be justified; inspect field carefully when the first one-third grown squares appear and base the control decision on the presence of damaged squares or adult weevils; (c) if the Trap Index is 2.5 or greater, treat for overwintered weevil just prior to or at the appearance of first one-third grown square.

The use of pheromone traps offers the advantage of allowing for control decisions for boll weevil to be made at a time when the overall population is at its lowest point for the year and in advance of any oviposition that may occur. However, a considerable degree of judgment based upon boll weevil ecology is needed to get the optimum usage from the pheromone trap. The Trap Index is not an absolute value; it is general in nature. For example, a very low average trap catch during the week of first matchhead-size square would be suspect if the trap averages for the two prior weeks were high. In addition, if the cotton field was the earliest in the area and the emergence pattern of the boll weevil was just beginning, the use of insecticides to control this population would be less effective. The trapping system works best when the peak emergence occurs before the appearance of first square.

The boll weevil pheromone trap is recommended by all Mid-South cotton states to evaluate overwintering populations. If pheromone traps around fields catch certain levels of boll weevils prior to pinhead square stage of growth, insecticide applications are recommended to suppress overwintered populations. In Arkansas, insecticide applications are recommended if an average of three boll weevils are found per trap the two weeks prior to pinhead square stage of growth (Johnson *et al.*, 1993). Mississippi recommends treating if four boll weevils are accumulated per trap the four weeks prior to squaring (Head, 1993). Louisiana recommends treating if five weevils are captured per trap the two weeks prior to pinhead square (Baldwin, 1993).

In-Season Control of Boll Weevils — Once boll weevil reproduction begins in one-third to one-half grown squares, square damage should be assessed to determine the need for insecticide treatments. In-season control principles of the boll weevil are basically the same as that of early control programs. Isely (1933) recommended that when infestations were scattered over whole fields treatment applications should be made when 10 to 15 percent of the squares were freshly punctured. Currently, boll weevil control applications are recommended in Mississippi (Head, 1988) and Tennessee when 10 percent of the squares are punctured, and in Louisiana at 15 to 25 percent damaged squares. Missouri recommends treatment when 25 percent damage occurs under normal conditions and 10 to 15 percent when wet conditions occur or if the populations are building rapidly. Arkansas recommends treatment at one-damaged square per row foot.

The current philosophy on the selection and use of insecticides is based on the biology and life cycle data available on the boll weevil. Since the egg, larval and pupal stages are present only inside squares, either on the plant or in abscised squares on the ground, insecticide treatments must be directed to control the adults. The freshly damaged squares are considered to be the best overall indicator of the adult weevil population level. Once the treatment level is reached, three to five insecticide treatments (at three- to five-day intervals) may be necessary to break the reproduction cycle generally considered to be about 21 days. The insecticide selected should have good residual activity; it should be effective enough to attain good adult mortality during the first 24 hours after application and have continued activity for about 72 hours. This level of activity allows the producer to maintain about a five-day interval between treatments for moderate populations of boll weevils.

CUTWORMS

Several species of cutworms attack cotton. Most cutworms overwinter in the larval stage, but some overwinter as pupae. The eggs are laid on grass or soil in low spots of fields. The eggs hatch in two to five days and larval feeding time averages two to three weeks. Cutworms usually cut off plant stems at the soil surface. Stand reduction may be more visible in field margins and low lying weedy areas. Cutworm damage can be severe enough at times to require replanting.

In Arkansas, Louisiana, Missouri and Tennessee, control decisions are based on the presence or absence of cutworms and cutworm damage. In Mississippi, control is recommended if cutworms reduce the stand below 35,000 plants per acre (3 plants per row-foot) in a field or part of a field.

COTTON APHID

The cotton aphid has been recognized as a pest of cotton in the Mid-South since Isely (1946) reported that injury by the cotton aphid most frequently followed a succession of insecticide dust applications for boll weevil control. High aphid populations stunt seedling cotton growth and hinder plant development through direct feeding. Production of honeydew by late-season aphid populations can cause decreased fiber quality due to black sooty mold associated with honeydew dropped onto cotton fiber.

The cotton aphid has a high reproductive capacity and large populations may develop in cotton in a relatively short period of time. The cotton aphid has a detrimental effect on cotton plant development. The population level density where damage occurs is thought to be fairly high. The precise population level that causes damage is difficult to determine and is affected by the physiological condition and growth stage of the cotton plant.

The cotton aphid has many biological control factors that play a major role in the overall population regulation of this insect. The primary natural enemies in the Mid-South are the braconid parasite, *Lysiphlebus testaceipes* (Cresson) and a fungal pathogen, *Neozygites fresenii*. Both will significantly reduce high aphid populations in a short period of time. These natural enemies have been the major factor in control of aphids in the Mid-South since the onset of aphid resistance to many insecticides.

The cotton aphid was traditionally controlled with organophosphate insecticides such as dimethoate (Cygon®, Rebelate®) and dicrotophos (Bidrin®) prior to 1987. However, control became more difficult as the cotton aphid developed resistant to four classes of insecticides (O'Brian *et al.*, 1991). Kerns and Gaylor (1991) reported that cotton aphid resistance to insecticides increased rapidly within fields shortly after insecticide applications. A similar trend was observed in the Mid-South where early treatments for thrips or plant bugs tended to increase resistance of the cotton aphid to those insecticides. The only successful control was achieved using bifenthrin (Capture®) or a combination of pyrethroid plus an organophosphate (Johnson and Studebaker, 1991). In many cases, the population reached a high level as controls were being applied and the only effective control was the epizootic[1] of the fungus *Neozygites fresenii* or the braconid parasite, *Lysiphlebus testaceipes*.

As a result of these problems, several states developed recommendations to aid in overcoming aphid control problems. These recommendations were directed toward conservation of beneficial insects and insecticide usage, utilizing early maturing cotton varieties, using in-furrow insecticides and careful insecticide selection.

SPIDER MITES

Spider mites may cause damage and occur at any time during the cotton growing season. They generally move into fields from borders which serve as overwintering sites. Spider mites may build high populations in a relatively short time since they develop from an egg to adult in five to seven days during the summer. Early-season applications of pyrethroid insecticides have been shown to increase the probability of spider mite infestations. Areas in fields infested with spider mites may appear lighter in color or reddish from a distance. Treatment for spider mites is recommended when leaves become discolored and mites are numerous or when 50 percent or more of the leaves five nodes from the terminal are infested (Johnson *et al.*, 1993; Head, 1993; Baldwin *et al.*, 1993; Roberts and Lentz, 1993; Jones and Nabors, 1988).

WHITEFLIES

Populations of whiteflies usually occur in late-season. The nymph and adult of the whitefly damage cotton by sucking juices from the plant and by excreting honeydew when the cotton bolls begin to open. The accumulation of honeydew on the lint provides a substrate for the growth of black sooty mold that stains the lint and lowers cotton grades. Treatment for whiteflies is recommended when 50 percent of the plant terminals are infested.

FALL ARMYWORM AND BEET ARMYWORM

The fall armyworm and the beet armyworm may occasionally infest and cause damage to cotton fields in the Mid-South. The eggs are laid indiscriminately in masses of about fifty to several hundred. The masses are covered with a grayish fuzz and hatch in two to four days.

The beet armyworm larvae feeds on foliage, squares, blooms and bolls. The larvae tend to feed in groups and the feeding results in a general ragged appearance of the cot-

[1]Epizootic is the outbreak of a disease that affects large numbers of the same kind of organism at the same time.

ton plant. The fall armyworm does not feed in groups but disperses when the egg masses hatch. The fall armyworm tends to feed on bolls even when the larvae are small but may feed on squares and blooms.

Treatment is recommended in the Mid-South under the following conditions: (a) when three to five egg masses and live larvae are found per 100 plants, or when four or more larvae are found in 100 blooms and bolls; (b) when one small larva is found per four row-feet; or (c) when damaging populations are found.

CABBAGE LOOPER AND SOYBEAN LOOPER

The cabbage looper and soybean looper occasionally may develop into damaging populations in the Mid-South. The larvae are very susceptible to disease outbreaks especially during damp cool weather. Large numbers of the larvae may severely defoliate cotton and potentially reduce yields. Populations of cabbage and soybean looper have been relatively low since the introduction of the pyrethroid insecticides, probably due to the insects's high susceptibility to these insecticides. However, the soybean looper now has developed resistance to most pyrethroids; it is becoming an occasional problem and may cause cotton defoliation in late-season. Treatment is recommended in the Mid-South when 25 percent defoliation has occurred or when populations threaten premature defoliation.

SCOUTING TECHNIQUES IN THE MID-SOUTH

Cotton insect pest management is based on the principles of insect scouting and the use of economic thresholds. Scouting cotton fields for insects at regular intervals during the growing season is one of the most valuable cotton insect management practices available to growers. Insect scouting detects developing insect infestations and population levels; it indicates when an insecticide should be applied based on threshold levels; and, it evaluates insecticide treatments. Fields should be scouted at least weekly and twice weekly is highly recommended to enhance the early detection of damaging insect populations and timely application of insecticides.

Insects are not distributed uniformly and all areas of each field must be covered every time the field is scouted. The pattern followed may be a "Zig-Zag," or a "U" pattern that allows adequate sampling in the center, sides and corners of the field. The major sampling methods used in insect scouting are the point sample, random sample and sequential sample.

POINT SAMPLING

The point sample method involves selecting four points at random (Johnson, 1990) in the field to sample. At each point, all plants are searched on a designated length of row, usually 3.5, 7, or 14 feet. In addition, the shake or drop cloth is used to sample beneficial insects and plant bugs. Small square set is also determined by examining the presence or absence of small squares in the plant terminal. The square set data often reflects the condition of the plant and aids in decisions concerning plant growth.

Square shed may be caused by dry conditions, fertility problems, plant bug populations or newly hatched bollworms.

RANDOM SAMPLING

The random sample method involves examining terminal buds, squares and leaves and sweeping the top one-third of the plants in a random pattern throughout a field. A standard 15-inch diameter sweep net should be used. The number of samples taken should be dictated by the field size. One hundred squares and terminals should be examined in fields of 20 acres or less. The number of samples should be increased accordingly as field size increases. Square samples and leaf samples should be taken from the bottom, middle and tops of the plants to minimize bias. The insect damaged squares should be examined for boll weevil, bollworm and other insect damage. The data is recorded as a percent of the total examined. Insects caught in the sweep net should be recorded as the number per 100 sweeps.

SEQUENTIAL SAMPLING

The sequential sampling method is a modification of the random sample method. It allows decisions to be made to treat or to not treat while the sampling is underway. Background knowledge of the distribution of the insect is required for sequential sampling. Results from using sequential sampling indicate that sampling time may be reduced without loss in accuracy.

AREAWIDE PROGRAMS FOR COTTON INSECT MANAGEMENT IN THE MID-SOUTH

Areawide programs for suppression of cotton insect pests have been successful in the reduction or exclusion of several key cotton pests. These efforts are logical only for pests which infest a large area at a given point in time. Most programs in the Mid-South are targeted toward the boll weevil, bollworm and tobacco budworm and quarantine efforts against the pink bollworm.

BOLL WEEVIL PROGRAMS

Boll weevils were introduced into United States cotton in the later part of the 19th century and had infested cotton in Virginia by 1933. In recent years boll weevils have infested cotton in Arizona and California. From this distribution, it is obvious that boll weevils are truly an areawide pest. This is especially true in the Mid-South where the weevil has been well established since the 1920s.

The first areawide program for boll weevil control was reported by Ewing and Parencia (1950). This program targeted overwintered boll weevils with early-season applications of insecticides. Insecticide applications were terminated early enough to preserve parasites and predators of the bollworm.

Diapause, the winter survival mechanism first reported for the boll weevil by Brazzel and Newsom (1959), insures a continued survival of some individuals which infest cotton the following season. The rate of survival is normally about 10 percent but may be lower following colder winters (Cross, 1983).

Brazzel and Newsom (1959) described a control program that involved late-season applications of insecticides to destroy overwintering boll weevils before they enter ground trash. This concept was later expanded to include the last generation of reproductive weevils. In the Mid-South, Lloyd *et al*. (1966) demonstrated the effectiveness of this program in a reproductive diapause program that reduced the overall population.

Young (1969a) reported on the results of two areawide boll weevil diapause control programs conducted in Monroe and Sharkey Counties in Mississippi. The results were a 30-50 percent cost reduction, fewer insecticide applications, preservation of beneficial insect populations and increased yields.

The Optimum Pest Management Program was conducted in Panola County, Mississippi, from 1978 to 1980. The boll weevil was the target insect but other cotton pests were monitored and controlled. The success of this program on about 30,000 acres of cotton was indicated by an increase in yield of 85 pounds of lint cotton per acre over the previous ten-year average for the county. The number of in-season applications of insecticide per acre decreased from 8.6 (ten-year average) to 3.23 (three-year average). In 1980, the cost of insect control plus scouting was only $17.40 per acre (Andrews *et al*., 1980).

Boll Weevil Eradication — The original Boll Weevil Eradication Test was initiated in Mississippi in July, 1971, and terminated on August 10, 1973. The Technical Guidance Committee concluded "that it is technologically and operationally feasible to eliminate the boll weevil as an economic pest in the United States by the use of techniques which are ecologically acceptable" (Parencia, 1978). For further information, refer to "Cotton Insect Management with Special Reference to the Boll Weevil," Agriculture Handbook Number 589, edited by R. L. Ridgway, E. P. Lloyd, and W. H. Cross.

COMMUNITY MANAGEMENT OF BOLLWORMS/TOBACCO BUDWORMS

In many areas of the Cotton Belt, including all Mid-South states, the bollworm and tobacco budworm are the major pests of cotton. Almost 100 percent of planted acres are infested at one level or another. In some seasons, insecticide resistant tobacco budworms have caused total crop destruction.

Since bollworm/tobacco budworm frequently infest a high percentage of acreage in an area, they are candidates for areawide management. The first successful efforts to manage these pests over a large area were initiated in Arkansas in 1976 (Phillips, 1978). It was assumed that if the June population was reduced in excess of 50 percent, the overall July population would be reduced. As the research progressed, thresholds were developed to treat each generation during the summer (Nicholson *et al*., 1984). The community bollworm management approach requires that at least 90 percent of the cotton acreage participate. The scouting results are summarized daily and bollworm/tobacco budworm pheromone traps are utilized to determine peak flights and egg deposition. When populations reach designated levels, the entire community applies a larvacide plus an ovicide within a three-day period. The success or failure of community programs is dependent on grower support and participation, accurate data collected by the point sampling method, and daily review of the community data to support decisions on control measures. Communities utilizing this approach in Arkansas have realized excellent bollworm/tobacco budworm control, increased yields reduced insecticide costs.

These programs have been expanded to several areas of Arkansas and are currently accepted as standard management practices. Cochran *et al*. (1985) reported that these programs had expanded to 80,000 acres and gave a return of $1,500,000 to cooperators. In addition, insecticide use was reduced by 92,000 pounds per year.

A similar type program was conducted on about 40,000 acres of cotton in Leflore County and 9,000 acres in Monroe County, Mississippi, during the 1980-81 growing seasons. Some reports credited these efforts with returning cooperators $45 per acre. These programs were conducted with cooperation among industry, research, and extension (Head, 1981). An areawide program for bollworm/tobacco budworm and boll weevil management was conducted on about 90,000 acres in the eastern delta of Mississippi in 1982-83 (Head, 1983). Many of these management components continue.

IMPLICATIONS FOR FUTURE AREAWIDE PROGRAMS

With the Boll Weevil Eradication Program successfully in place in North and South Carolina and recently expanded to Florida, Georgia and Alabama, Mid-South producers should expect this program to expand into Mississippi, Tennessee, Arkansas, and Louisiana.

Areawide management will be required for successful introduction of parasites and predators or for release of sterile insects such as the backcross *Heliothis virescens - H. subflexa*. This program showed promise of success in the trial on St. Croix Island (Proshold and Smith, 1982). Stadelbacher (1985) reported that cutleaf geranium, *Geranium dissectum* L., is a major early-season host of bollworm/tobacco budworm. Destruction of these hosts by use of herbicides or mowing, or spraying the hosts with insect growth regulators, shows promise in areawide suppression of bollworm/tobacco budworm.

SUMMARY

The management of cotton insects begins when the cotton seed is placed in the soil. The insect populations in cotton fields are diverse and directly or indirectly affected by production practices used during the production year. Similarly, the methods used to manage insects will affect the earliness, quality and yield of the crop. Early-season insect damage is one of the many factors affecting "earliness" of cotton. Delays in maturity in the early part of the season affect insect pest pressure later in the season (Gilliland, 1981), cotton quality (Schuster, 1977), and yields (Hoskinson *et al.*, 1974). Indirect yield loss may occur particularly in northern areas of the Mid-South where early fall harvesting is critical (Hoskinson *et al.*, 1974). Earliness has been reviewed recently within the context of the value of short-season cotton production (Smith, 1980; Herzog, 1980), insect control (Clark, 1988; Hargett, 1988; Roof, 1988), plant growth regulators (Guthrie, 1988), weed control (Bonner, 1988), and varying agronomic (Burch, 1988) points of view.

Insect control decisions are based upon the detection of insect populations by use of various scouting procedures. However, scouting must be used in conjunction with a working knowledge of insect biology, treatment levels and potential consequences of any control measures that may be applied. Decisions on insect management in mid- to late-season must be directed toward setting and protecting the boll load while considering the many factors that may affect cotton production and insect populations. The key to all successful insect management programs is proper timing of management decisions applied. If a control strategy is needed, it should be applied without delay.

Chapter 22

INSECT AND MITE PEST MANAGEMENT IN THE SOUTHWEST[1]

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INTRODUCTION

The Southwest region of New Mexico, Oklahoma and Texas is rich in entomological history. Contributing to the story have been the insects of cotton and man's efforts to manage them. It was at Brownsville, Texas where the boll weevil first entered the United States in 1892, forever changing the face of cotton production and shaping the development of insect management for years to come. Both Texas and Oklahoma have shared the weevil experience that has molded the development of their current management strategies. Lacking infestations of weevils, New Mexico's management approaches are more similar to the Texas High Plains area, another area where the boll weevil has failed to gain a foothold. The successful development of cotton insect management systems in all three states was dependent upon the unique ecological conditions found in these regions of limited rainfall. In this chapter we will examine the historical progression of insect and mite control recommendations and management guide changes, and the factors responsible for these changes.

[1]USDA's Crop Reporting Service, the United States cotton industry and other groups generally include New Mexico in the West region along with Arizona and California. Because of similarities in insect and mite problems and management practices to those in Texas, the authors of this chapter chose to include New Mexico in the Southwest region along with Texas and Oklahoma.

TEXAS RECOMMENDATIONS

The 1920s were a time of optimism for Texas cotton growers. Acreage had been increasing yearly, with about 18 million being grown in 1926. The chief cotton entomologist of the Bureau of Entomology of the United States Department of Agriculture (USDA), B. R. Coad, had only recently declared that the long awaited solution for the boll weevil, *Anthonomus grandis grandis* Boheman, problem, calcium arsenate, had passed all reviews and now was ready for farmer use (Little and Martin, 1942). This came as the best of news to Texas growers farming about 13 million infested acres. Moreover, airplane application of calcium arsenate, technology pioneered by Coad, seemed imminent. To expedite the development of calcium arsenate at the farmer level, special USDA agents were dispatched to key locations in all cotton growing districts, where they conducted on-farm demonstrations (Parencia, 1978).

On another front, the Texas Agricultural Experiment Station had been graced in 1927 with a special appropriation from the Texas Legislature, money that would hire seven entomologists to research cotton insects (Little, 1960). The Legislature had been moved to this action by the outcries of farmers from South Texas who were suddenly encountering the unanticipated damage from an insect that had long infested cotton but apparently had caused no damage. The insect was the cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter). In 1933, following emergence of this new pest, a USDA laboratory at Port Lavaca, Texas was established for fleahopper investigations. In short order a remedy seemed at hand — sulphur dust and sulphur mixed with certain arsenicals (Parencia, 1978).

A third insect was discovered infesting limited cotton acreage in the far western area of Texas in 1918, the pink bollworm, *Pectinophora gossypiella* (Saunders). In 1936, the pest invaded the Lower Rio Grande Valley (LRGV), a cotton district of substantial acreage. Lacking an effective insecticide for the insect, USDA and later state experiment station scientists concentrated on developing cultural management tools that gave farmers the means to control the pink bollworm. But for the other pests, insecticides seemed the only answer.

Hence, insecticide research by the entomologists necessarily involved the boll weevil, the cotton fleahopper—and to an extent the bollworm, *Helicoverpa zea* (Boddie). Many small and large plot experiments were conducted in the 1930s in East, Central and South Texas. Apparently, the results of this experimentation overstated to farmers the value of sulphur and calcium arsenate. The positive benefits noted in controlled experiments were rarely as evident when the materials were applied by farmers. Sulphur, in reality, was a poor material for the fleahopper, and if calcium arsenate was a superb remedy for the weevil, its use was commonly followed by secondary insect outbreaks (Walker, 1984). The cost-benefit ratio, especially of calcium arsenate, was not a persuasion for wholesale farmer adoption. Though imperfect insecticides, the base of understanding derived from their testing cleared the way for the organic insecticides of post-World War II.

No matter that farmers never wholeheartedly accepted calcium arsenate or sulphur, the experiences involving them set the stage for the more effective insecticides that were to come. Current Texas cotton insect control philosophy often has evolved from the experiences with the far less effective insecticides of sixty years ago. For example, earliness in cotton production was emphasized as a goal when it was recognized that the cotton fleahopper was interfering with the process, and the mediocre results of sulphur applications certainly intensified the focus. With calcium arsenate applications for the boll weevil, there appeared the problem of secondary insects: cotton aphid, *Aphis gossypii* Glover, and to some extent, the tobacco budworm, *Heliothis virescens* (Fabricius), and the bollworm. Calcium arsenate often created more problems than it solved. When the modern and effective insecticides became available in the late 40s, mixtures were commonly recommended to specifically answer the anticipated secondary pest problems.

The outlook and agenda of cotton entomologists of the 1930s were influenced by the stark realities of their situation. If they knew that the boll weevil could be managed by prompt and early stalk destruction in the fall, they also recognized that such a practice was beyond their means. Hand harvesting, lack of harvest-aid chemicals, a protracted harvest period, and stalk destruction severely limited by the available equipment, was the dominating reality. Entomologists being utilitarians, could conclude only that, in a practical sense, boll weevil control really meant controlling summer generation weevils with a series of insecticide treatments during the blooming period. They saw this as the logical course. The prevailing management today, by contrast, is to avoid multiple applications during the blooming period, if at all possible. Today, earliness is the heart of insect management in Texas, and we understand how to secure it with effective insecticides.

Sulphur and calcium arsenate, admittedly inferior products, may well have been effective if the materials had been applied properly and in a timely manner. We can never answer that, but because of the limitations of the Texas Agricultural Extension Service (TAEX) education program in cotton entomology at that time, many growers might not have been properly informed. There was only a single extension entomologist from 1920-1938, and this person, R.R. Reppert, had educational responsibilities in all areas of entomology including: crops, household and livestock.

According to J. C. Gaines, one of the seven entomologists of 1927 and later Head of the Department of Entomology at Texas A&M University (Personal communication), the research entomologists of the 1930s were often called upon for extension activities because of the limited extension capability. Adding a second extension entomologist in 1939 improved the lines of communication and increased extension's capabilities. The new extension entomologist, Cameron Siddall, worked closely with J. C. Gaines, and conducted extension demonstrations on calcium arsenate throughout Central Texas. Gaines saw an improvement in grower understanding after Siddall's arrival. In contrast to only two extension entomologists in the late 1930s, there are over forty extension entomologists in Texas today.

The idea of a statewide extension guide to aid growers in cotton insect control originated with Cameron Siddall. The first such guide was published in 1942 (Siddall and

Gaines, 1942). A single guide served all the different cotton regions of Texas. USDA entomologist K. P. Ewing, of the 1939 created cotton insect laboratory at Waco, also helped draft the 1942 guide. Interrupted by World War II, the development and publication of an annual state guide did not resume until 1947. It has continued each year since.

The remainder of this section is an examination of the changes and evolution of the Texas cotton insect management strategy and extension guide as chronicled through the guides since first published in 1942.

PRODUCTION AREAS IN TEXAS

There are several production regions of Texas that differ significantly in growing season, rainfall, temperature and pest problems. Because of these dramatic differences, a single guide of recommendations for the entire state is no longer published. Instead, specific guides are developed for each of the regions. An understanding of the geography and climate that shapes regional pest problems is necessary to follow the development of Texas' insect and mite management recommendations as presented in the guides. Texas is a large state with several cotton production regions that have evolved over time. Rainfall ranges from near 50 inches per year in extreme East Texas to about 10 inches in western El Paso. The boll weevil, a much more serious pest in high rainfall areas, encouraged the planting of considerable acreage in the lower rainfall areas to the west. These were the very areas that provided the environmental resistance that farmers were looking for to manage the boll weevil, i.e., shorter growing season, lower fertility (and hence more rapid maturing cotton), harsher winters, and less overwintering habitat for the boll weevil. Most Texas cotton production now is located in areas receiving 35 inches or less rainfall per year. Roughly 90 percent of Texas cotton acreage is planted to short-season stripper cottons.

The major cotton production areas of Texas today are the: (a) Lower Rio Grande Valley (LRGV), (b) Gulf Coast, (c) Winter Garden area near Uvalde, (d) Blacklands Prairie area, (e) Central River Bottoms, (f) the Rolling Plains, (g) the High Plains, and (h) Far West Texas. The Lower Rio Grande Valley encompasses 300,000 acres utilizing a medium season system without relying on rapid-maturing varieties. Fifty percent is irrigated. The Gulf Coast is characterized by moderate temperatures, fertile soils, and an annual rainfall ranging from 26 to 56 inches. Cotton is planted on 266,550 acres of cropland from immediately east of Houston to Kingsville. Most of the cotton production is dryland, but only 20 percent is stripper harvested. The Winter Garden area consists of 40,000 mostly irrigated acres of high input production, including Pima cotton. At various times, the Lower Rio Grande Valley, Gulf Coast, and Winter Garden areas were combined into a single management region referred to as South Texas. The Central River Bottom area, mainly the Brazos Valley, is a very fertile production area of 50,000 acres utilizing management practices that were employed in the era of season-long insecticide programs. It is the one place that has not embraced the shorter-season production concept. The Blacklands Prairie area from Dallas to Austin has shrunk from five million acres of cotton during the 1920s to about 200,000 acres of mostly dryland stripper-harvested cotton. The River Bottom and Blacklands Prairie areas often were referred to collectively as Central Texas. The Rolling Plains consists of 1,000,000 acres of predominantly dryland stripper-harvested cotton. The High Plains area encompasses about 3,000,000 acres of short-season stripper cotton. Less than 50 percent is irrigated. The Far West Texas area is a desert area with isolated pockets of production totaling 400,000 acres. The High Plains, Rolling Plains, and Far West Texas areas make up what is known as the West Texas region.

INSECT AND MITE PROBLEMS IN TEXAS

Major insect pest problems in the state are the boll weevil, bollworm, tobacco budworm, cotton fleahopper, early-season thrips, and recently the cotton aphid. Sporadic pests include: spider mites, plant bugs, pink bollworms, stink bugs, cutworms, grasshoppers, leafworms and the silverleaf whitefly, *Bemesia argentifolii* (Bellows and Perring). The importance of pests varies geographically. The boll weevil is important to all areas except the High Plains and most of Far West Texas. The cotton fleahopper can be important in all state areas and its management can have a profound effect on the development of later pest problems. Plant bugs, in association with fleahoppers, can be a serious Blacklands problem. Thrips are primarily a problem in the Blacklands and High Plains areas. Bollworms are a major concern for most of the state while the tobacco budworm, a pest that has developed resistance to several insecticides, tends to plague the more southern and eastern production areas. The cotton aphid only recently has been elevated to major pest status, primarily in the western part of the state.

Boll Weevil — Successful management of the boll weevil has been of paramount consideration in developing workable management systems for Texas cotton insects and mites. From the earliest days of weevil infestations until the present, insecticides have been an integral part of that management. Calcium arsenate dust was the first effective weevil insecticide, but its benefits were never fully realized in the state because of various shortcomings. Cotton aphids, and at times bollworms, would appear in calcium arsenate treated fields; and there were no adequate insecticides for controlling these pests. Nevertheless, researchers often showed that the use of calcium arsenate in experimental plots made money—cotton yields were increased. Entomologists developed economic thresholds for the material in the 1930s. The economic threshold used for the boll weevil in the early 1940s for calcium arsenate applications was set low, insuring that most acreage met the criteria to dust from early to late season (Table 1). However, by 1947, Texas entomologists were recognizing the value of insecticides applied to presquaring cotton for controlling overwintered weevils. This permitted an early crop set and avoided the need to make late season applications to protect late fruit. Late-season weevil applications destroyed beneficial insects, leading to bollworm outbreaks (TAEX 1947). Nevertheless, entomologists of those times believed that in the long-season production areas such as the irrigated Lower Rio Grande Valley, multiple late-season treatments were a reasonable course.

Table 1. Evolution of key boll weevil control recommendations in Texas.[1]

Year	Region	Recommendation
1942	State	Overwintered weevil control. At 1/3rd grown squares, ET[2]=10 percent punctured squares. Late season[3] control, ET=15 percent punctured squares. Calcium arsenate dust.
1948	State	Overwintered weevil control. Presquare applications where history dictates. Late season control, ET=10-25 percent punctured squares.
1949	State	Late season control, ET=25-35 percent punctured squares. Organochlorines.
1957	State	Recommended organophosphates for organochlorine resistant weevils.
	LRGV[4]	Late season control, ET=15-25 percent punctured squares.
1964	West Texas	Overwintered weevils. Where weevils found. Late season, ET=15-25 percent punctured squares.
1979	State	Overwintered weevils. ET=1 weevil found or field history. Two automatic sprays 3-5 days apart.
	West Texas	Late season, ET=30 percent punctured squares.
1982	Corpus Christi	Overwintered weevils, Trap Index.
1988	West Texas	Overwintered weevils, Trap Index. Field ET=5 weevils per 100 row feet.

[1]Recommendations from published extension guides.
[2]ET=economic threshold.
[3]Late season=boll period.
[4]Lower Rio Grande Valley.

The weevil-infested acreage of Texas needed a product other than calcium arsenate for these scheduled application programs. This need was met shortly after World War II with the appearance of several new insecticides of different chemistry. First mentioned in the Texas guide in 1947, the gamma isomer of benzene hexachlorine (BHC) met part of this need but caused bollworm problems. DDT dust, an ineffective chemical for the boll weevil but effective for bollworms, was added to BHC in one of the first dust mixtures designed to avoid these bollworm flareups. Toxaphene dust, another new insecticide, also provided good weevil and bollworm control and fair aphid suppression. Later, toxaphene sprays were found not to be as effective as the dust formulations, and DDT was added to increase weevil and worm control.

The addition of the organochlorine insecticides in 1947 provided Texas farmers a cheap and effective means for controlling the boll weevil and secondary pests. First used as dusts, the organochlorines were later applied in spray formulations. Dusts had far more application limitations than sprays and could only be applied at daybreak or at dusk when the air was calm. Automatic application programs were adopted and promoted by banks and chemical companies (Walker, 1984). Increased nitrogen use and the acceptance of prolonged fruiting varieties followed. Without the threat of the weevil, cotton farmers "pulled out all stops" and yields increased dramatically.

While farmers enthusiastically followed the scheduled programs, extension was advocating a more conservative insecticide use approach with an elevated economic threshold of 25-35 percent punctured squares for late-season weevil control (TAEX, 1949). State entomologists were also recommending the use of early uniform planting dates followed by timely stalk destruction and general field cleanup to reduce the potential overwintering weevil population. These were old practices, but advances in mechanical harvesters and stalk cutters were making these practices a reality in the 1950s.

Boll weevil resistance to the organochlorines was first reported in 1956 in Robertson County and soon was detected in the remaining infested areas. Disaster was averted in 1957 by recommending the use of low but effective rates of the organophosphate insecticides, first mentioned in the 1951 guide (TAEX, 1957a, 1957b). DDT was routinely added because organophosphates, applied at weevil rates, did not adequately control bollworm/tobacco budworm. When both the bollworm and tobacco budworm exhibited resistance to the organochlorines (DDT in most instances), organophosphate rates were sharply increased and application intervals were reduced. Even these adjustments did not bring the level of organophosphate insecticide control up to that provided by DDT in its first year of use. Control programs were increasing in complexity while becoming more expensive. With cheap control no longer a reality, automatic scheduled spray programs ceased to be attractive. Farmers became more willing to follow the advice presented in extension guides advocating cultural control coupled with an early season spray program.

The value of adding either methyl parathion or azinphosmethyl (Guthion®) to defoliant applications was not overlooked as an effective means of reducing potential overwintered weevil numbers. This 1966 Guide recommendation provided yet another management tool that minimized the necessity of disruptive in-season applications (TAEX, 1966a, 1966b, 1966c).

The boll weevil expanded its range in East Texas to include the Rolling Plains, with spotty infestations detected as early as 1920. Overwintering weevils did not reach alarming numbers until the early 1960s (Walker, 1984). Harsh winters, limited hardwood leaf litter (important for successful weevil overwintering), and hot, dry summers had severely limited weevil survival. But the pest apparently adapted to these environmental constraints. The boll weevil invaded the eastern edge of the High Plains in 1963 as the culmination of its westward expansion across the Rolling Plains. Growers reacted strongly, initiating in 1964 a large scale diapause control program which stretched north to south along the Caprock Escarpment separating the High Plains from the Rolling Plains (Moritz, 1979; Rummel *et al*., 1975). The technology used was developed by J. R. Brazzel in 1961. It was extraordinarily successful and has continued to keep the High Plains production area weevil-free for the last 27 years. In this approach to weevil management, adult weevils are killed with insecticides before they can move to leaf litter and successfully overwinter. Smaller diapause control programs have been successful to varying degrees in other West Texas areas.

The latest additions to weevil management have addressed the early part of the production season. The value of delaying planting until after mid-May and then planting uniformly across a community was recognized as a means of maximizing suicidal emergence of overwintered weevils in the Rolling Plains (Rummel, 1965). This practice has been aggressively promoted and widely adopted as a voluntary control method since 1980 in the Rolling Plains area (Slosser, 1978; Masud *et al*., 1985).

The 1979 recommendation for overwintered weevil applications was augmented for the first time since 1947 with the addition that "when one or more weevils are found, apply an insecticide". Only field history had been considered before (TAEX, 1979a,b,c,d). This permitted a slightly more conservative insecticide use approach for many areas where the vagaries of winter weather often had made field history an unreliable basis for prediction.

Studies first conducted between 1977 and 1979 established a positive relationship between the number of overwintered weevils caught in pheromone traps and the percent oviposition-damaged squares during the early one-third grown square period (Rummel *et al*., 1980). This led to the development of the more accurate Trap Index method for determining the need for overwintered boll weevil control in the Rolling Plains area. Four to five traps are placed along field margins near weevil overwintering habitat or near areas of the field with a history of early infestations. The Trap Index guidelines suggest that if more than four weevils are found per trap during the week that first squares appear, treatment is probably justified (Leser *et al*., 1988). If one or fewer weevils are caught per trap during this key week, treatment is not required. When trap catches average more than one but less than five weevils during the pinhead-sized square week, field inspection is necessary to make a management decision. A field monitoring-based economic threshold of five weevils per 100 row-feet examined, was developed by J. Slosser, Texas Agricultural Experiment Station Entomologist at Vernon, and added to the extension service's overwintered boll weevil management guidelines in 1988.

A different Trap Index was developed for the Corpus Christi area (Benedict *et al*., 1985) and incorporated into the management guidelines for that area in 1982 (Parker and Benedict, 1982). This index was based on the cumulative average weevil numbers caught during the six week period prior to the appearance of one third grown squares. Treatment is justified using this method when weevil numbers average more than 2.4 per week. When weevil numbers average less than one per trap per week, treatment is not needed. An insecticide application is warranted only when field scouting confirms the presence of weevils or damage when weevil numbers average 1 to 2.4 per trap-week. The pheromone trap index has presented a much more efficient and reliable method of assessing the need for overwintered weevil control for the Corpus Christi and Rolling Plains areas of Texas.

When tobacco budworms became resistant to organophosphates in the late 1960s, entomologists again were reminded that insecticides might not be the long term solution to most insect pest problems. Bollworms were increasingly a problem, probably the result of weevil insecticide applications that destroyed the beneficial insects, which otherwise controlled the early flurries of bollworms (Walker, 1984). The registration of pyrethroid insecticides in 1979 returned highly effective control for bollworms and tobacco budworms but did little to provide the cure-all insecticide everyone desired. In the mid 1980s, pyrethroid resistance in tobacco budworms began to appear, again making insect management a tenuous affair. While pyrethroids were proven to be as effective as organophosphates for weevil control when used on a 3- to 5-day schedule, their use for this pest is impractical due to cost and is discouraged to prevent the unnecessary risk of increasing resistance levels in the tobacco budworm and bollworm.

It was not until the insect management potential of the new rapid-maturing varieties was elucidated that the short-season cotton production system for weevil management began to flourish. These varieties shortened the vulnerability period, providing a means of escaping high late season weevil and worm infestations. Reference to this important management component did not appear in any of the Texas guides until 1979 when short-season varieties and their production was compared to the long-season production system in the Lower Rio Grande Valley guide (TAEX, 1979d). By the early 1980s, short-season cottons had all but replaced the slower fruiting Lankart types in the Rolling Plains.

Prompt stalk destruction following harvest, long regarded as a boll weevil management tactic, did not receive concerted farmer compliance. There were no laws that required this farmer activity for weevil management. But there were laws in place for stalk destruction for the management of the pink bollworm. Since 1947, the Lower Rio Grande Valley had relied on these pink bollworm regulations to assist in managing weevils. While the value of these practices is well documented, compliance often was not adequate to obtain the desired results with weevils. The absence of damaging pink bollworm infestations for many years had made it impossible to enforce these regulations. In 1986, new mandatory plow-down, stalk destruction and planting dates were legislated for weevil management. Compliance is enforced by the Texas Department of Agriculture. These regulations presently affect pest management zones established in South Texas (includes Lower Rio Grande Valley and Gulf Coast, but excludes the Winter Garden Area near Uvalde) and part of Far West Texas.

Current management practices to exploit the weaknesses of the boll weevil are: (a) utilizing planting dates suitable for the region and more rapid fruiting varieties that shorten the vulnerability period; (b) crop residue destruction to deny food, oviposition sites, and habitat for overwintering weevils; (c) the addition of insecticides to defoliants prior to harvest to eliminate as many weevils remaining in the field as possible; (d) use of diapause control programs where appropriate; and (e) early season applications at the time of first appearance of pinhead-sized squares for control of overwintered weevils. These combined practices often eliminate or reduce the need for mid- to late-season insecticide applications for weevils and preserves beneficial insects that are needed to defend against later bollworm and tobacco budworm problems.

Cotton Fleahopper — In 1947, DDT as a mixture with sulphur quickly began to replace sulphur dust alone for controlling cotton fleahopper. It was soon recognized that the addition of DDT could release secondary pests or bollworms. Also important was proper timing, as early season DDT applications were far less disruptive. By 1947, the 1942 economic threshold, (15-25 percent infested terminals), had been elevated to 25 percent (Siddall and Gaines, 1942; TAEX, 1947). But as the years passed, different thresholds would be used (Table 2). For example, in 1949, area-wide preventative programs for overwintered weevils and cotton fleahoppers tended to replace the threshold concept (TAEX, 1949). These programs were to be completed early in the season, well before blooming.

Applications made after blooms appeared were treated with much reservation in 1949 because of the threat of bollworm problems that could follow cotton fleahopper control applications. The economic threshold was raised for this period to 25-35 percent infested terminals. Entomologists vacillated considerably on establishing thresholds as they tried to avoid early bollworm problems, yet prevent unnecessary losses to cotton fleahoppers. After all, early fruit set was the cornerstone of the emerging short-season production system.

There were, as well, geographical differences in approaches to cotton fleahopper management. Initially the Lower Rio Grande Valley (TAEX, 1952a) and then the Blacklands (TAEX, 1959b) set thresholds lower than the rest of the state. West Texas soon followed in 1961 (TAEX, 1961c). The Blacklands fleahopper problem is exacerbated by the multitude of alternate hosts, from which adult fleahoppers often move to cotton as the first tiny squares are forming in the plant terminals. Significant delays in earliness can follow as a result of square loss from cotton fleahoppers. Hence, a lower threshold was needed to avoid these losses which seemed to be excessive for cotton grown on Blackland soils. Applied at the sixth to eighth node stage, insecticide applications are made no later than 10 days before first blooms appear. The Lower Rio Grande Valley refrained from the use of insecticides for overwintered weevil control between 1968 and 1976, a practice viewed as ineffective there, but did advocate fleahopper treatments more aggressively than some other areas of the state. Applications were to cease at least 10 days before bloom to allow beneficial insects to build up prior to the bollworm season (TAEX, 1976a).

Cotton fleahopper control in Central and South Texas is practiced to shorten the production season and avoid late season weevil, bollworm and tobacco budworm problems. The High Plains area has a weather-induced short growing season. Hence, farmers here can ill afford to lose their early crop to fleahoppers. A low threshold of 15 to 35 percent infested terminals was used until 1976 (TAEX, 1976b).

The increasing difficulty of controlling organophosphate resistant tobacco budworms and less than adequate management of bollworms encouraged state entomologists to retreat from the more liberal insecticide-use fleahopper control guidelines of

Table 2. Evolution of key cotton fleahopper control recommendations in Texas.[1]

Year	Region	Recommendation
1942	State	ET[2]=15-25 percent infested terminals. Sulphur dust.
1947	State	ET=25 percent infested terminals. Organochlorines.
1949	State	2-3 weekly applications early in area-wide program. Late season[3] ET=25-35 percent infested terminals.
1953	LRGV[4]	ET=10-15 percent infested terminals.
1959	Blacklands	ET=25 percent infested terminals. Carbamates and organophosphates.
1961	West Texas	ET=15-25 percent infested terminals.
1962	LRGV	ET=15-35 percent infested terminals.
1970	West Texas	ET=25-35 percent infested terminals.
1971	River Bottoms	ET=35-50 percent infested terminals.
1974	Gulf Coast River Bottoms	ET=25-50 percent infested terminals
	Blacklands	ET=15-25 percent infested terminals.
1975	Blacklands	ET=25-50 percent infested terminals.
1977	Blacklands	ET=15-25 percent infested terminals.
	LRGV	ET=25-50 percent infested terminals and 15-25 percent square damage.
1978	West Texas	ET=25-35 infested terminals and 15-25 percent damaged squares.
1979	Gulf Coast River Bottoms	ET=15-35 percent infested terminals.
1987	Gulf Coast LRGV River Bottoms	ET=15-25 percent infested terminals.
	Blacklands	ET=10-15 percent infested terminals.

[1]Recommendations from published Extension guides.
[2]ET=economic threshold.
[3]Late season=boll period.
[4]Lower Rio Grande Valley

the 1960s and elevate the economic threshold to 25 to 50 percent infested terminals in 1971 (TAEX, 1971a, 1971b, 1971c). However, the Blacklands could not afford to follow these conservative guidelines and has maintained a lower threshold of 15 to 25 percent during most of this period (TAEX, 1974a). The return of adequate bollworm and budworm control in 1979 with the introduction of the pyrethroids, eventually encouraged extension entomologists to lower thresholds to 10 to 15 percent for the

Blacklands (Robinson and Stewart, 1987), and 15 to 25 percent for the remainder of Texas, except West Texas, where a more conservative approach had evolved.

Cotton produced in the weather-shortened growing season of the High Plains is particularly vulnerable to early fruit losses. But severe infestations of cotton fleahoppers are uncommon because of the scarcity of alternate spring hosts (Leser, 1986b). Fleahopper numbers are often low when cotton begins to square, requiring one or more generations to reach potentially damaging levels. This typically does not occur until after cotton has the fruit it can mature. This is particularly true of the dryland acreage. Treatment levels are higher, set at 25 to 30 fleahoppers per 100 plant terminals since 1970 (TAEX, 1970). Even these levels of fleahoppers sometimes fail to cause noticeable losses, especially as the bloom period approaches. Square damage exceeding 15 to 25 percent was added to the cotton fleahopper number economic threshold in 1978 to address this problem (TAEX, 1978d).

The attainment of an early-season prebloom management system of both fleahoppers and boll weevils before bollworms appeared has been crucial to the management of bollworms and other late season pests. In spite of 63 years of often intense research efforts since the Texas Legislature appropriated funds to address the cotton fleahopper problem, management is still a controversial subject. Perhaps a greater knowledge of the cotton plant and its response to the insect will eventually bring understanding.

Though there are risks in triggering secondary attacks of bollworms and tobacco budworms with insecticide treatments for cotton fleahoppers, entomologists generally agree that the risk of losing earliness due to cotton fleahoppers is the transcending consideration. Earliness reduces much of the threat from these pests as well as from the boll weevil, even if insecticides are used to secure this earliness.

Bollworm and Tobacco Budworm — Prior to the arrival of the boll weevil in 1892, only sporadic damage was described from insects. Cotton leafworms, *Alabama argillacea* (Hübner), aphids, and bollworms occasionally caused damage but most farmers ignored these infrequent problems. With a concerted insecticidal effort to control the boll weevil, bollworm problems appeared with greater frequency. This proved true with calcium arsenate and later with the organic insecticides. Bollworm problems could develop suddenly, producing a tremendous amount of damage. Bolls were vulnerable to damage for a much longer period than from the boll weevil.

Texas' first extension guide recommended calcium arsenate dust for bollworm control. The product was to be applied every five days until eggs and larvae were no longer found in the field (Table 3). These treatments were triggered by the economic threshold of 35 to 40 eggs or small worms found per 100 terminals (Siddall and Gaines, 1942). Calcium arsenate was only marginally effective, primarily on small larvae. This almost preventative-like approach all but insured that considerable acreage was targeted for treatment, even though knowledgeable entomologists were well aware that many times bollworm/tobacco budworm infestations caused little damage because of the great amount of biological control of eggs and small larvae that we now know occurs in untreated cotton (Walker *et al.*, 1978). Fortunately, it seems that many cotton growers ignored the calcium arsenate recommendation, and the use of the material was restricted to areas that often experienced bollworm outbreaks, such as the Brazos River Valley (Personal communication, J. C. Gaines, former entomologist and department head, Entomology Department, Texas A&M University, College Station, TX).

By 1947, a DDT recommendation had been added to the guide. DDT was very effective for bollworms when applied against small larvae (TAEX, 1947). Not effective against boll weevils, DDT was added to those organochlorines that were effective for weevil control. It was recognized that these mixtures, applied on a multiple application schedule, eliminated the beneficial insects that might suppress egg and larval populations from bollworm moths moving from maturing corn to cotton. Hence, DDT was added as a bollworm preventative to each weevil insecticide application. In 1948 the economic threshold was changed to 4 to 5 small worms per 100 terminals inspected (TAEX, 1948). This threshold provided little improvement over that of 1942 but remained in place until 1972 with only minor revisions. The recommendation was expanded in 1949 with the addition of eggs to the worm number threshold (TAEX, 1949), perhaps to emphasize that without the threat of further infestation pressure, there was no need to spray these lower worm infestations. Five-percent square damage was added to the worm threshold in 1956 (TAEX, 1956a).

Organophosphates were added to the guides for aphid, cotton leafworm, and spider mite control by 1953 (TAEX, 1953a, 1953b), but were not routinely added to the organochlorine mixture for boll weevil control until boll weevil resistance appeared in 1956. By the early 1960s, bollworms were no longer readily controlled by organochlorines, and a five-day schedule was recommended to maintain control (TAEX, 1961a,b,c). The 1963 guides first mentioned organochlorine resistant tobacco budworms and provided separate comments for tobacco budworms and bollworms (TAEX, 1963a,b,c). In 1967, higher rates of the more expensive organophosphates were recommended (TAEX, 1967a,b,c). These compounds provided only short residual activity against small larvae and were much harsher on beneficial insects than the lower rates used for weevil control. Application intervals were often reduced. Suddenly the bollworm and tobacco budworm had become more important than the boll weevil as pests of Texas cotton. As the organophosphates were increasingly used, resistance in the tobacco budworm began to appear (Adkisson, 1965; Adkisson and Nemec, 1967).

The resistance of the tobacco budworm to all known insecticides in the late 1960s and the concern that pesticides were contributing to the deterioration of the environment caused governmental agencies to assess the wisdom of relying solely on insecticides for control of cotton pests. In 1972, pilot stage integrated pest management (IPM) programs were established in the Lower Rio Grande Valley, Blacklands, Winter Garden, and Far West Texas areas (Frisbie and McWhorter, 1986). These programs provided the opportunity to test IPM practices and educational methods over a wide variety of agricultural systems. Starting with cotton entomology, IPM programs have evolved into multidisciplinary educational efforts to assist and train producers to properly manage all facets of production for cotton and several other crops.

Table 3. Evolution of bollworm and tobacco budworm management recommendations in Texas.[1]

Year	Region	Recommendation
1942	State	ET[2]=35-40 eggs per 100 terminals or small worms found. Calcium arsenate dust every 5 days until eggs and worms gone.
1947	State	Organochlorines added.
1949	State	ET=4-5 small worms per 100 terminals.
1952	LRGV[3]	ET=4-5 small worms + eggs per 100 terminals or 5-7 percent top square damage.
1953	State	Organophosphates added.
1956	State	Added 5 percent damaged fruit to ET.
1969	State	(A) Terminal ET=4-5 small worms + eggs or 5 percent square damage per 100 samples. (B) Whole plant ET=1.5 larvae per 10 row feet.
1972	State	(A) Prior to first insecticide application 1. Prebloom—15-25 percent square damage. 2. After bloom—5-8 percent square damage. (B) After insecticide application. 1. Eggs and 4-5 small worms per 100 terminals and 5 percent damage. 2. 2 larvae per 10 row feet.
1979	State	Added microbial insecticides.
1980	State	Added synthetic pyrethroids.
1980	West Texas	(A) Preblooming ET=15-25 percent square damage. (B) After bloom. 1. ET=8-10 percent square damage and less than 20 percent predator infested terminals. 2. ET=4 worms/10 row feet.
1981	West Texas	(B) After bloom 1. Random whole plant method ET=5,000 small worms/acre and less than two predators per worm.
1987	LRGV[3]	(B) After insecticide: 6 to 10 young worms/100 terminals and five percent squares and small bolls damaged.
1989	West Texas	Cluster scouting method substituted for single random whole plant inspection.

[1]Recommendations from published Extension guides.

[2]ET=economic threshold.

[3]Lower Rio Grande Valley

An extension IPM professional (Extension Agent-Entomologist) with at least a bachelor's degree (preferably a master's degree), is headquartered locally to provide leadership for introducing the IPM concept to producers. The Texas Pest Management Association was established in 1977 as a statewide, producer-operated, non-profit organization dedicated to encouraging the implementation of pest management practices, coordinating statewide pest management activities, providing a mechanism for producer-operated scouting services, and to serving as a liaison between various state and federal agencies. Program acreage has expanded to include 2.3 million crop acres in 22 program areas across Texas.

While field scouting and the use of economic thresholds are the highly visible components common to all programs, they are by no means the only tactics utilized to insure the appropriate use of insecticides. The Texas short-season cotton production system is central to the success of IPM programs. The elements of this system include: (a) selection for rapid fruiting and early maturing varieties; (b) planting dates, (c) nitrogen and irrigation water management; (d) host plant resistance for disease control; (e) crop rotation for nematode control; (f) conservation of beneficial arthropods, (g) use of pheromone trapping and predictive computer models such as MOTHZV; (h) weed management; (i) vegetative growth management with mepiquat chloride (PIX®); (j) use of harvest-aid chemicals for early crop termination; and, (k) stalk destruction and crop residue elimination (Frisbie *et al.*, 1989).

Educational methods used include either intensive individual field scouting or community survey programs where appropriate, use of print and electronic media and weekly newsletters to provide insect situation reports and management advice, turn-row meetings to train producers in proper field scouting techniques, demonstrations to evaluate and facilitate adoption of new IPM technology, and economic evaluation of the IPM program. Texas programs have been very successful and have fostered the rapid development of the private consulting industry. Improved crop management promoted by IPM programs has contributed to the successful management of bollworm/tobacco budworm and other cotton pests over the last 18 years.

The first real improvement in the bollworm/tobacco budworm economic threshold appeared in 1969 when the "row-foot" monitoring method was added as an alternative to the existing threshold choices (TAEX, 1969a,b,c). Whole plant inspections of five 10-foot row sections in each field was advocated. Treatment was recommended when counts averaged 1.5 larvae per 10 row-feet. This averaged about 2,000 larvae per acre and was similar to the 4-5 larvae per 100 terminal method in estimating economic thresholds at 2,000 to 2,500 larvae per acre. This threshold was increased to two larvae per 10 row-feet or about 2,500 worms per acre in 1971 (TAEX, 1971a,b,c).

The lack of an adequate insecticide to address the resistant tobacco budworm problem, the need for multiple applications of short residual organophosphates to combat the bollworm, and the devastation of beneficial insect populations by insecticides finally led to the first major breakthrough in bollworm/tobacco budworm management since 1949. The 1972 guides recognized for the first time that there was a difference between fields that had been treated with an insecticide and those that had not (TAEX, 1972a,b,c). Two sets of economic thresholds that drew on this distinction were offered to cotton farmers. The 1972 guides further recognized that early, preblooming worm damage could be compensated for and set a higher threshold of 15 to 25 percent square damage as the spray trigger. For blooming cotton, the threshold was lowered to 5-8 percent square damage. This was increased to 8-10 percent in 1974 (TAEX, 1974a,b,c,d). Once insecticides had been used and beneficial insects were no longer available to regulate bollworms and tobacco budworms, the older thresholds were followed. Above all, the extension service cautioned farmers to try to avoid treating bollworms until after blooms appeared. This provided at least a ten-day window from the last early-season application to the first needed bollworm spray, hopefully sufficient time for beneficial insect numbers to recover.

Methyl parathion plus toxaphene became the most widely used spray mixture for bollworms and budworms. This lasted until the pyrethroids were first widely used in 1979. It was recognized that under heavy infestations and high resistance, there was no chemical cure for the tobacco budworm problem. Abstinence, or at least restraint, appeared the best course. And for much of Texas cotton, perhaps 95 percent, this view was appropriate. In spite of the problems with the then current arsenal of chemicals, there were no easy-to-use alternatives when damaging infestations appeared. As early as 1964, state guides had added statements that the release of *Trichogramma* or lady beetles had not proven to be an effective control method (TAEX, 1964a,b,c). This advice remains in the guides today.

The MOTHZV computer model developed by Hartstack *et al.* (1976) has been used in Texas for the last fifteen years to predict the occurrence of bollworm and tobacco budworm eggs and larvae. MOTHZV is a heat-unit based model which utilizes pheromone trap catches to provide an area or county-wide prediction. This information is utilized by extension entomologists to alert growers and consultants as to the need to intensify field scouting. The timing of crop irrigations in relation to predicted peak oviposition by bollworm/tobacco budworm moths is a crop management practice that has been recommended to growers for twelve years. (TAEX, 1979a). Termination of crop irrigation at least ten days prior to a MOTHZV predicted peak egg-lay is recommended to reduce plant attractiveness to bollworm/tobacco budworm and to provide less favorable field humidity conditions for survival of eggs and newly hatched larvae.

TEXCIM50 is the current version of a decision-aid computer model developed to provide pest management decisions based on the predicted cumulative economic losses from cotton fleahoppers, boll weevils, and bollworm/tobacco budworm (Hartstack and Sterling, 1989). Simulations for bollworm/tobacco budworm can be initiated using pheromone trap catches and MOTHZV or field counts of eggs and larvae. The estimated costs of pest damage can be used to evaluate the economic benefits of natural and insecticidal control. While TEXCIM50 claims to be user-friendly, it has not gained wide acceptance in the agricultural community. The time required to collect and enter the necessary data on an individual field basis discourages most crop managers from using the model. Perhaps the main benefit of TEXCIM50 is as a research tool. Through the development, validation and implementation of this type of model, areas of weakness in our knowledge base can become evident.

The microbial insecticides provided some promise of control without the destruction of beneficial insects. Entomologists discussed the use of *Bacillus thuringiensis* (Bt) and the commercial formulation of a nuclear polyhedrosis virus, Elcar®, in newsletters by 1978, recommending them officially the next year in the state guides (TAEX, 1979a,b,c,d). Microbials were most effective against low to moderate worm numbers and when moderate to high numbers of beneficial insects were found. Results were inconsistent, with some good successes, but many resounding failures. These products were recommended before adequately researched for appropriate use patterns. Farmers, consultants and state entomologists alike, reluctant to disturb the delicate balance that existed in a cotton field, often used microbials in place of the harsher organophosphates. After all, once organophosphates were used and beneficial insects were eliminated, bollworm management meant multiple sprays for the rest of the season. Little did they realize, as we shall discuss later, that field scouting coupled with realistic economic thresholds could preclude this outcome.

Microbials were widely and indiscriminately used. As a result of the attendant frequent failures, most crop managers became reluctant to use these specialized materials. This was unfortunate since they do indeed have a place in the management of bollworm/tobacco budworm. By 1982, research was demonstrating that the biological materials should be recommended only before blooms are present, recognizing the coverage problem with larger plants as well as the nature of bollworms to remain sequestered inside large cotton bolls. (Allen and Norman, 1982; Fuchs *et al.*, 1982; Parker and Benedict, 1982; Turney *et al.*, 1982). Microbials can be effective at an infestation level of up to 15 larvae per 100 terminals. A specific microbial section was added to the 1983 guides (Allen and Norman, 1983; Buxkemper *et al.*, 1983; Cole, 1983; Neeb *et al.*, 1983). Basically, it recommended the use of microbials in prebloom cotton for infestations of 6,000-10,000 small larvae per acre if beneficial insect numbers were high. Once pyrethroids were registered, microbial insecticide use plummeted to the extremely low levels that exist today.

The addition of the ovicide chlordimeform (Galecron®, Fundal®) to the guides in 1974 provided yet another approach to combating organophosphate resistant bollworm/tobacco budworm (TAEX, 1974a,b,c,d). Texas did not recommend the use of ovicides alone. Methomyl (Lannate®, Nudrin®) and thiodicarb (Larvin®) were later added as contact ovicides with the same use restrictions. Chlordimeform was voluntarily removed from the market in 1977 but returned in 1980, and lasted until 1989, when it was withdrawn permanently from the cotton market. In later years, chlordimeform was also recognized as a synergist for pyrethroids when these were used against pyrethroid resistant tobacco budworms. Many Blacklands producers have been using ovicides since 1987 to forestall the need to use pyrethroids and minimize the risk of enhancing resistance and losing control completely (Personal communication , Allen Knutson, Texas Agricultural Extension Service, Dallas). Not based on research, this approach may have resulted in many unnecessary applications.

Under the emergency use provisions of Section 18 of FIFRA in 1977 and 1978, and with conditional registration in 1979, pyrethroid use reintroduced a level of bollworm and budworm control not seen since the early days of DDT use. Much more expensive, these products had long residual activity and were effective against even larger larvae. These characteristics made them widely accepted by state entomologists and farmers. A period of relative impunity from bollworm/tobacco budworm problems lasted until tobacco budworm resistance resurfaced in 1986. By 1987, the cotton guides were addressing resistance management (Fuchs *et al.*, 1987; Cartwright and Norman, 1987; Robinson and Stewart, 1987). Resistance monitoring using traps and the vial bioassay technique was initiated, and special resistance management guidelines were published. Essentially, pyrethroid use is discouraged early in the season and against pests other than bollworm/tobacco budworm or the pink bollworm. Pyrethroid applications are advocated only during the July generation of bollworms and budworms. Carbamates, organophosphates, and microbials are recommended at other times. This meant that pyrethroids were not to be used prior to first bloom and not late in the season. The short-season cotton production system developed for boll weevil management is a very effective adjunct to this insecticidal approach. The resistance management program appears to be working thus far in preserving the effectiveness of the pyrethroids.

West Texas recommendations began to diverge from other areas of the state by 1979. Extension entomologists observed that economic thresholds defined from Brazos River Valley small plot work dealt with mainly chronic, relatively low level, multi-generation bollworm problems. This was the situation that the 1949 economic threshold of 2,500 larvae per acre clearly addressed. But West Texas infestations generally occurred later in the boll maturation period. These were acute infestations of shorter duration. The 1979 West Texas guide increased the state recommendation from two to four per 10 row-feet, the number of larvae necessary to initiate a treatment (TAEX, 1979a). This represented about 5,000 larvae per acre. The five-point field scouting method of 1942 was replaced with four quadrants per 100 acres with 25 squares or terminals examined in each quadrant.

Recognizing the role of biological regulation of eggs and small larvae, entomologists integrated predator numbers more fully into the economic threshold during the boll period in the 1981 and 1982 guides (Leser *et al.*, 1981; Fuchs *et al.*, 1982). This eliminated the distinction of pre- and post- insecticide treated fields, which remains in other area guides today. West Texas guides advise producers that control measures may not be needed or that a microbial insecticide may be a more appropriate control measure when two or more key predators are found for each small larva or egg. These key predators include several species of spiders, the big-eyed bugs (*Geocoris* spp.), the damsel bugs (*Nabis* spp.), assassin bugs (*Zelus* and *Sinea* spp.), minute pirate bugs (*Orius* spp.), lady beetles (*Hippodamia* spp.), and green lacewings (*Chrysoperla* spp.)

The development of annual, widespread bollworm problems in the High Plains area, starting in the 1970s, provided further impetus for area entomologists to refine existing economic thresholds. The weakness of the row-foot method and square-damage techniques was apparent to several West Texas extension entomologists. The row-foot method was too time consuming and did not appear to permit adequate, representative sampling of the whole field. The square- monitoring technique did not satisfactorily define the larval infestation, often underestimating its magnitude. Consequently, the row-foot scouting method for the boll period was augmented in 1981 with the random whole-plant method where individual dominant plants were inspected across the field; a minimum of ten plants were checked per quadrant (Leser *et al*., 1981). The use of dominant plants permitted reasonable decisions with less sampling. The economic threshold was set at 5,000 small larvae per acre. This system has worked for several years on the High Plains and detects the frequent infestations that occur below the plant terminal. Numbers are expressed on a per acre basis rather than as percent infested plants. This compensates for probable errors resulting from plant densities varying between fields.

The terminal checking method was added in 1983 mainly for the Rolling Plains area where terminal infestations are more the rule than the exception (Neeb *et al*., 1983). A cluster method replaced the single dominant plant method in 1989. This sampling technique was developed from the research of Walters *et al*. (1990) where probabilities for accuracy for a given economic threshold also are presented. Sample units consist of 3-5 clusters of consecutive plants at each field check point. Five such clusters are checked per field quadrant. The economic threshold has remained the same although experienced crop advisors often elevate it to 8,000-10,000 per acre with no indication of a problem. The key is the recognition that considerable numbers of bollworms can be tolerated without undue damage if the infestation is of short duration. Chronic infestations are another matter and are not altogether adequately addressed by the current set of economic thresholds.

Bollworm/tobacco budworm management in Texas succeeded in isolating worm problems from the issues of early season fleahopper and boll weevil control and their consequences. Early season applications for overwintered boll weevils and fleahoppers are terminated with sufficient time to allow beneficial insects to repopulate before the bollworm and tobacco budworm egg flurries begin. More conservative economic thresholds and reliable scouting techniques have reduced the use of insecticides while still preserving yield. Where the tobacco budworm is a mid-season problem, the pyrethroid resistance management program is followed by the majority of crop managers. The short-season cotton production system that has evolved for weevil management in Texas provides the rest of the tools necessary to manage bollworm/tobacco budworm successfully.

Thrips — The status of thrips as a pest has vacillated from time to time, as much a product of changing management philosophies as to actual damage potential. Several species of thrips have been involved including tobacco thrips, *Frankliniella fusca* (Hinds); flower thrips, *Frankliniella tritici* (Fitch); and western flower thrips, *Frankliniella occidentalis* (Pergande). Recently the western flower thrips has been the more serious and extensive species. Control of thrips is first mentioned in the 1952 Lower Rio Grande Valley guide where preventative sprays were recommended when leaf silvering appeared (TAEX, 1952a). This corresponded with the prevailing philosophy of preventative control for early season pests in general. In 1956, the state guide added phorate (Thimet®) seed treatments to the list of foliar insecticide treatments for early season infestations of thrips, leafminers, aphids, and spider mites (TAEX, 1956a). At the same time, Lower Rio Grande Valley entomologists took a more conservative insecticide use approach to early season insect control and removed all preventative treatment recommendations from their guide (TAEX, 1956b). This corresponded with concerns for controlling organochlorine resistant boll weevils and with a general consensus that early season treatments usually created more problems than they solved.

By 1961, thrips control was suggested based on the mere presence of thrips at plant emergence in Texas areas other than the Lower Rio Grande Valley (TAEX, 1961a). Disulfoton (Disyston®) granules were added as an in-furrow application at planting with the realization that cool, wet weather could cause stand reductions. Even multiple early season sprays were often observed to retard plant growth and squaring, a poor tradeoff for insect control. Phorate (Thimet®) was added by the Texas Agricultural Extension Service (1963a) as an in-furrow granular application recommendation for thrips control.

A reaffirmation of preventative treatments was observed in 1964, even in South Texas. At-planting insecticides were listed in the table of insecticide recommendations for the first time and the very effective foliar organophosphate insecticide dicrotophos (Bidrin®) joined the ranks of control tools (TAEX, 1964a,b,c). The economic threshold had changed little during the 20-year period since 1952. Thrips infested fields were treated either based on damage, presence of thrips, or both criteria. West Texas guides made a major change by removing all at-planting insecticides, preferring to rely on actual observed need rather than field history of problems (TAEX, 1971a). This change took place just before aldicarb (Temik®) was registered for use on cotton, the first truly effective at-planting systemic insecticide offered to farmers. Even the Central Texas guide stated a preference for treatments based on need over preventative at-planting applications (TAEX, 1971b).

The river bottom area of Central Texas was the only area still recommending at-planting insecticides for early season insect control in 1974, even though this advice had been removed from the insecticide table proper (TAEX, 1974a). Aldicarb was added with the warning that higher rates could cause bollworm problems. Clearly, the early research with aldicarb had shown the effectiveness of the material but at the same time noted the potential for increased bollworm problems. It was not recognized for another ten years that the higher rates initially tested were not needed to achieve thrips control, and that lower rates did not aggravate the bollworm situation. Accordingly, the 1977 South Texas guide removed discussion of systemic insecticides entirely (TAEX, 1977a). The underlying issue in all this, of course, was the persuasive argument of one of IPM's tenets, that insecticides should be applied only as needed, based on field scouting. Little did entomologists realize in those days that the onset of thrips damage can be so sudden in some areas that only preventative treatments could adequately address the problem.

Research was beginning to identify several areas of the state that did not benefit from thrips control (TAEX, 1978a,b,c). This included the Central Texas River Bottoms, Gulf Coast and Lower Rio Grande Valley. South Texas went so far as to eliminate thrips as a pest from the guide. During the period from 1979 to 1982, thrips were removed from the table of insecticide recommendations for the Central River Bottoms and Gulf Coast areas. Clearly the sentiment was against preventative treatments and early-season control of insects other than weevils and fleahoppers. After all, early-season thrips, leafminers, aphids and spider mites were viewed as minor pests—more an emotional problem than one with substance—with little research to show an economic advantage in their control.

West Texas entomologists generally concurred with the rest of the state but could not completely ignore the fact that High Plains farmers were addressing thrips as a serious problem, treating over 500,000 acres with aldicarb (Temik®) (Leser, 1986a). Research tests by 1976 had showed little yield response from thrips control. Thrips had been relegated to minor pest status with damage often exacerbated by weather problems common during the emergence period on the Texas High Plains. But the research findings of Rummel and Quisenberry (1979) showed the faults of earlier tests, which based treatment timing on damage and not on actual thrips numbers. Treatments delayed until damage appeared did not result in yield increases while those applied prophylactically, before damage was evident, were successful in providing respectable yield increases. Clearly, entomologists had been misled by earlier faulty research. Increasing concern for what was now obviously a more serious pest led extension entomologists to add the first thrips economic threshold to the West Texas guide, utilizing counts of 2-5 thrips per plant during poor growing conditions as an action level (Leser *et al.*, 1981).

Extensive thrips control testing was done between 1981 and 1986. Treatments tested included at-planting granular insecticides, seed treatments and foliar sprays based on damage, thrips numbers, or applied automatically (Leser, 1986a). These tests clearly demonstrated that preventative treatments were superior in providing yield increases, averaging 22 percent in irrigated production areas north of Lubbock. Other conclusions drawn from these tests were: (a) wheat acted as a reservoir for thrips that move to emerging cotton as wheat matures; (b) planting dates influenced the juxtaposition of thrips moving from wheat to cotton; (c) aldicarb (Temik®) was the best of the at-planting insecticides; (d) higher rates of aldicarb (Temik®) and lower rates of phorate (Thimet®) and disulfoton (Disyston®) could cause considerable phytotoxic problems including a reduction in early set squares; and (e) moisture limitations in much of the dryland acreage often eliminated earlier advantages gained from thrips control. One other conclusion drawn from these studies was that there could be no yield response from insecticide treatments without damaging thrips numbers. Many of the earlier thrips control tests lacked sufficient thrips numbers to cause yield reductions.

These findings led to the reintroduction of at-planting systemic insecticides into the West Texas guide in 1986 after a hiatus of 15 years (Leser *et al.*, 1986). The Blacklands guide had already added at-planting systemic insecticides back into the thrips control recommendations four years earlier (Turney *et al.*, 1982). By this time it was recognized that the Blacklands and High Plains areas were generally the only regions with damaging thrips problems. The large winter wheat acreage and coincidence of cotton emergence dates with wheat maturity is probably responsible. The Rolling Plains area has the wheat acreage but the use of a delayed planting date for weevil management places cotton emergence later than wheat maturity. Thrips simply are not a problem.

Pink Bollworm — While calcium arsenate and sulphur appeared to be the answer for most cotton pests, the lack of an effective insecticide encouraged USDA and state experiment station entomologists to develop a cultural control strategy for the pink bollworm. This pest had invaded the substantial acreage of the Lower Rio Grande Valley in 1936 after an initial sortie in the limited cotton acreage at El Paso in 1918. The second state cotton guide issued in 1947 reflected the cultural control research addressing the pink bollworm (TAEX, 1947). The state was divided into zones with planting dates and stalk destruction following harvest regulated by the county or the Commissioner of Agriculture. The adoption of the proposed post harvest cultural control practices was not possible until mechanical harvesters and stalk cutters were available, the same limitations facing entomologists waging a war against the boll weevil.

The 1950s saw severe outbreaks of pink bollworms up into Central Texas. Insecticidal control was first advocated in 1949 with the arrival of the effective organochlorines, DDT and BHC (TAEX, 1949). Much of the control was realized from the destruction of the adult stage. Generally, insecticidal control was not recommended unless winter carryover created a problem. Treatment of fields was advocated where rosetted blooms indicated a heavy infestation. Insecticides were to be applied on a weekly schedule until cotton bolls opened. The 1953 Lower Rio Grande Valley guide first mentioned an economic threshold, recommending control when there were 10 percent rosetted blooms or 200 larvae per acre prior to the boll setting period (TAEX, 1953a). Treatment was to be delayed until bolls were 20 days old if only five percent rosetted blooms or 100 to 200 larvae per acre were found. All other infestations were to be addressed when 10 to 15 percent of the bolls were infested.

The 1959 economic thresholds were modified only slightly by elevating the pre-boll economic threshold to 500 larvae per acre, based on the new sampling technique where rosetted blooms were counted in 1500 feet of row in each field checked (TAEX, 1959a). Harvest-aid chemicals were advocated to force open remaining bolls as an encouragement for early harvest and stalk destruction. By 1960, the economic threshold had evolved to 350 larvae per acre or 10 to 15 percent infestation once bolls were present (TAEX, 1960a). Worm count criteria were used for the period prior to the appearance of bolls. New insecticides augmented the organochlorines for pink bollworm control with the addition of azinphosmethyl (Guthion®) in 1956 and carbaryl (Sevin®) in 1959 (TAEX, 1956b, 1959a). Except for the addition of monocrotophos (Azodrin®) in 1975, no new insecticides were listed until the synthetic pyrethroids were added in 1983 (TAEX, 1975a,b; Neeb *et al.*, 1983).

The only area remaining with occasional problems with pink bollworms is Far

West Texas. The Lower Rio Grande Valley guide ceased to list the pink bollworm as a pest of cotton after 1976, following several years of only spotty problems (TAEX, 1976a). The pink bollworm is a late season pest in Far West Texas. The goal there is to produce an early crop and then terminate by mid-September. Generally, the first three weeks of the boll setting period are addressed with insecticides when 10 to 15 percent of the bolls are infested. Late infestations as high as 40 to 50 percent are not a problem in top bolls that will not mature. By 1983 the West Texas guide had added the lower economic threshold of 5 to 10 percent for Pima cotton, distinguishing it from the less susceptible upland cottons (Neeb *et al.*, 1983). Pheromone traps were also added as an early indicator of pink bollworm problems. Once moths are captured in traps, fields are to be inspected for rosetted blooms. Treatment is recommended when bolls are 15-20 days old, using the 1953 Lower Rio Grande Valley guide recommendation.

Cotton Aphids — By the time of the drafting of the 1948 guide, research had established that the gamma isomer of BHC, one of the new organochlorines, would control cotton aphids (TAEX, 1948). The product was formulated as a dust and mixed with sulphur (for spider mite suppression) and DDT (for bollworm control). BHC also controlled boll weevils. This represented the first insecticide that could control aphids and be accepted by growers. Earlier, nicotine sulphate had been added to calcium arsenate for aphids, but this product was not widely accepted. Organophosphate insecticides were added in 1951 (TAEX, 1951). Initially, infestations were to be controlled when honeydew appeared (TAEX, 1949), but later, leaf curling was added as a damage symptom (TAEX, 1952a). By 1971, Texas guides were presenting a more restrained approach to insecticidal control of aphids, suggesting that beneficial insects generally hold aphid numbers below damaging levels (TAEX, 1971a,b,c). The 1979 West Texas guide went one step further, indicating that bollworm outbreaks were probable following insecticide applications targeting aphids (TAEX, 1979a). In truth, there were no data to support this statement, which had been added to further discourage what was perceived as unnecessary aphid control applications.

In 1979, after a four-year hiatus from the last severe outbreak (Rummel, 1975), a serious, widespread aphid problem occurred in West Texas. These late season infestations have been an annual problem ever since. Statements to the effect that sooty mold and incomplete fiber development from aphid infestations could reduce fiber quality were added to the guide (TAEX, 1979a). By 1983, early insecticide screening trials against late-season aphid infestations in West Texas dryland production acreage indicated yield reductions averaging 60 pounds of lint per acre would result from infestations above 50 aphids per leaf. At this time, very effective low rates of the insecticides dicrotophos (Bidrin®), disulfoton (Disyston®), and dimethoate (Cygon®) were available for aphid control (Neeb *et al.*, 1983).

Field monitoring currently consists of estimating the number of aphids per leaf by examining randomly selected mainstem leaves equally divided between the upper, middle and lower parts of the plant. Once aphid numbers reach 25 per leaf, infestations usually increase rapidly to damaging levels (Leser, 1989). This management approach is not presently recognized officially in Texas guides. By 1986 it was clear that aphids were a major yield detractor in dryland cotton fields to the south of Lubbock. Since 1979 between 500,000 to 850,000 acres have been treated annually either as applications solely for aphids or as combinations with bollworm treatments. Control problems were experienced in 1988 and 1989, when infestations appeared in June prior to squaring, two months earlier than usual. The 1990 season brought unofficial recommendations to increase insecticide rates to address a more insecticide-tolerant aphid.

Silverleaf Whitefly — This insect was recorded from cotton in the Lower Rio Grande Valley as early as 1946 (Russel, 1975), however, the first severe infestations in cotton were reported in 1990. Norman *et al.*, 1992 estimated the total impact of this pest on the overall cotton economy in the Lower Rio Grande Valley for 1991 was in excess of $73 million.

Silverleaf whitefly attacks many vegetables and fruits such as cabbage, cucumbers, cantaloupes, and watermelons; thus in subtropical areas, such as the Lower Rio Grande Valley, it is able to maintain populations through fall, winter, and spring to infest cotton through the spring and summer. This lack of a substantial host free period plus poorly timed and limited control measures have contributed to the tremendous outbreaks in the Lower Rio Grande Valley (Riley and Wolfenbarger, 1993). Other production areas (Far West, Gulf Coast, and Winter Garden) have experienced sporadic infestations, but damage to cotton has not reduced yields (Personal communication, John Norman, Texas A&M Extension Service, Weslaco).

Recommendations for management of this apparently well established pest in the Lower Rio Grande Valley involve integrating several control tactics with primary emphasis on temporal and spatial separation of host crops. Specifically, Norman *et al.*, 1993 suggest: (a) plant cotton early to avoid high infestation in the summer; (b) use resistant, tolerant, or non-preferred cotton varieties; (c) destroy old crop residues that harbor whitefly infestations; (d) avoid planting next to other crops infested with the pest; (e) delay planting fall vegetables until migrating whitefly populations diminish; (f) adopt application technology that improves coverage to the leaf underside; (g) incorporate one to two percent oil or soap mixtures in high volume spray treatments; (h) use insecticides selectively to preserve beneficial insects; (i) alternate insecticide chemistries to delay/avoid development of resistance; and (j) consult extension service for effectiveness of insecticides and other treatments.

Other Insect and Mite Pests — There are other pests of cotton that occasionally have created problems for Texas cotton farmers. They have been listed at various times in the cotton guides. These include cotton leafworm, *Alabama argillacea* (Hübner); brown cotton leafworm, *Acontia dacia* Druce; plant bugs; spider mites; armyworms; cabbage looper, *Trichoplusia ni* (Hübner); the soybean looper, *Pseudoplusia includens* (Walker); several species of grasshoppers; cutworms; wireworms; garden webworm, *Achyra rantalis* (Guenée); whiteflies; cotton square borer, *Strymon melinus* Hübner; false chinch bug, *Nysius raphanus* Howard; and others too restricted geographically and of limited duration to really matter.

Cotton leafworms were an old but serious pest of cotton prior to the use of calcium arsenate dust. Leafworms have received only limited attention in the development of state guides since 1942. Except for those rare years when leafworms have moved across Texas, causing extensive defoliation as far as the southern High Plains, leafworms have been relatively minor pests. Insecticides have dealt handily with predominantly late season, spotty leafworm infestations.

Plant bugs have been a continual problem mainly for Blacklands cotton production, although occasional serious infestations have developed in the South Texas area as well. The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is the eastern species attacking cotton in the Blacklands and South Texas. The western lygus bug, *Lygus hesperus* Knight, is the western species. *Lygus* can be particularly damaging because, unlike the fleahopper, even larger squares, blooms, and small bolls are vulnerable to attack. The 1947 guide recommended toxaphene and sulphur for their control (TAEX, 1947). By 1959, organophosphate insecticides were beginning to be listed as effective *Lygus* control materials (TAEX, 1959a,b).

Economic thresholds for plant bugs have evolved since first introduced in the Lower Rio Grande Valley guide in 1952 (TAEX, 1952a). The economic threshold of 10-12 bugs per 100 squares that year lasted until replaced by the 1954 threshold of 8-10 per 100 sweeps (TAEX, 1954a,b). This threshold persisted until 1971 when an early bloom economic threshold of 10 bugs per 50 sweeps and a late season threshold of 20-30 bugs per 50 sweeps were added (TAEX, 1971a,b,c). Nymphs are counted as two bugs. These guidelines promoted a much more conservative insecticide use approach than the earlier treatment recommendations. Today the Blacklands area has a combination economic threshold for both fleahoppers and *Lygus*. A considerable arsenal of organophosphate and carbamate insecticides have been added since 1959 (Cole, 1988; Leser *et al*., 1988; Norman, 1988).

Spider mite problems have invariably been regarded as the consequence of insecticide applications targeting other pests. The mite problem persists today where multiple applications of most synthetic pyrethroids can induce the development of later season spider mite problems. Two species are generally recognized, the carmine spider mite, *Tetranychus cinnabarinus* (Boisduval), and the twospotted spider mite, *Tetranychus urticae* Koch. The red spider mite, first identified as the desert spider mite, *Tetranychus desertorum* Banks, was the earliest recorded problem mite in Texas. This may have been a mis-identification since the desert spider mite and the currently recognized two species of mites can have red coloration and are not easily distinguished from each other. Regardless of species involved, these earlier mite problems were avoided by adding sulphur dust to calcium arsenate applications (TAEX, 1947). Aramite®, parathion, methyl parathion, malathion, and Systox® were soon added (TAEX, 1951; 1952a,b,a,b). Twospotted spider mites were addressed for the first time in the 1954 state guide (TAEX, 1954b).

Prior to 1966, the only changes in mite control recommendations were the addition and deletion of particular miticides. The 1966 guide covering the Blacklands and Central River Bottom areas mentioned resistance problems for the first time (TAEX, 1966a). By 1968, monocrotophos (Azodrin®) had been added to address control problems (TAEX, 1968). In 1979, state guides recognized that hot, dry, dusty conditions or elimination of beneficial insects with insecticides often led to mite problems (TAEX, 1979a,b,c). In general, no economic thresholds have been developed for these pests, and with the loss of monocrotophos (Azodrin®) in 1989, only bifenthrin (Capture®) and avermectin (Zephyr®) are available for effective, but very expensive mite control.

Armyworms, consisting of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith); yellowstriped armyworm, *Spodoptera ornithogalli* (Guenée); and beet armyworm, *Spodoptera exigua* (Hübner), have long been recognized as mainly foliage feeders. As such, state entomologists chose to ignore most infestations. Until an economic threshold of 10 to 20 percent infested plants was added to the West Texas guide (TAEX, 1971a), beet armyworms had been treated like any other armyworm *i.e.*, treat on an as needed basis. But this was dropped the next year, 1972. Following widespread, devastating beet armyworm problems in West Texas in 1980, it was recognized that this pest could feed on terminals, squares, blooms and bolls (Leser, 1986b). This resulted in the only significant management change for armyworms to date. Taking into account the relatively unimportant and high degree of leaf feeding by beet armyworms, West Texas entomologists set the armyworm economic threshold at 20,000 larvae per acre, four times higher than the bollworm economic threshold (Leser *et al.*, 1981). This was amended in 1984 to require at least 10 percent of the plants checked to be infested to avoid sampling problems resulting from the very clumped distribution of armyworms (Boring *et al.*, 1984). The addition of thiodicarb (Larvin®) in 1987 provided an effective material for armyworm control (Fuchs *et al.*, 1987).

Formerly, sudden appearance of some unexpected pest during one year precipitated a quick response at the fall guide revision conference with the listing of this new pest in the following year's management guide. These new pest listings rarely were accompanied with meaningful management advice, and control suggestions were often predicated on excessive damage. Usually ephemeral (short term), these pests often failed to appear in subsequent years. Recent years have seen a more prudent approach to the appearance of new pests. Rarely are these new, occasional pests listed in guides without sufficient data to support appropriate management recommendations.

OKLAHOMA RECOMMENDATIONS

HISTORICAL BACKGROUND

Cotton production has been a major cash crop in Oklahoma since the state's conception as Indian and Oklahoma territories. Maximum planted acreage within the state reached 5.4 million acres in 1925. However, by the end of the next decade, cotton acreage had dwindled to 1.9 million acres, which was largely due to drought (i.e., 1930, 1934, 1935 and 1936) and the inability of the producers to control cotton pests, primarily the boll weevil. Cotton acreage continued to decline during the next 40 years, bottoming out in 1983 with only 320,000 planted acres. Since the PIK (Payment In Kind program) year of 1983, planted acres have ranged between 350,000 and 420,000 acres annually with production concentrated in the southwest quarter of the state (Anonymous, 1982).

Prior to the arrival of the boll weevil in 1905, the bollworm was the dominant but sporadic pest. Heavy infestations of bollworms with concurrent significant yield losses were reported from Texas, Oklahoma, and the Indian Territory from 1903 to 1906 (Bishopp and Jones, 1907). In 1905 the Oklahoma Territorial Legislature attempted to prevent establishment of the boll weevil north of the Red River by imposing a quarantine that prohibited the importation of cotton seed, seed hulls, and sacks from neighboring states. These efforts failed, however, for in the summer of 1905, boll weevils appeared in fields along the railroad tracks near Caddo, in Byran county (southeastern Oklahoma). By 1915, the weevil had covered the entire state (Sanborne *et al.*, 1935). For the most part, damaging infestations of boll weevils remained in the eastern two-thirds of the state until the late 1950s.

The shift in cotton acreage from Eastern Oklahoma to the southwest quarter of the state was due, in part, to the farmer's attempts to escape the ravages of the boll weevil as well as to the economic advantage cotton enjoyed over alternative crops. Semi-arid conditions and lower winter temperatures enhanced boll weevil mortality and reduced the overall loss annually inflicted by weevils compared to losses in the higher rainfall areas of eastern Oklahoma.

The Oklahoma cotton industry lost over 438 million dollars in the 16-year period between 1916 and 1932. Most of this could be attributed to the boll weevil (Sanborne *et al.*, 1935). Without the efforts of the Oklahoma Cooperative Extensive Service in the introduction of cultural practices and the demonstration of the usefulness of calcium arsenate, the losses could have been much greater. Still, the lack of personnel, travel limitations, and poor communications hindered the adoption of these practices. There was only one extension entomologist for the entire state during this period (1917-1961) and this person, Charles Stiles, had responsibilities in all areas of entomology.

An increased incidence of cotton aphid and bollworm outbreaks was observed when arsenical dusts were used during the early attempts at controlling the boll weevil. Sulphur and nicotine dust were added to arsenical dusts in an effort to reduce these secondary pests. While the success of these early insecticide applications was limited, producers saw the merit of controlling cotton pests, and broadened the use, and perhaps areawide abuse, of insecticides as more efficacious products became available after World War II.

The Cooperative Extension Service was a separate entity of the university (Oklahoma State University) until 1964 when all state extension specialists were realigned and placed within the appropriate departments. This administrative action improved the interface between research and extension, allowing more collaboration to solve the problems facing the cotton producer in Oklahoma. In 1969, the state finally answered the cries for help from the cotton industry and hired the first area extension entomologist, Eldon Cleveland, at Cordell in southwestern Oklahoma.

INSECT AND MITE PROBLEMS IN OKLAHOMA

Major pest problems in the state are the boll weevil, bollworm/tobacco budworm and cotton fleahopper. Sporadic pests include thrips, cotton aphids, armyworms, spider mites, grasshoppers and loopers. Most years, the boll weevil is restricted to the southern tier counties (Harmon, Jackson, Tillman, Greer and Kiowa) because of climatic constraints. The bollworm infests the entire state, but annually causes the most damage in irrigated cotton concentrated in Jackson, Harmon and Tillman counties. The cotton fleahopper infests the entire cotton acreage and causes the greatest damage in late-planted cotton.

Boll Weevil — Successful management of the boll weevil is the key to developing a workable management system for Oklahoma cotton insect and mite pests. Cultural practices have been emphasized for weevil management since approximately 75 percent of the total state cotton acreage is produced under dryland conditions in a semi-arid climate. With a relatively low yield potential, farmers of this dryland cotton area can not afford a large insecticide input. Adoption of cultural practices developed in the 1930s continues to be stressed. Throughout the 1950s, extension personnel recommended early uniform planting dates followed by timely stalk destruction after harvest.

Current management practices exploit the weakness of the boll weevil. Much of the changes in strategies to reduce or delay boll weevil infestations have been the result of agronomic advancements made over the last 20 years. Probably the two advances making the most impact have been the introduction of high-yielding, fast-maturing varieties and the use of harvest aids (desiccants, defoliants and plant growth regulators). These practices have shortened the length of time the crop requires protection from damaging insects and reduced the chance of accelerating resistance to insecticides. Harvest aid chemicals also reduce oviposition sites as well as the food supply that emerging weevils need to accumulate sufficient fat reserves to overwinter successfully.

Due to the uncertainties of weather and a limited growing season, the delayed, uniform planting date has never been widely accepted as an alternative to insecticidal control for overwintered weevils in early squaring cotton. Diapause boll weevil control applications of insecticides applied with a harvest-aid chemical have likewise met with only limited acceptance. The reasons for their limited success include: (a) lack of widespread organized support such as that associated with the West Texas Diapause Control Program, (b) limited use of harvest-aid chemicals especially in low input dryland cotton, and (c) the high mortality of boll weevils during years with harsh winters.

Besides in-season insecticidal control of boll weevils, the application of an insecticide for overwintered weevil control prior to bloom, and timely, post harvest stalk destruction are the most widely used practices within the state. Boll weevil pheromone traps are used for surveillance and to help determine weevil emergence and proper application timing to prevent weevil establishment in early-planted fields.

Prior to the introduction of organochlorine and organophosphate insecticides, the weevil economic threshold was set low, insuring that most of the infested fields that were treated received scheduled applications throughout the season (Table 4). As more effective tools in the form of organochlorine insecticides became available after World War II, Oklahoma producers fully employed the full-season spray programs that were being endorsed and promoted by chemical companies. During this period of cheap chemical control, cultural practices for insect control were deemphasized in favor of production practices emphasizing long season varieties and increased fertility to promote high yields. The extension service advocated a more conservative insecticide use approach by increasing the economic threshold in 1950 to treat either when one or more weevils were found per 100 feet of row or when 25 percent of the squares were infested. By the mid 1960s, insecticide resistance was causing problems in controlling both bollworms and boll weevils. The economic threshold was modified to 15-25 percent infested squares, where it remains today. The resistance problem reemphasized the importance of pinhead square insecticide applications for overwintered boll weevils in the traditional weevil infested areas.

Bollworm and Tobacco Budworm — The bollworm continues as a sporadic pest of dryland cotton. However its status has changed over the years as production practices emphasizing high yields were adopted for irrigated cotton. Prior to 1950, there was no exact economic threshold on which to base spray or dusting decisions. All recommendations dealt with control intervals, recognizing that most larval infestations would be controlled with insecticide applications for weevils. Determination of larval density was not regarded as important or necessary.

The first economic threshold of 4-5 bollworms per 100 terminals appeared in the 1950 state insecticide recommendations (Table 4). By 1955, the threshold had been expanded to include the presence of eggs and 5 small larvae. Perhaps the addition of eggs to the economic threshold was an attempt to recognize the cyclic nature of the bollworm and to emphasize that without additional oviposition, light larval infestations need not be treated. Detection of bollworms is the key to the success or failure of the economic threshold concept. To help alleviate the difficulty associated with scouting and detection of small larvae, the economic threshold was modified in 1960 to include infested squares.

Spray interval recommendations over the years have changed from a 3-5 day interval to as needed. The reason for this change was the arrival of the synthetic pyrethroids in the late 1970s, at a time when the other insecticides had lost much of their former activity due to bollworm/tobacco budworm resistance. Standard insecticides or mixtures relied upon during the mid 1970s were 2-1 toxaphene + methyl parathion. EPN was occasionally added to the formulation for bollworms and azinphosmethyl (Guthion®) for boll weevils. A formulation containing ethyl-methyl parathion (6-3) was also used by many producers. Reducing the spray interval and increasing the dosage rate did not give satisfactory bollworm control once resistance became widely established (Personal communication, Jerry Young and Richard Price, Oklahoma State

Table 4. Evolution of key cotton insect control recommendations in Oklahoma[1].

Year	Recommendation
	Boll weevil
1935	In-season weevil control. Late season control[2]= 10 percent punctured squares. Calcium arsenate dust.
1950	Overwintered weevil control. At 1/3rd grown squares, ET[3]=1 or more weevils found per 100 feet of row. Late season control, ET=25 percent punctured squares. Organochlorines.
1965	In-season control, ET=15 to 25 percent punctured squares.
	Bollworm
1950	ET=4 to 5 worms per 100 terminals.
1955	ET=5 worms + eggs per 100 terminals.
1960	ET=5 small worms and eggs per 100 terminals or 10 percent infested squares in July or 5 percent infested squares in August.
1988	ET=10 small worms and eggs per 100 terminals for preblooming cotton and cotton after Sept. 10th.
	Cotton Fleahopper
1950	Preblooming cotton, ET=25 fleahoppers per 100 terminals.
1975	Preblooming cotton, ET=40 fleahoppers per 100 terminals.

[1]Recommendations from published Extension guides.
[2]Late season=boll period.
[3]ET=economic threshold.

University, Stillwater). Routine field scouting coupled with the improved control achieved with the pyrethroids has allowed insecticide applications to be applied only as needed.

The average insecticide application interval for control of bollworm/tobacco budworm in cotton enrolled in the Oklahoma Cotton Improvement Association scouting program has increased to 17 days in 1986 and 15 days in 1987 (Stoll, 1987). Overall, insecticide applications have been greatly diminished in Oklahoma in the last 15 years. Part of the success of widening the spray interval was due to the addition of the ovicide chlordimeform (Galecron®, Fundal®) to the state recommendations in 1974. Oklahoma did not recommend the use of ovicides alone. Methomyl (Lannate®, Nudrin®) and thiodicarb (Larvin®) were also added as contact ovicides with the same restriction. Chlordimeform was widely used during the period it was available to cotton producers—much of its usage was with the pyrethroids and other insecticides to control bollworm/tobacco budworm. In many situations, chlordimeform was applied with insecticide applications targeting secondary pests to reduce the chance of a bollworm outbreak. The widest use of *Bacillus thuringiensis* (Bt) has been in conjunction with chlordimeform for bollworm control in dryland cotton. Success of these tank mixtures is dependent upon proper timing of the application. The higher cost of the microbial tank mixtures has limited their use, since insecticides such as the pyrethroids could be applied for less money.

Resistance resurfaced across the Cotton Belt in 1986. Although no control difficulties have resulted in Oklahoma, resistance to the pyrethroids in Oklahoma was confirmed in 1987. A resistance management section was added to the extension guide in 1988, and resistance monitoring using the Texas A&M University vial technique was initiated (Plapp, 1988). Economic thresholds were modified by eliminating percentage square damage and focusing on detection of bollworm larvae. The threshold was increased to 10 small larvae and eggs present per 100 terminals for preblooming cotton and for cotton after September 10th in an effort to reduce the number of early and late pyrethroid applications. Use of alternative insecticides of different chemistries is encouraged during these periods with pyrethroid usage limited to July and August. This works well for Oklahoma because these months represent the two peak activity periods for the bollworm, a pest still easily controlled with pyrethroids.

A major constraint for relying on beneficial insects for the control of bollworm/tobacco budworm has been the lack of knowledge on the level of protection a certain density of predators would confer. Collops beetles and lady beetles are the two most common predators in Oklahoma cotton fields. According to Young and Wilson (1984), when densities reach or exceed 0.9 beetle predators per row foot, the field will be protected from bollworm damage.

Cotton Fleahopper — Research conducted by the Oklahoma Agricultural Research Station between 1936 to 1945 showed the cotton fleahopper seldom caused significant yield reductions that would justify control costs. Extension recommendations implied that control losses would result only in those areas of the state where heavy infestations of boll weevil and cotton fleahoppers were found together (Brett *et al.*, 1946). The controversy surrounding the cotton fleahopper and its potential to delay maturity continued, and in 1951, a fleahopper section was added to the cotton insect recommendations (Personal communication, 1988, Newt Flora, Cooperative Extension Service, Oklahoma State University, Stillwater).

Unlike the rest of the cotton producing states which over the past 15 years have emphasized the importance of early season insect control, Oklahoma recommendations have increased the economic threshold for cotton fleahoppers from 25 per 100 terminals in 1950, and subsequently to the current threshold of 40 per 100 terminals (Table 4). In many cases, control of marginal cotton fleahopper infestations had predisposed fields to later bollworm damage. Much of the square shed attributed to fleahoppers has been caused by environmental stress related to Oklahoma's climate (Molnar, 1975). Increasing the economic threshold for fleahoppers reduces insecticide use thereby conserving the beneficial insect population. This is an essential component of the Oklahoma cotton insect management approach.

Other Insect and Mite Pests — There are other pests of cotton that Oklahoma producers may occasionally have to address. These insects may cause annual, isolated damage or sporadic widespread damage. These other pests include thrips, spider mites, armyworms, grasshoppers and cotton aphids. They are listed in the state insecticide recommendations.

NEW MEXICO RECOMMENDATIONS

HISTORICAL BACKGROUND

Cotton was first planted in New Mexico in 1918 with harvested acres totaling 97,000 by 1927. This acreage was due largely to the Elephant Butte Irrigation project of 1919 located along the Rio Grande River between the cities of Truth or Consequences, New Mexico and El Paso, Texas (Hauter, 1928). The Rio Grande (Mesilla) Valley in south central New Mexico has continued to be one of the four major cotton producing areas of the state. The other areas include the Far West region in the southwest corner, the High Plains along the eastern border adjoining Texas, and the Pecos Valley immediately to the west of the High Plains.

Statewide, cotton emerged early as one of the major cash crops; however, the total number of acres planted to the crop is small compared to Texas and Oklahoma. A "see-saw" cotton production pattern has been the case with a state record of 315,000 acres in 1953 and a low of 58,100 acres harvested in 1983 (New Mexico Department of Agriculture, 1962, 1989). Intervening years saw acreage fluctuate between 200,000 and 70,000 acres. Government programs have been the primary factor influencing state cotton acreage. Bollworm/tobacco budworm control difficulties were encountered during the late 1960s and early 1970s. This further contributed to the acreage decline precipitated by government programs. The pink bollworm was also a major pest in the southern-most counties during this period. Cotton acreage has made a modest advance in the late 1980s in response to record yields and higher prices, reaching 85,200 harvested acres in 1989.

INSECT AND MITE PROBLEMS IN NEW MEXICO

Major pest problems in the state are very similar to Texas, except for the absence of the boll weevil. Important pests are the bollworm, pink bollworm, cotton fleahopper and other mirids (plant bugs), early season thrips, and, recently, the cotton aphid. Other sporadic pests include: spider mites, stinkbugs, beet armyworms, cutworms, grasshoppers and leafworms. The importance of pests varies geographically. The cotton fleahopper and other mirids can be important in all state production areas and their management can have a profound effect on the development of later pest problems. Thrips are primarily a problem in the High Plains, Pecos Valley, and Far West areas. Bollworms are a major concern for most of the state while the tobacco budworm, an insect with a propensity for resistance, is not important in any area. The cotton aphid has only recently been elevated to major pest status and then only in the eastern part of the state that adjoins the Texas High Plains.

Cotton Fleahopper and Other Mirids — The cotton fleahopper, whitemarked fleahopper, *Spanagonicus albofasciatus* (Reuter), and plant bugs [especially pale legume bug, *Lygus elisus* Van Duzee; western lygus bug, *Lygus desertinus* (Knight); and tarnished plant bug] can be both mid- and late-season pests throughout the state (Ward, 1985; Wilborn and Ellington, 1984), but tend to be of less importance in the Far West production area. The eastern part of the state is very similar to the Texas High Plains, with the cotton fleahopper the primary pest.

Long-time observers of the cotton pest problems in the Pecos Valley production area indicated that damage from these pests is frequently ignored or considered as a minor problem when in fact they cause general economic damage in 8-9 years out of ten (Personal communications, Bill Campbell, Ag Products, Inc., Artesia, New Mexico and Carl E. Barnes, New Mexico State University, Agricultural Science Center, Artesia). Early loss of fruit from these pests also probably encourages farmers to try to produce a late crop of bolls when they discover that their yield potential is below expectations in the latter part of the season. *Lygus* problems in late season are sporadic, occurring one out of every five years (Ward, 1985). They may be associated with alfalfa hay cutting, but this has not been documented for New Mexico. Entomologists differ greatly on the importance of mirids in the Rio Grande Valley and Far West areas. The whitemarked fleahopper is also present in these areas as well as in the Pecos Valley (Ward, 1985). This species is believed to be involved in early-season fruit losses.

As in Texas, sulphur dust in 1942 and then DDT and sulphur dust mixtures in 1947, were the early products of choice for controlling these pests. Eyer and Medler (1942a, 1942b) tested insecticidal dusts on plant bugs during this period. Prior to the first extension service guides, there is no record available on any economic threshold adjustments made during these years, when it was recognized that bollworm problems often followed fleahopper applications. Although the importance of sampling was recognized (Moore, 1950), the first published guide in 1951 (NM A&M, 1951) placed heavy emphasis on automatic dust and spray applications of the organochlorine insecticides DDT, toxaphene and gamma BHC, for both early and late season pests. To a large extent these treatments were recommended to be made on a five- to seven-day schedule for fleahoppers and *Lygus* spp., beginning at the four leaf stage or earlier if necessary (Table 5). As with earlier Texas recommendations, these early-season insects were to be controlled on a community or countywide basis. The larger the area treated, the greater the benefits accrued. The last application was to be made 30 days prior to the usual appearance of the bollworm thereby allowing beneficial insect numbers to rebound. In spite of the bollworm concern, late season plant bugs (Table 6) were to be controlled when the economic threshold of 8-10 insects captured per 100 sweeps was reached (NM A&M, 1951).

The reference to an areawide early season program was removed in 1953. Other recommendations were left unchanged (Swoboda, 1953). John Durkin (1961) replaced the recommendation for automatic early-season sprays for fleahoppers in 1961 with the economic threshold of 6-8 fleahoppers or *Lygus* per 100 sweeps with a 15 to 16-inch diameter insect net. Coppock (1962) provided separate economic thresholds the next year for the fleahopper (15 to 20 per 100 sweeps) and for *Lygus* (6 to 8 per 100 sweeps). This change may have been a response to research conducted by Race (1960) on sampling techniques. These guides included mixtures of organophosphates and organochlorines as recommended treatments for plant bugs and most other insects.

The sampling variability encountered using the sweep net for monitoring fleahoppers was recognized in 1973 by changing the economic threshold to 15-20 fleahoppers per 100 plants, with sampling to include terminals and small squares (Durkin, 1973). No further changes in threshold were made until 1984 when an economic threshold of 15 to 20 percent infested plants was coupled with square-set falling below 75 percent (Bozeman, 1984). The last change was to suggest sampling terminals rather than whole plants, with the range of infested terminals increased to 15 to 25 percent (Ward, 1991a). This is the same fleahopper economic threshold used in West Texas. (Boring *et al.*, 1989a).

Until 1962, fleahoppers and *Lygus* were considered equal in damage potential during the early part of the season (Coppock, 1962; Swoboda, 1953). The late-season *Lygus* economic threshold was lowered in 1953 from 8-10 to 7-10 insects per 100 sweeps. Coppock (1962) also introduced the concept of doubling counts of nymphal *Lygus* in determining the economic threshold. In 1966, Durkin (1966a) added the cautionary note that insecticide treatments for mirids could result in bollworm problems. Durkin (1973) made another significant adjustment of the late-season economic threshold in 1973 by raising it to 25-30 *Lygus* per 100 sweeps, coupled with 20 percent large square and/or young boll injury. The latter criterion was removed in the 1980 guide (Durkin and Gholson, 1980). Ward (1982) also advised that during late season, an ovicide should be added to any insecticide application for *Lygus* if 10-15 bollworm eggs per 100 terminals were found.

Bozeman (1984) presented a single, season long economic threshold of 6-8 *Lygus* per 100 sweeps, counting nymphs as two, paired with a square set reduced below 75 percent. Combining mid- and late-season thresholds was an error, which was corrected in 1989, (not published until 1991) by adding a late-season recommendation (Ward, 1991a, 1991b). Sweep counts for both mid- and late-season are the same as those used in Texas (Boring *et al.*, 1989a). However, the mid-season economic threshold for whole-plant counts remains as an alternative. In both cases, nymphs are counted double and the thresholds must be exceeded on two consecutive sampling dates four to five days apart. Also, a weighted combined economic threshold is recommended if both fleahoppers and *Lygus* bugs are present in the same field.

Bollworms — Since the boll weevil has never appeared at economic levels, the major late-season pest in New Mexico has been the bollworm. Although the tobacco budworm was considered to be involved in the apparent resistance problems encountered in the late 1950s and early 1960s, few documented reports of infestations of this species can be found. The bollworm has been of major economic concern in the Pecos Valley in about one out of every three years since the 1950s with from 3 to 6 insecticide applications made during peak years (Ward, 1985).

Table 5. Evolution of key fleahopper control recommendations in New Mexico.[1]

Year	Recommendation
1951	2-3 weekly insecticide applications beginning at 4-leaf stage or earlier in area-wide program. Late season ET[2]=8-10 fleahoppers per 100 sweeps of a 16 inch net.
1953	Removed mention of area-wide programs.
1961	ET=6-8 per 100 sweeps; treat at 5- to 7-day intervals.
1962	ET=15-20 per 100 sweeps.
1973	ET=15-20 per 100 plants (terminals & small squares).
1978	ET=15-20 fleahoppers per 100 plants.
1984	ET=15-20 percent infested plants; and square set drops below 75 percent.
1991	ET=15-25 percent infested terminals and square set drops below 75 percent.

[1]Recommendations from published Extension guides.
[2]ET=economic threshold.

Table 6. Evolution of key *Lygus* control recommendations in New Mexico.[1]

Year	Timing	Recommendation
1951	Early-season	2 to 3 insecticide applications beginning at the 4-leaf stage or earlier if necessary.
	Late-season[2]	ET[3]=8-10 *Lygus* taken per 100 sweeps of a 16 inch net.
1953	Early-season	Same as 1951.
	Late-season	ET=7-10 *Lygus* taken per 100 sweeps of 15- or 16 inch net.
1961	Early-season	ET=6-8 *Lygus* per 100 sweeps, treat at 5-7 day intervals.
	Late-season	ET=7-10 *Lygus* per 100 sweeps, treatment at 5-7 day intervals.
1962	Mid-season	ET=6-8 *Lygus* per 100 sweeps, treat at 5-7 day interval. Count nymphs as two.
	Late-season	ET=7-10 *Lygus* per 100 sweeps, treat at 5-7 day interval.
1973	Mid-season	Same as 1962.
	Late-season	ET=25-30 *Lygus* (count nymphs as 2) per 100 sweeps and 20 percent of large squares and young bolls show injury.
1984	Mid-season	Same as 1962 but added square set reduced below 75 percent.
	Late-season	ET not given.
1991	Mid-season	ET=10 *Lygus* (count nymphs as 2) per 50 sweeps or 6-8 *Lygus* per 100 plants checked on 2 consecutive sampling dates 4-5 days apart; use combined weighted ET if fleahoppers are also present.
	Late-season	ET=20-30 *Lygus* per 50 sweeps if plants failed to set sufficient fruit the first 4-5 weeks.

[1]Recommendations from published extension guides.
[2]Late season=boll period.
[3]ET=economic threshold.

During the early 1940s, the economic threshold followed was probably similar to that used in Texas, with calcium arsenate dust recommended every five days until eggs and larvae were no longer found. The first published economic threshold included the presence of eggs as well as 4-5 small larvae per 100 terminals (Table 7). Durkin (1961) raised the threshold to six small larvae per 100 terminals and recommended treatment on a five to seven day schedule. The threshold was raised again in 1966 to 6 to 10 small larvae plus eggs per 100 plants, with a warning not to count eggs as worms unless beneficial insects had been eliminated by previous sprays (Durkin, 1966a).

Following the mid 1960s, a growing number of producers discontinued treatments for bollworms. This was primarily due to the large monetary outlay being made for insecticides that had generally become ineffective. Insecticide resistance was the major factor producing poor control results. Several of these "non-insecticide users" attempted to utilize releases of the minute egg parasite, *Trichogramma minutum* Riley, and the convergent lady beetle, *Hippodamia convergens* Guerin-Meneville (Durkin 1959). This practice has not been studied in detail locally, but historically has met with little success in other states at the release rates reportedly being used (Durkin, 1959; Later personal communication, J. J. Durkin, Cooperative Extension Service, New Mexico State University, Las Cruces).

These early attempts at biological control and the introduction of *Bacillus thuringiensis* (Bt) and a nuclear polyhedrosis virus for bollworm control, led Durkin (1978) to include a warning to evaluate these products no sooner than 5 to 7 days following application. The microbial insecticides are slower acting than the organophosphates and pyrethroids. Durkin and Gholson (1980) also included Bt and virus combinations with ovicides in the 1980 guide as recommended treatments when beneficial insects were plentiful. This also was the first year the pyrethroids were included in the guide. The exceptional results obtained with these materials in bollworm control demonstrations in the Pecos Valley led to increased acreage being treated for bollworm infestations (Ward, 1985).

Ovicides also were first included in guides in 1980 with an economic threshold of 10 to 15 bollworm eggs per 100 terminals (Durkin and Gholson, 1980). This egg control suggestion was continued in 1982 (Ward, 1982), but was omitted in the 1984 abbreviated guide (Bozeman, 1984). Ovicides are now recommended to be used only in conjunction with larvicides (Ward, 1991a, b). Combinations with microbial insecticides are encouraged in blooming cotton against worm numbers up to 10,000 per acre. After bolls appear, the economic threshold is lowered to 8,000 larvae per acre.

The 1991 to 1992 guide largely follows the 1989-1990 Texas guide which suggests using either (a) cluster scouting of five whole plants and an economic threshold of 5,000 or more small bollworms per acre and less than two predators per larva or (b) dominant terminal scouting with an economic threshold of at least 8 to 10 percent of the terminals infested with small larvae and less than 20 percent of the terminals having key predators (Boring *et al*., 1989a). Resistance management is also discussed in this guide in an attempt to extend the useful life of the synthetic pyrethroids. The Texas guidelines were largely followed.

Table 7. Evolution of key bollworm and tobacco budworm control recommendations in New Mexico.[1]

Year	Recommendation
1951	ET[2]=when eggs are present and/or 4 to 5 small worms per 100 terminals are found.
1961	ET=6 small worms per 100 terminals, treat at five day intervals.
1966	ET=6 to 10 small worms + eggs per 100 plants; count eggs as worms only if "beneficials" have been eliminated.
1982	ET=same as 1966 except monitor egg lays to time control for small worms; warning to evaluate Bt on basis of damage first, 5 to 7 days posttreatment, then evaluate worm control; also use combinations of Bt and ovicides when "beneficials" are plentiful.
1991	1. Cluster scouting of five whole plants, a minimum of 12 clusters per field: ET=5,000 or more small worms/acre and less than two predators found per worm. 2. Dominant terminal scouting: ET=8 to 10 percent small worms; higher if 20% of the terminals have key predators. 3. Biological and ovicide suggestions reinstated.

[1]Recommendations from published extension guides.
[2]ET=economic threshold.

Pink Bollworm — Hoyt (1953) indicated that the first major outbreaks of the pink bollworm in this country were recorded in 1952 in 39 South Texas counties with losses estimated at $29 million. However, there are indications that pink bollworms were a problem in the New Mexico Rio Grande Valley as early as 1949 and 1950 (Thompson, 1951). The 1951 cotton insect control guide included recommendations for controlling the pink bollworm (Table 8). White (1953) and Spencer (1953) also stated that all cotton producing counties in New Mexico were included in the 1952 Pink Bollworm Federal Quarantine Regulations.

The 1953 guide indicated that "during the past harvest season, enough pink bollworms were found to cause everyone . . . to be concerned" (Swoboda, 1953). Stalk destruction and farm cleanup on a community-wide basis was urged. These suggested cultural practices followed recommendations similar to those discussed by Spencer (1953) at the 1952 Beltwide Cotton Production Conference, and were basically the same as those listed in the first cotton insect control guide of 1951.

Pink bollworm infestations increased to economic levels in the 1960s but declined through the 1970s primarily as a result of mandatory stalk destruction promulgated by Regulatory Order No. 2 (Amended) Plant Protection Act of 1968 (New Mexico Department of Agriculture, 1968), requiring stalk destruction in that year (Durkin, 1966b, 1967, 1968). Even in the 1960s, only about 10 percent of the fields were treated in the Pecos Valley for this pest (Ward, 1985). Isolated fields in Eddy and Dona Ana

Table 8. Evolution of key pink bollworm control recommendations in New Mexico.[1]

Year	Recommendation
1951	Cultural practices, especially uniform planting date and late season stalk destruction required on a community-wide basis; recommended organochlorines as cupplemental control.
1961	Treat at seven day intervals when infested blooms or bolls are found.
1968	Mandatory stalk destruction law passed; required destruction by January 15 in seven southern counties.
1973	Listed cultural practices and bloom and boll inspection methods; rosetted bloom ET[2]=35 per 1500 of row 5 to 15 days after bloom; boll ET=5 to 10 percent infested green bolls; treat at five day intervals until 70 percent of bolls are open.
1984	Rosetted bloom ET=same as 1973. Boll ET=same as 1973 except >40 to 50 percent infested bolls in late September and October.
1991	Upland cotton ET=10 to 15 percent infested bolls and Pima cotton ET=5 to 10 percent infested bolls the first 6 weeks of boll set; the late September and October ET=40 to 50 percent was retained. Terminate treatments in upland cotton when last bolls expected to be harvested are 30 days old; in Pima cotton, continue until 70 percent of the bolls are open. Continue to stress cultural control and use of rosetted blooms and pheromone trap catches as indicators to initiate boll surveys.

[1]Recommendations from published extension guides.
[2]ET=economic threshold.

Counties frequently had pink bollworm problems even in the 1970s and 1980s. This pest continues to be a major potential threat, because mid- to late-September infestations can easily be missed when scouting of the crop is prematurely ended.

Research conducted from 1957 to 1960 in New Mexico on the effects of insecticides on beneficial insects, and on sampling methods, began to influence the recommendations for cotton insect control (NM A&M, 1957, 1958, 1959; Race, 1960). Except for preventative treatments with systemic insecticides, calendar spray dates were giving way to scouting and economic thresholds. This trend was reflected in the establishment of an economic threshold for pink bollworm in the 1973 guide (Durkin, 1973). Both bloom and boll thresholds were given. These thresholds remained unchanged until 1984, when the boll economic threshold of 5-10 percent infested green bolls was increased to greater than 40-50 percent for late September and October (Bozeman, 1984).

This increased late-season threshold was a reflection of other changes taking place in New Mexico cotton production. One major change was the switch from the production of primarily extra long staple Pima cotton types to shorter stapled upland cotton, especially the Acala types. Like Oklahoma and Texas, the introduction of these high-yielding, fast-maturing varieties, coupled with the use of harvest-aids (desiccants, defoliants and plant growth regulators), greatly affected insect management strategies. The length of time the crop needed protection from insects was shortened. Harvest-aid chemicals reduced the food supply that pink bollworms required to build up overwintering infestations late in the season.

The recent increase in cotton acreage devoted to the longer-season Pima-type cottons, especially in the Rio Grande Valley and Far West production areas, is again increasing the potential of pink bollworm outbreaks in New Mexico. This has led some growers to initiate adult control in the fall, on the basis of pheromone trap catches. This practice is placing additional selection pressure on late-season bollworms and other pests and could hasten the development of resistance. Therefore, this practice is specifically discouraged in the 1991 to 1992 Guide (Ward, 1991a). The economic thresholds are the same as those recommended in the 1989-1990 Texas guide (Boring *et al*., 1989a), providing separate recommendations for upland and Pima cotton (Table 8). The threshold for rosetted blooms was eliminated to encourage boll sampling early in the pink bollworm season. Rosetted bloom surveys and pheromone trap catches are recommended only as indicators for the need to initiate boll sampling.

Thrips — The results of thrips control research conducted by Eyer and Medler (1941) and Faulkner (1950a,b) probably formed the basis for the early foliar automatic insecticide treatment recommendations for fleahoppers, *Lygus*, and thrips beginning at the "four-leaf stage or earlier if necessary" (NM A&M, 1951). Durkin (1961) continued this approach through 1961 by recommending three applications on a seven-day schedule, beginning at the two-leaf stage.

Research on systemic insecticides in New Mexico was initiated in 1958 (NM A&M, 1959) by J. G. Watts, R. C. Dobson, S. R. Race, and others. The 1961 and 1962 guides marked the introduction of preventative seed-furrow treatments with systemic insecticides for thrips, aphid and mite control (Durkin, 1961; Coppock, 1962). The 1961 treatments of granular disulfoton (Disyston®) and phorate (Thimet®) were "recommended for use on a trial basis . . . on seedling cotton." The 1962 Guide carried a full recommendation for these preventative treatments in areas where these insects appeared as perennial pests (Coppock, 1962). Foliar dust and spray treatments continued to be recommended on a scheduled basis.

New chemicals such as azinphosmethyl (Guthion®), carbaryl (Sevin®), carbophenothion (Trithion®), demeton (Systox®), malathion (Cythion®), dicofol (Kelthane®), and Aramite® had also appeared in the 1961 and 1962 guides. Several of these treatments were still being recommended in 1964 for thrips control using the earlier automatic guidelines or as an alternative, when damage first became apparent. Subsequent applications were recommended if thrips persisted (Durkin, 1964).

Recommendations for preventative thrips control persisted in guides until 1984 (Bozeman, 1984). At that time, the economic threshold proposed by Texas of 2-5 thrips per plant was adopted as a threshold for foliar sprays. Research conducted in Texas as well as in New Mexico (Ward, 1985) resulted in the deletion of damage as an economic threshold factor. With the elimination of damage as a treatment guideline, and because of the difficulty involved with scouting for this tiny pest, producers opted to treat much of the thrips-infested acreage with systemic insecticides as a seed or in-furrow treatment. Barnes estimated that as much as 40 to 50 percent of the state acreage has been involved, because of the prevalence of seedling damage in most years. (Personal communication, Carl E. Barnes, New Mexico State University, Agricultural Science Center, Artesia).

Other Insect Pests — One of the earliest references to insect problems in New Mexico was the grasshopper outbreaks in the late 1920s and mid 1930s (Quesenberry, 1936). Although cotton was not specifically mentioned, a total of 183,640 acres of cropland was reported to have been protected from grasshoppers in 1934, at the peak of the outbreak. Grasshopper management recommendations were added to the guide in 1961, and the application of baits containing aldrin or dieldrin were recommended for treating field margins to curtail migration into cotton fields. Spotty infestations of grasshoppers have required control five years out of the last twenty (Ward, 1985). Control efforts over most of the area have depended upon the Cooperative Control Program (state, federal, and private funds) in rangeland surrounding the cultivated valleys.

Other sporadic insect pests are: the seedcorn maggot, *Hylema platura* (Meigen); various species of wireworms and spider mites; darkling beetles; cutworms (especially the variegated cutworm, *Peridroma saucia* (Hübner); and armyworms (especially the yellowstriped armyworm, *Spodoptera ornithogalli* (Durkin and Gholson, 1980). Cotton aphids and beet armyworms have occurred as economic pests somewhat more frequently, the latter especially in late season. Aphids have been an economic problem in some fields in the Pecos Valley in two out of four years. Wireworms and darkling beetles tend to be a problem limited to cotton planted the first year following alfalfa or other high residue crops. Spider mites have been noted as early season pests in one out of four years. Late season problems with spider mites occur with similar frequency (Ward, 1985).

Cabbage loopers were a more consistent pest in the 1950s and 1960s with economic problems in one out of three years. High numbers of this pest were observed recently in only two of the last ten years (Ward, 1985). Treatments made for other pests have generally checked population increases of cabbage loopers. The cotton leafworm has not been a problem in the last decade, but two outbreaks were noted in the 1960s. Stink bug (various species) problems are generally associated with migrations from maturing small grains such as barley and oats (Ward, 1985).

Although a few boll weevils have been trapped in recent years in New Mexico on both the eastern and southern borders with Texas, a diapausing population has not become established. Therefore, the devastation experienced in Texas and Oklahoma in the early 1900s did not affect New Mexico's cotton producing areas. The effective diapause control program initiated in west Texas in 1964 is apparently largely responsible for keeping the boll weevil out of eastern New Mexico. The recent invasions of the boll weevil into the state however, has led to inclusion of the boll weevil as a pest in the proposed revision of the 1989 state guide but not published until the 1991 guide (Ward, 1991a, b). The recommended management strategies are the same as those for the Texas High Plains.

EXTENSION SERVICE GUIDES AND THE GUIDE REVISION PROCESS

TEXAS

Prior to 1949, the first extension service guides were developed informally by a handful of extension and research entomologists. In later years, the writing of the Texas guides became a pluralistic effort, involving a sizeable group of state and USDA cotton entomologists. Starting in 1949, an organized research review and guide revision conference was initiated where issues and proposed guide changes were discussed, debated and finally voted upon. The two-day, closed door affair was followed by a third day in which guide revisions were made public to invited representatives of the agricultural sector, chemical industry, and the press. Early guide revision relied heavily on testimony and opinion, often supported only by limited research. Strong personalities often prevailed over reason. As more entomologists swelled the ranks of the extension service and the experiment station, the process became more democratic. But sheer numbers sometimes have led to protracted discussions and limited progress.

Formal rules were established for the conference in 1982, requiring a minimum of two years of replicated, statistically analyzed, small plot tests for support of any guide change involving insecticides. For the first time, suitable data from other states' universities and USDA were accepted. Changes in sampling techniques, economic thresholds, and other management techniques require reproducible research results similar to those specified for insecticides. Only products and techniques suitable for Texas IPM programs are considered. Environmental issues are very important in molding the management advice in the extension guides.

Some of the guide changes, taken at face value, appear to be nothing more than format modifications. Much more was often involved. Often these arose out of heated philosophical battles over how to best encourage guide users into reading both cultural and chemical control recommendations. Guides were fold outs for many years; insecticide tables with economic thresholds and scouting methods were included with attendant small sections on cultural control. This format remained unchanged until a stapled 4X9 inch guide was introduced in 1980. Beginning in 1981, West Texas guides placed insecticide listings in tables under each pest narrative (Leser *et al.*, 1981). Guides expanded in the 1980s as more information was included on pest management, scouting techniques, pest descriptions and economic thresholds. Following a 1986 meeting in Dallas, the guides were published in a 8 1/2" X 11" format with insecticides listed in the back as a single table. Revision of area guides is now coordinated to prevent unnecessary differences from developing. Ultimately, publication costs won over the greater philosophical battles with a separate insecticide publication produced annually to supplement the biannual narrative guide (Boring *et al.*, 1989b; Norman, 1989b; Parker and Swart, 1989).

Differences in management philosophy and techniques have led to several area guides over the past four decades. The Lower Rio Grande Valley was the first to leave the state guide in 1951 and remained a separate guide until 1961, when it was combined with the Gulf Coast, resulting in the South Texas Guide (TAEX, 1961b). This guide lasted 13 years, until the Lower Rio Grande Valley once again became a separate guide, one of three that remain today. The Gulf Coast recombined with the traditional state guide. West Texas entomologists, recognizing the great differences that existed with East Texas, initiated a new guide in 1961 (TAEX, 1961c). The Rolling Plains area did not officially join this guide until 1966. The Blacklands area split from the state guide between 1974 and 1985. The decline in Blacklands cotton acreage and increasingly short publication resources prompted the absorption of this guide back into the state guide in 1986. The original state guide traditionally covered the Central River Bottom area, the Gulf Coast and the Central Blacklands area at various times. Presently there are three sets of recommendations: the Lower Rio Grande Valley, Central Texas and Gulf Coast, and the West Texas guide.

OKLAHOMA

Prior to the first Extension Agents' Handbook of Insect Control in 1958, information concerning insect pests, damage and control recommendations was disseminated to extension personnel, cotton producers and agribusiness through a weekly newsletter during the growing season. Control information presented in this newsletter was adopted by the Entomology Department and extension entomologists from information compiled annually by the Federal Cooperative Extension Service in Washington, D.C. Each state received copies of research and insecticide recommendations submitted by all cotton producing states in the United States. This procedure was followed during the 1950s (Personal communication, Newt Flora, Cooperative Extension Service, Oklahoma State University, Stillwater). A postcard survey was inserted weekly in the newsletter mailing. This weekly survey helped extension entomologists identify insect population trends and determine the type of information needed in upcoming newsletters.

The Extension Agents' Handbook is currently reviewed and revised annually. Information collected from insecticide screening trials and more basic studies conducted by research and extension personnel are reviewed and compared to similar work conducted in other parts of the Cotton Belt. Besides efficacy, environmental concerns are also discussed before a practice or pesticide is approved for the guide. A spin-off of the handbook was the publication of fact sheets that addressed specific topics. The first cotton fact sheet was printed in 1967.

State pesticide recommendations are more than a listing of the pests and products labeled for their control. The guide is a publication to assist cotton producers in making sound pest management decisions. The information provides a sound integrated approach firmly based on research trials from universities and USDA and adapted to Oklahoma's climate and production practices. Due to generally limited resources in Oklahoma, some of the research concerning economic thresholds and control measures were adapted from other states, especially Texas.

NEW MEXICO

The acknowledgement section of the 1951 cotton insect control guide indicated the contribution of the Texas A&M College, Agricultural Extension Service, and Experiment Station for information on which the circular was based (NM A&M, 1951). The author of the 1951 Guide, L.H. Moore (Personal communication, 1990, L. H. Moore, retired, Clemson, South Carolina), indicated that one of his associates in the experiment station, either E.J. "Pewee" O'Neal or earlier workers, may have had some "mimeographed" cotton insect control information, but it too would have been based on work from other states, especially Texas and Arizona. Watts (1980) also mentioned the use of mimeographed materials such as the <u>College Courier</u> (1912-1916), <u>New Mexico Farm Courier</u> (1916-1921), and the 400 Series (1945 to present) that included insect control suggestions for cotton and other crops. The <u>Insect Letter</u> (1970-1976) and <u>Pesticide Chemical News</u> (1970-1976) also included suggestions for cotton insect control and changes in pesticide registrations.

This dependence on Texas, Oklahoma and Arizona for research results has continued to a great extent to present times, but the written acknowledgment disappeared from the 1953 Guide (Swoboda, 1953) and has not been reinstated. With only one full-time extension entomologist and one research entomologist with part-time responsibilities for cotton during 1951 to 1980, efforts to cover all aspects of the pest problems in cotton have been limited. This situation has not improved in recent times. No formal guide revision procedure has been established such as followed in neighboring Texas.

The cotton guide has not been revised for several years. The 1991 revision is patterned after the 1989-1990 west Texas guide and 1990 insecticide supplement (Boring *et al*., 1989a,b), and consists of two parts, with Guide 400 J-7A containing the narrative biology, economic thresholds, cultural, and biological control information and Guide 400 J-7B containing the chemical control suggestions (Ward, 1991a,b). This will allow the annual revision of the chemical control suggestions to match label and other use changes without necessitating the revision of the longer narrative portion which requires less frequent modifications. This allows more timely revisions in the future.

SUMMARY

Cotton insect and mite problems have varied in time in accordance with climatic conditions, geographical shifts in cotton acreage, advances in crop production practices and the availability of effective pest control technologies. The boll weevil initially shaped cotton pest management systems in both Texas and Oklahoma during the early cotton production years. While New Mexico lacked this menacing pest, the pink bollworm provided adequate incentive to follow a similar course of action adopted by its sister states to the east. All areas of the Southwest region have relied heavily on a shortened crop vulnerability period obtained from growing rapid-fruiting, fast-maturing varieties; and utilizing harvest-aid chemicals to terminate the crop so that timely harvest and stalk destruction can be implemented. These practices have been the cornerstones of a successful management system that continues to prosper into the 1990s. The result of this approach has been a greatly reduced reliance on insecticides and embracement of integrated pest management (IPM) programs and their concepts.

Recently the boll weevil and pink bollworm have relinquished the top pest ranking to the bollworm/tobacco budworm complex. This has been largely the result of the continuing insecticide resistance problem that almost counted the pyrethroids as a recent casualty. It is this threat of resistance and the unleashing of damaging late season bollworm/tobacco budworm problems that has encouraged the continued restraint in controlling early season plant bug infestations, as well as the occasional flurry of bollworm activity which sometimes occurs prior to bloom. Entomologists of the Southwest learned a long time ago to be cautious about destroying the natural enemies so important to managing these earliest bollworm cycles.

Early season thrips are the only pests remaining where preventative or automatic treatments still appear to fit best. Although Oklahoma does not perceive the thrips issue the same as its neighboring states, their lack of support for automatic treatments merely reflects the minor importance of this pest to their production area. Texas and New Mexico also recognize there are areas within their respective states where thrips are not the perennial damaging pest so often seen in the High Plains region.

The geographical diversity which exists among the three states in the Southwest is no greater than that found in Texas. This has lead to the development of regional management strategies and subsequent insect management guides. The guide revision process ranges from highly structured involving over twenty entomologists in Texas to the more informal process in New Mexico involving one or two entomologists often unable to maintain timely published recommendations. Both Oklahoma and New Mexico have relied heavily upon the research and control recommendations of Texas. Only recently has Texas begun to utilize information from other states. This cooperation has lead to a more efficient and timely guide revision process.

Entomologists of the Southwest region should never ignore the insect management lessons learned in the past. To embrace production systems that maximize yield without regard to pest consequences—or that promote excessive use of insecticides, fertilizer, and irrigation—will negate the management advantages provided by the environment, that is, the natural restraint on pest populations. These benefits can only be maximized through cultural and biological control practices. Sole reliance upon repeated insecticide applications will only bring ruin to a system that has persevered for many years and has been learned through pitched battles with the bollworm and boll weevil.

ACKNOWLEDGEMENT

We want to thank John Thomas for information he provided on the history of the Texas guide revision process. Newt Flora, Eldon Cleveland, Don Peters, Richard Price, and Jerry Young provided valuable assistance in writing and reviewing the Oklahoma portions of this chapter. Sincere appreciation is extended to L. Mike English, J. Gordon Watts, and Joe Ellington for reviewing and making helpful suggestions for improving the New Mexico manuscript. The New Mexico Section of this chapter is dedicated to the memory of the late John J. Durkin, Extension Entomologist, who served the State well from 1955-1982.

Chapter 23

INSECT AND MITE MANAGEMENT IN THE WEST[1]

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INTRODUCTION

Insect and mite pests of western cotton were reported from the earliest cotton production. Insect pressure was relatively light compared to current pest problems and control was limited to use of the few chemicals available and to cultural practices detrimental to the pests.

Pest problems have increased over the years and change has occurred in the methods and materials used to control them. Chemical control became dominant in the late 1940s and is still an important part of integrated pest management systems currently used. Emphasis in current pest management is placed on utilizing a broad base of control components implemented on a community-wide basis.

Research and extension programs have been very important in developing new technology and in information dissemination to growers and others involved in western cotton production.

[1]USDA's Crop Reporting Service, the United States cotton industry and other groups generally include New Mexico in the West region along with Arizona and California. Because of similarities in insect and mite problems and management practices to those in Texas, the authors of the previous chapter chose to include New Mexico in the Southwest region along with Texas and Oklahoma.

HISTORY AND EVOLUTION OF INSECT AND MITE MANAGEMENT

THE MAJOR PESTS

Cotton became an important crop in the desert areas of Arizona and southern California in the early 1900s. Numerous insects were recorded as pests, but prior to the occurrence of the pink bollworm, *Pectinophora gossypiella* (Saunders), damage was primarily from plant bugs, particularly the western lygus bug, *Lygus hesperus* Knight (Morrill, 1918; McGregor, 1961). McGregor (1961) reported that *Lygus* caused an estimated $1,280,000 damage to California's Imperial Valley cotton in 1918. Morrill (1918) recorded *Lygus* as the major pest in Arizona cotton but noted that occasional problems from the bollworm, *Helicoverpa zea* (Boddie); stink bug; cotton leafworm, *Alabama argillacea* (Hübner); cotton leafperforator, *Bucculatrix thurberiella* Busck and other pests occurred. He also reported that lead arsenate, calcium arsenate, Paris green and nicotine sulfate were used to control pest infestations in localized areas. Growers were encouraged to use indirect control strategies such as winter plowing and trap crops.

In the San Joaquin Valley of California, *Lygus* have been the dominant insect pest of cotton since its earliest production in the region. Early management was through cultural practices, particularly weed management and early harvest of alfalfa grown for hay. These practices were of only limited value. While arsenical insecticides were recommended in the early 1940s, they were not highly effective and presented a direct threat to honey bees and dairy cattle. Introduction of the synthetic organic insecticides in the late 1940s revolutionized *Lygus* management on cotton for a time, providing levels of control not previously possible.

Spider mites, particularly the strawberry spider mite, *Tetranychus turkestani* Ugarov and Nikolski, have been pests of cotton since the earliest production in the San Joaquin Valley. Only outbreaks of the strawberry spider mite were common prior to use of the synthetic insecticides. As a result of crop and pest management changes, the twospotted spider mite, *Tetranychus urticae* Koch, and Pacific spider mite, *Tetranychus pacificus* McGregor have assumed major significance as pests of cotton. Major infestations of all species develop on nearby crops, particularly crops under intensive insecticide use, and invade cotton when infestation levels on these alternate hosts are high.

Bollworms have been recognized as pests of San Joaquin Valley cotton since the late 1930s. Outbreaks have been periodic and appear to relate largely to destruction of their natural enemies through use of insecticides against other arthropod pests. Severe outbreaks followed use of DDT and other synthetic insecticides, particularly in the early to mid-1960s.

Whiteflies, particularly the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), have been pests of San Joaquin Valley cotton since the mid-1930s. Associated with the introduction of the synthetic insecticides was a general decline in the occurrence of this pest until the early 1970s. Thereafter, occasional outbreaks appeared associated with excessive pesticide use. Silverleaf whitefly, *Bemisia argen-*

tifolii (Bellows and Perring), although found in greenhouses, was not a pest in the field until 1992, when it was collected from numerous locations in the San Joaquin Valley. Economic infestations occurred in limited cotton acreages in 1993.

CONTROL RECOMMENDATIONS

Early cotton growers in Arizona and California apparently relied heavily upon university bulletins and reports, information from U.S. Department of Agriculture and state agriculture employees, and dealers who sold insecticides for information regarding insect control. This pattern of cotton insects, their control, and assistance provided to growers continued through the 1920s, 1930s and into the 1940s.

University of Arizona and University of California Extension Services began to issue cotton insect control publications in the 1940s that were revised annually. They also provided information to growers through other means such as newsletters, meetings and field clinics. J. N. Roney, Extension Entomologist, began providing recommendations to Arizona growers in 1943.

The earliest records of insect control recommendations for California are contained in letters (1941-45), from Gordon L. Smith, Associate Entomologist, University of California to farm advisors and agricultural commissioners. These letters suggested weed control to eliminate spider mite sources, and early harvest of alfalfa to reduce the threat of *Lygus*; cotton aphid, *Aphis gossypii* Glover, and strawberry spider mite. They also indicated control of *Lygus* and migrating western yellowstriped armyworm, *Spodoptera praefica* (Grote), and hornworm, *Celerio lineata* F., with arsenical insecticides and cautioned regarding the hazards of these chemicals to honey bees and dairy cattle. The use of DDT was included in the letters of Smith after 1945.

Newsletters by Smith (1947), Smith and Bryan (1949) and subsequent authors, to growers and the cotton industry reported the efficacy of several synthetic insecticides, and recommended several organochlorine, organophosphate and other classes of insecticides and miticides. These earliest recommendations contained admonitions concerning the effect of the insecticides on parasitic and predaceous insects and on honey bees.

CHEMICAL CONTROL ERA

The availability of DDT and other synthetic organic insecticides that followed, beginning in the mid-1940s, revolutionized cotton insect control in desert areas of the West. Growers began to rely more and more on chemical control to solve insect problems. A large chemical industry developed that provided not only materials for sale but also fieldmen who sampled fields and recommended insecticides. Often these fieldmen were authorized to take care of the details of application, leaving the grower with little or no involvement in pest control on his farm. An aerial application industry also developed, and in 1958, the Agricultural Aircraft Association Inc., along with a few University of California entomologists, promoted the idea of licensing chemical sales persons (personal letters of Robert van den Bosch and Vern Stern). It was not until 1968, however, that California legislation dealing with the matter was introduced. In

1970, Claude Finnell, California's Imperial County Agricultural Commissioner and local pest control advisors (PCAs) conceived a county ordinance that required licensing and testing. That beginning saw the first chapter of what is now the California Agricultural Production Consultants Association, Inc. (CAPCA). The law requiring licensing and testing was passed and examinations were begun in 1972. Requirements for continuing education were promulgated and CAPCA was fully organized and incorporated in 1975. In Arizona, licensing of commercial applicators and pest control advisors (PCAs) began in 1972, and a continuing education requirement was begun in 1987, involving PCAs and both commercial and private applicators.

Heavy reliance on chemical control of western cotton pests that began in the 1940s continued through the 1950s and 1960s, evolving through an era of organochlorine insecticide use into a period utilizing organophosphates and carbamates. Resistance and residue problems were the primary causes of reduced organochlorine use. Residue levels were especially critical in Arizona and southern California where cotton and forage crops, such as alfalfa, are grown in close proximity. These problems were increased by a shift in the early- and mid-1960s toward automatic treatment programs for cotton that called for applications from planting until harvest. Carter (1966) stated that slowly but surely research was pointing the way to automatic treatment and season-long plant protection. His suggested program to Arizona cotton growers called for three segments of treatments beginning at planting and ending in September. DDT was the first casualty of this period of insecticide over-use as it was removed from university recommendations in 1968 and banned from use in Arizona in 1969 due to residues in forage crops and the resultant adverse impact on the dairy industry. This began an era of increasing restrictions on pesticides use in the West and nationally.

PRODUCTION PRACTICES AND PEST PROBLEMS

A factor that contributed to the evolution of pest problems in the West, particularly in Arizona, was the practice of stub (perennial) cotton production. Stub cotton production occurred except when prohibited by state regulations. The regulations were enacted to deal with increasing pest problems. Pest problems subsided during periods when stub cotton was not permitted, but growers would successfully petition to go back to stub production. It was during and after one of these periods in the mid-1960s that the boll weevil became established in local areas in central Arizona and the pink bollworm spread across Arizona and southern California and became an annual key pest.

Measurable infestations of the boll weevil were not recorded in Arizona cotton from 1966 to 1978, when the growing of stub cotton was banned and mandatory plowdown and planting dates were enforced to maintain a host-free period. During and after the next period of legal stub cotton production, from 1978 to 1982, boll weevils spread across Arizona and southern California (Bergman *et al.*, 1983). Boll weevils were found in stub cotton fields near Gila Bend, Arizona, during 1978 and the spring of 1979. Subsequently heavy boll weevil infestations spread from stub to planted cotton and continued to increase even after stub cotton was banned in 1983. The Arizona

Cooperative Extension, with assistance from experiment station and USDA entomologists, began a program in 1981, to create awareness of the boll weevil problem and to provide assistance to growers in controlling the pest. A California state and grower funded boll weevil eradication program was initiated in 1983, and continued through 1984. It was expanded in 1985 with USDA, State of Arizona and grower assistance into the southern California valleys, northern Mexico, and western Arizona. That southwestern regional program was expanded again in 1988 to include central Arizona. Since 1990 very few boll weevils have been trapped throughout the eradication area and the program is considered highly successful.

The pink bollworm was first found in Arizona in 1926, in Cochise and Graham Counties, and in 1927, in Greenlee and Pima Counties (USDA 1961, unpublished report). Infestations in Pinal and Pima Counties were first reported in 1929, and in Santa Cruz County in 1938. Infestations were sporadic in central Arizona counties until 1958, following increasing levels of infestations in Greenlee and Graham counties in 1956. Concerted eradication efforts of state and federal agencies reduced population levels from 1958 to 1963 in central Arizona. In 1959, only one pink bollworm larva was found despite intensive sampling. After terminating these efforts, stub cotton production was again allowed in 1963, and pink bollworm infestations increased rapidly, spreading across Arizona into the Imperial Valley of southern California in 1965. Infestations spread to Riverside and San Diego Counties by 1967, as well as the high desert area of Los Angeles, San Bernardino, and Kern Counties.

Increased populations of the pink bollworm in the western desert cotton agroecosystem, beginning in 1965, had a profound impact on the social, environmental and technological aspects of cotton cropping and pest management systems. Chemical control to prevent cotton losses was heavily relied upon despite the encouragement of entomologists, as early as 1968, to adopt cultural practices that had been demonstrated to effectively control the pink bollworm (Watson and Larsen, 1968; Rice and Reynolds, 1971; Watson *et al.*, 1973; Moore, 1972). Authority for the appointment of a California Cotton Pest Control Board was provided in the State's Agricultural Code of 1967. Soon to follow were provisions to strengthen the law pertaining to host-free periods and regions as well as to establish mechanisms for assessing monies on a per bale basis. These funds were to be used in control and eradication programs and for research.

INSECTICIDE RESISTANCE

Problems with the organochlorine insecticides during the 1960s caused growers to turn increasingly to the organophosphates and carbamates for cotton insect control until 1977 and 1978, when resistance to methyl parathion, especially in the tobacco budworm, *Heliothis virescens* (F.), resulted in control failure and serious yield losses (Crowder *et al.*, 1979). Thus, the problems of insecticide resistance, destruction of natural enemies and resulting secondary pests, as well as bee poisoning and environmental contamination, did occur as predicted.

Pyrethroid insecticides became generally available in 1979, and were effective against the pest complex of concern in Arizona and southern California. These new insecticides reversed the devastating losses caused by the bollworm/tobacco budworm complex during 1977-78, and have held these pests in a state of minor importance in most subsequent years. On the other hand, other pests, such as spider mites and the silverleaf whitefly that were rarely a problem in the desert areas of the West prior to introduction of the pyrethroids, have become major pests. These two pests, along with mid- to late-season thrips, *Frankliniella* spp., populations, have been noted to increase in association with use of some pyrethroids.

Trends toward resistance to pyrethroids by the tobacco budworm in the early 1980s, and later by the pink bollworm, have brought about resistance management programs that encourage use of other insecticide classes prior to July 1 and at other times when effective. An IPM system emphasizing cultural control practices is very important in resistance management. It is recognized that government "set-aside" programs and fluctuating cotton prices cause annual shifts in planted acres; however, increasing problems just mentioned including pesticide use and cost brought about by the pink bollworm, were largely responsible for a decrease in planted cotton acres in California's Imperial Valley from a high of 143,000 in 1977 to a low of 17,169 in 1986.

EFFECT ON HONEY BEES

Reduced efficiency of honey bees in the West with regard to honey production and crop pollination has been a major problem. Because of the volume of insecticides used on cotton over an extended period, it is the number one crop implicated in bee poisoning and reduced honey production efficiency. The problem was particularly severe during the early period of chemical control where calcium arsenate was used extensively on cotton insects. It reached even higher levels of intensity with the development of certain organochlorines, organophosphates and carbamates. These pesticides vary from relatively non-hazardous to hazardous (McGregor, 1976).

Levin (1970) reported that 70,000 honey bee colonies were killed in Arizona and 76,000 in California. Swift (1969) reported losses in California of 83,000 colonies. Bee colonies in Arizona were reduced approximately 45 percent from 1965 through 1972 (Arizona Agric. Statistics, 1980). The numbers of hives in Arizona have increased from about 77,000 in 1972 to 96,000 in 1985. This improvement has been the result of nighttime pesticide applications, increased use of the less toxic pyrethroid insecticides, improved bee colony handling techniques, and pest management practices that reduced pesticide loads in the bee environment.

INTEGRATED PEST MANAGEMENT PROGRAMS

DEVELOPMENT

Pesticide resistance and development of secondary pest problems along with increased cost of control and other peripheral problems caused concern among western growers and led to development of Integrated Pest Management (IPM) programs (Carruth and Moore, 1973). IPM development followed insect pest evaluation programs known as supervised control that were initiated in California in the 1940s.

Objectives of supervised control included timely use of insecticides related to infestation development and avoidance of unnecessary applications. An extension-sponsored program in Graham County, Arizona, in 1969, led to a pilot IPM program supported by a federal grant for Pinal County, Arizona, in 1971. Following this pilot work, IPM expanded throughout the West and nationally; it remains the predominant method of cotton insect control. IPM is a complex systems approach to pest control that requires good field sampling and use of economic thresholds levels as the basis for a combination of control components. Delivery of IPM resulted in the establishment of grower cooperatives and increased numbers of private consultants capable of implementing community-wide programs as well as those for individual farms.

COMPONENTS AND IMPLEMENTATION

The development of IPM led to broad-based recommendations that promoted a more complex systems approach to cotton insect and mite control (Ellsworth *et al*., 1993; Toscano *et al*., 1979; Anonymous, 1984). Control components included cultural practices, host-plant resistance, biological control, microbial agents, mechanical-physical methods and chemical control.

A major consideration of IPM is conservation of and the role of naturally occurring beneficial insects in regulating pest species below economic levels. Natural enemies along with good cultural practices have long been considered by entomologists to be the most important factors in minimizing many insect problems (Graham, 1980). This fact was not fully appreciated in western cotton production systems until the extensive use of insecticides to control pink bollworms in the 1960s and 1970s led to serious yield losses from uncontrollable infestations of tobacco budworms in 1977 and 1978.

Numerous authors have emphasized the importance of indigenous parasites and predators in regulating pest insect populations of cotton, as well as the adverse effect of insecticides in reducing numbers of these natural enemies (Newsom and Smith, 1949; Wille, 1951; Gaines, 1942, 1954, 1955; Ewing and Ivy, 1943; Van Steenwyk, *et al*., 1975; van den Bosch *et al*., 1956).

The need to preserve the beneficial insects in western cotton, made evident through outbreaks of secondary pests following *Lygus* control, led to implementation of new alfalfa harvest practices referred to as strip-cut harvesting (Stern *et al*., 1964) and alfalfa interplanting (Stern, 1969). While not widely adopted by growers, these cultural practices are quite effective and can greatly reduce the threat to cotton by *Lygus* and several other pests. Current grower practice is to closely monitor infestations and to treat for *Lygus* control based on *Lygus* numbers and plant fruiting condition. When therapeutic treatment is needed growers are encouraged to utilize the most selective insecticide.

DISSEMINATION OF INFORMATION

Western growers and pest control advisors are encouraged to consider year-around IPM implementation. Integrated Pest Management for Cotton (1984) is a Western regional publication written by scientists from California, Arizona and New Mexico, that is a complete guide to cotton IPM in the West. Arizona Cotton Insects (Werner *et* *al*., 1979) and Pest Management Guide for Insects and Nematodes of Cotton in California (Toscano *et al*., 1979) provide information on identification and biology of insects and spider mites found in western cotton. These publications are supplemented by annually-revised pamphlets and reports and occasional newsletters that provide both chemical and nonchemical alternatives for cotton pest control (Ellsworth *et al*., 1993; Burton, 1981).

University of California recommendations for use of insecticides and miticides are based on field experiments conducted by university research entomologists and farm advisor cooperators within California. University of Arizona recommendations, however, may also be based upon USDA information or other sources deemed reliable by the person(s) making the recommendations. Not all registered insecticides and acaricides (miticides) are recommended in either Arizona or California. Climatic and cultural conditions as well as length of season differ substantially between California's San Joaquin valley and the smaller, more isolated Coachella, Imperial, and Palo Verde desert valleys. These dissimilarities, along with differences in the components within the cotton insect complex, require attention to local information, situations and regulations as recommendations are being formulated and disseminated.

In both California and Arizona, concern exists within the university systems relative to liabilities associated with recommendations, or, suggestions as they are now called by the University of Arizona. The University of California has revised its "Policy Communication No. 18" (Policy for Pesticide and Related Chemicals Use and Experimentation) and issued a handbook describing the essential elements of compliance requirements for its researchers (Stimmann, 1986). Subjects included are: (a) employer responsibilities and employee training; (b) experiments on or off university property; (c) licensing and certification; (d) written recommendations; and (e) special use authorizations.

Continued urbanization in California and Arizona, and public attitude concerning pest control, will lead to increased restrictions on pesticide use. Greater reliance will be placed on recommendations that emphasize control components such as cultural practices, resistant cultivars and biological control agents to reduce the threat of cotton pests and the need for chemical control.

COMMUNITY ACTION PROGRAMS

PINK BOLLWORM AND BOLL WEEVIL

Communitywide IPM programs have become common in Arizona and southern California. Problems with yield losses and control costs from insects such as pink bollworm, boll weevil and whiteflies, were largely responsible for increased interest in community action groups. A Cotton Pest Abatement District in the Imperial Valley was promoted by growers, and established by California Department of Food and Agriculture regulation in 1982. This regulation required the mandatory application of the pink bollworm pheromone, gossyplure, for all early-season control measures against that pest. With that as a requirement, chlordimeform (Fundal®, Galecron®)

reregistration was allowed and the product was again permitted in that district for a period of five years, subject to restrictions and detailed monitoring by the Department's Division of Health and Safety. Use of chlordimeform products was also permitted in the Palo Verde Valley for the last four of the five years. Imperial Valley growers in California developed a community program within the pest abatement district to help them deal with the pink bollworm and whiteflies, including early crop production, chemical termination of the crop by September 1, followed by harvest and plowdown by November 1. Growers in the Palo Verde Valley have been reluctant to establish regulations calling for crop termination as early as September 1. For the 1993 season however, they did request and receive a variance from the host-free period of January 15 - March 15 to one of January 1 - March 1. Maintaining the 60-day host-free period, they petitioned the California Department of Food and Agriculture to grant a variance for the 1994 season which called for a plowdown date of December 15 and permits planting on February 15. Moving the plowdown to an earlier date forced, although not by regulation, earlier harvest which tends to reduce the extent of diapausing pink bollworm larvae.

In addition, many growers have adopted the practice of winter irrigations, following cotton, to reduce the extent of pink bollworm survival and spring emergence. That cultural control practice has been reemphasized by Beasley (1991). Similarly, most cotton producers in the Palo Verde Valley plant to moisture and strive to water back sufficiently early to promote maximum pink bollworm emergence prior to the hostable square stage of the crop (Beasley, 1990).

Three groups, formed in central Arizona in 1986 and 1987 to combat the boll weevil and other pests, used cultural, chemical and biological control components. Specific control components included: (a) trap crops; (b) delayed uniform planting; (c) pinhead square treatments; (d) in-season control; (e) early irrigation termination; (f) use of harvest-aid chemicals; (g) early harvest; and (h) immediate stalk shredding. All of these programs center around a shortened growing season to place an additional stress on overwintering pest populations. Important to these community action programs are grower and pest control advisor committees that work closely with extension personnel in developing policy and activities. Regular meetings to keep all growers informed are important to program success. A program in the Marana-Avra Valley area uses multiple control components to effectively control all cotton insect pests in the community. The Marana-Avra Growers Task Force oversees the operation of this program in cooperation with extension and research personnel and pest control advisors. The Arizona Cotton Growers Association established a community-wide pink bollworm management program in the Parker area in 1989 in cooperation with local growers. The program was later expanded into the Gila Bend area and to include whitefly management.

Successful results by community action groups have been favorably received by growers and pest control advisors because of improved pest control and reduced adverse environmental impact. This is especially critical in areas of urban-agriculture interface where pesticide use is being increasingly challenged.

SILVERLEAF WHITEFLY

The silverleaf whitefly is a serious problem in Arizona and California primarily because of honeydew production, disease transmission, and yield loss. A complete effective management system for silverleaf whitefly is a goal for the future and at present, is in the early formative stages. However, extensive ecological, biological and fundamental research on the whitefly complex and its natural enemies is revealing many potential components for incorporation into an ecologically-based management system. Some crop management and community-oriented farm practices are being implemented in an effort to provide overall whitefly population reduction. The extensive cultivated crop host range, wild weed hosts and urban ornamental and weed hosts combine to provide a year-long spatial (relating to space) and temporal (relating to time) continuum of host biomass that provide food, shelter and reproductive substrate throughout the year. The resulting complex interrelationships of types of cultivated crops, crop growing sequences and urban community hosts have an impact and are of concern to the entire farm community in whitefly population development.

Areawide community-involved approaches to silverleaf whitefly management have the best possible chance of success. The cotton grower in a farming community must give careful consideration to the status of winter-spring cultivated crop sequences in proximity to prospective cotton planting locations. Although, low silverleaf whitefly populations occur on vegetable crops such as broccoli, lettuce and cole crops during October through February and March, populations developing in early spring melons increase dramatically in April to May and high numbers move to cotton. Thus, early harvest and melon crop residue destruction and plowdown is an essential silverleaf whitefly management component for the cotton grower.

Uniform, optimum cotton planting date scheduling may help escape high, early-season infestation levels. Planting upwind of infested or potentially infested cultivated crop hosts is a further precaution to managing early-season infestations. Smoothleaf cottons support lower silverleaf whitefly population levels than hairy-leaf cottons. Also, short-season cotton types to develop an early maturing cotton crop for early harvest and crop destruction are effective in reducing overall population densities in areawide farming community programs.

Water and fertilizer management are important factors in silverleaf whitefly management. Although the mechanisms involved in the complex interaction of the host plant condition and whitefly population dynamics are largely unknown, silverleaf whiteflies increase dramatically when cotton plants become stressed. Thus, frequent and adequate irrigation during the season delay the occurrence of high population densities.

Several insecticides alone or in combination have been found to provide adequate silverleaf whitefly control. Special attention must be given to good coverage, particularly to underleaf surfaces. Insecticide resistance is a particularly important factor in whitefly management. It is important to avoid using materials in the same chemical class for extended periods. Frequent population monitoring of the adult and immature populations on leaves is critical to assess effectiveness of control strategies. Definitive economic threshold values have not been established but high population levels cause severe defoliation and reduced yield as well as sticky cotton.

Late-season cotton crop and silverleaf whitefly management must be carefully planned and carried out. Logarithmic population increase of silverleaf whitefly populations begins in late July and early August shortly after peak cotton flowering. Thus, the cotton plant is subjected to increasing stress from whitefly feeding during the period of boll maturity and boll opening with increasing numbers of open bolls exposed to accumulations of honeydew. The critical timing of irrigation termination, defoliation and harvest leaves very little margin for error, but must be accomplished as early as possible considering optimal yield.

SAN JOAQUIN VALLEY PROGRAM

The current IPM program for cotton in California's San Joaquin Valley places major emphasis on pest detection and infestation monitoring (e.g., presence/absence sampling for spider mites). This provides for avoidance of unnecessary insecticide use and for timely scheduling of management practices. Biological control provides an opportunity to suppress pest infestations. Where insecticides or miticides must be applied, use of the more selective materials is encouraged. Use of broad spectrum pesticides during July, when the threat of lepidopterous pests is high, is discouraged.

FUTURE PROGRAMS

Pesticide regulation, especially water quality legislation and the Endangered Species Act, is reducing the flexibility of chemical pest control. It is this reduced flexibility that also may be accelerating, rather than delaying, the development of resistance to some chemicals by some insects (Trumble and Parella, 1987). This places added importance on the continued development and implementation of alternative control practices packaged as IPM community action programs.

EDUCATION AND EXTENSION LEADERSHIP

A major portion of the cotton acreage in Arizona and California is monitored for arthropod pests by trained personnel. Some of the larger farms utilize a permanent employee, supplemented by additional summer assistants, to monitor fields. Many cotton growers retain the services of private consultants who advise them of pest management needs and other practices. In some cases, however, growers rely on the representatives of pesticide retailers despite efforts from some groups to allow licensing of only crop consultants and/or pest control advisors who have no vested interest in sales. Extension educational activities such as meetings, publications and demonstrations are important in meeting the training needs and continuing education requirements of field monitoring personnel.

Continued efforts to improve grower acceptance and use of new IPM strategies and technologies are underway throughout the West, as well as in other cotton producing regions. Some examples may be seen in the University of California's IPM implementation program. This program was first established in 1981, by annually appropriated money from the State General Assembly and is now an in-line part of the University of California budget. The UC IMPACT computer network has, since 1982, provided a number of programs and databases to mini-computers housed in county extension offices. These include degree-day and phenology (relationship of climate and biological phenomena) models for the pink bollworm and cotton developmental stages, a comprehensive meteorology database for over 125 reporting stations, three-day agricultural forecasts, and realtime data for over 100 stations. In addition, information on biologies, monitoring guidelines and control tactics are available by computer for most important insect, weed, pathogen and nematode pests. The system has recently been made available by phone line to microprocessors of individual growers, pest control advisors and other interested persons. A similar system, known as AZMET, is operated by the University of Arizona. In addition to on-line computer data, the Arizona system provides weekly advisories (newsletters) that include localized information on heat unit accumulations, agronomic conditions, and insect control recommendations. Cotton models, including COTSIM, are being produced for microprocessors and expert systems are being developed for assisting in decision making by owner/operators, managers and pest control advisors.

The last 15 to 20 years have seen much activity in IPM research and implementation. Refined detection and sampling methods, coupled with a better understanding of the pests, their natural enemies and the cotton plant, have resulted in highly developed management recommendations (Anonymous, 1984). Research and implementation efforts must continue and interdisciplinary information exchange must expand in order to offset increasing problems of pest resistance, production costs, reduced availability of chemical control materials, expanding urbanization, environmental contamination and human health concerns.

SUMMARY

Western insect and mite management has evolved through periods of relatively light pest conditions to increased pest problems and changes in the methods and materials used to prevent or reduce their damage.

Synthetic organic insecticides were very important in reducing pest damage and increasing yields. Problems developed however from pest resistance, secondary pests and environmental hazards. These brought about integrated pest management programs that emphasized use of multi-component systems designed to reduce insecticide input. These systems are being implemented on a community-wide basis using cultural, biological and chemical components that attack weaknesses in the biology and ecology of key pests.

Extension educational programs have played a key role in creating awareness, disseminating information, and demonstrating new technology to western growers. It is important that research and implementation efforts continue and expand as a means of helping growers meet the challenges of the future in environmentally sound, cost effective insect and mite management.

SECTION VI

ECONOMICS OF INSECT AND MITE PEST CONTROL

Chapter 24

THE ECONOMIC IMPACT OF COTTON INSECTS AND MITES

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INTRODUCTION

Cotton farming is a major field crop enterprise and an important source of foreign exchange in the United States. In 1985-86, cotton ranked fifth among field crops in value of production with about 38,000 growers scattered from Virginia to California earning $4 billion from the sale of lint and cottonseeds (Starbird *et al.*, 1987). United States cotton production is particularly susceptible to losses caused by the presence of insect and mite pests. Indeed, a major factor influencing the viability of cotton production in many areas is the ability of growers to control insect and mite populations and, therefore, minimize production losses, risk and uncertainty.

Many insect and mite species attack cotton foliage and bolls limiting potential yields. The aggregate damage attributed to cotton insects and mites is often reported as annual yield reductions of 7 to 14 percent and control expenditures in excess of $200 million per year despite best control efforts (Anonymous, 1980, 1981, 1983; Head, 1982, 1984, 1985; and King *et al.*, 1986, 1987). Using recent years as examples, estimates of the extent of economic impacts caused by these pests are examined in this chapter. A brief survey was conducted of available data on grower control practices, crop damage and aggregate effects and public expenditures. Reported results provide approximations of current economic impacts on domestic agricultural production, producers and consumers.

KEY INSECT AND MITE PESTS

Cotton production areas are clearly defined in the United States, each with a different ecosystem and complex of serious insect and mite problems (Figure 1). In general, these areas can be classified as: the humid areas of the Southeast (Alabama, Florida,

Regions and subregions	Code
Appalachia:	
Virginia and North Carolina--North	1
North Carolina--South	2
Piedmont	3
Tennessee--North Brown Loam	4
South Brown Loam	5
Southeast:	
South Carolina--Coastal Plains	6
Piedmont	7
Georgia--Piedmont	8
East and Southwest	9
Alabama--Limestone Valley and South	10
Florida	11
Corn Belt:	
Missouri--Bootheel	12
Delta States:	
Mississippi--Non-Delta	13
Delta	14
Arkansas--Northeast	15
Southeast	16
Louisiana--Northeast	17
Red River Valley	18
Southern Plains:	
Texas--Lower Rio Grande	19
Upper and Lower Coast	20
Winter Garden	21
Central River Bottom	22
Blacklands	23
Rolling Plains and Upper Concho	24
High Plains	25
Trans Pecos	26
El Paso and Hudspeth Counties	27
Oklahoma--North	28
South	29
Mountain States:	
New Mexico--Southern Plains	30
Pecos Valley	31
Upper Rio Grande	32
Arizona--Southeast	33
Central	34
Yuma and Mohave Counties	35
West:	
California--Lower Desert Valleys	36
San Joaquin Valley	37

Figure 1. Subregions of cotton production in the United States Cotton Belt.

Georgia, North Carolina, and South Carolina); Delta or Mid-South (Arkansas, Louisiana, Mississippi, Missouri and Tennessee), and coastal areas of Texas where the bollworm, *Helicoverpa zea* (Boddie), tobacco budworm, *Heliothis virescens* (F.), boll weevil, *Anthonomus grandis grandis* (Boheman), plant bugs, and thrips are the key pests; the semi-arid areas of the Southwest (New Mexico, Oklahoma and inland Texas) where the key pests are the bollworm, tobacco budworm, cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter), and the boll weevil; and the irrigated deserts of the Far West (Arizona and California) where the pink bollworm, *Pectinophora gossypiella* (Saunders), spider mites, and the western lygus bug, *Lygus hesperus* Knight, are the key pests.

In the sections that follow, aggregate estimates of pest control incidence, chemical use, grower control expenditures and yield loss are reported for key insect and mite species in each cotton producing state and area in the United States. Estimates generally rely on selected cotton pesticide use surveys (USDA, 1964-87) and on cotton experts who have provided state and area specific estimates of pest incidence, control measures (Suguiyama and Osteen, 1988), and yield losses (Anonymous, 1980, 1981, 1983; Head, 1982, 1984, 1985; and King *et al.*, 1986, 1987). Target pests include individual species and two major complexes: (a) bollworm/tobacco budworm/boll weevils; and (b) pink bollworm/other pests. The individual pests category includes the bollworm, boll weevil, plant bugs, stink bugs, and other minor pest species.

PEST INCIDENCE

Early planting, the use of rapid fruiting and early maturing varieties, optimum fertilization and irrigation, plant spacing, trap crops[1], early harvest and crop residue disposal have long been recognized and adopted as excellent measures for reducing potential insect and mite damage on cotton production (National Academy of Sciences, 1975; Namken *et al.*, 1983; Grimes, 1985). These cultural practices have been extensively investigated and complement pest management strategies for detection, augmentation of biological control techniques, and timing of chemical control practices. Bradley and Agnello (1986) recently provided examples of four major cotton insect pests (bollworm, tobacco budworm, boll weevil and pink bollworm) whose management may be achieved through the application of cultural techniques as basic elements of cotton production programs.

Despite good agronomic practices, cotton insects and mites reach population and potential damage levels that justify the use of chemical control measures in every production area in the United States. An estimated range of 50 to 70 percent of the total cotton acreage harvested is treated annually one or more times with insecticides or miticides (Figure 2). Almost all of the cotton acreage is treated in southeastern, Delta, and western states. Only the southwestern states (New Mexico, Oklahoma and Texas) traditionally have considerably less than 100 percent of acreage treated.

[1]While trap crops have been recognized, they have not been adopted to any significant extent.

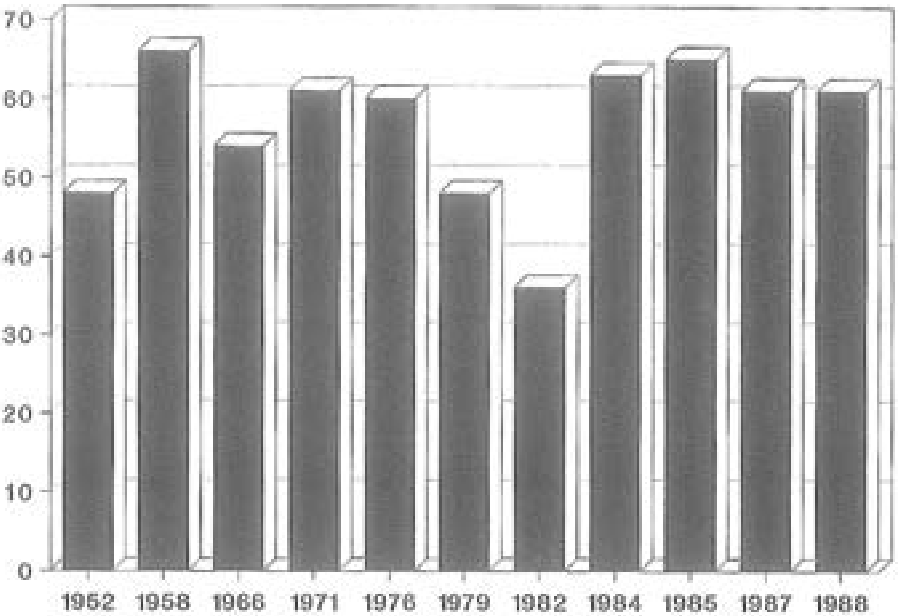

Figure 2. Percentage of cotton acreage treated with insecticides/miticides, 1952–1988. (Source: Economic Research Service, United States Department of Agriculture.)

On the aggregate, grower control efforts are mainly directed at bollworm/ tobacco budworm (an estimated 53 percent of harvested acreage), thrips (42 percent), boll weevil (40 percent), plant bugs (37 percent) and spider mites (17 percent) (Table 1[2,3]). These species predominate in most states and areas. Of particular regional importance are the pink bollworm, seedcorn maggot, *Delia platura* (Meigen), wireworms and whiteflies in western states; and grasshoppers in the Southwest. Estimates of harvested acreage treated for each species in specific cotton production areas are shown in Table 2.

The intensity of pest incidence during the growing season is indicated by the number of chemical applications required to control each population species. Bollworm/tobacco budworm and the boll weevil receive the most applications per harvested acre, on average, of all insect and mite target pests (Table 3[4]). Treated as single targets or as a complex, these pests account for over half of all chemical applications in United States cotton (2.4 out of 4.6 applications per harvested acre). Thrips and plant bugs also account for a large number of applications because of the heavy incidence of acreage treated for these pests in many states.

[2]Comparable estimates of cotton acreage treated for ten important insect and mite pests has been reported from a pesticide use survey for the 1979 crop year (Suguiyama and Carlson, 1985).

[3]All tables referenced in this chapter are found in a Chapter Appendix at the end of this chapter.

[4]The average number of applications per harvested acre in each state is a weighted estimate calculated as the product of the share of total acreage treated times the average number of applications per treated acre.

Great variability is found in the number of applications among producing states and areas (Tables 3, 4). Oklahoma and Texas cotton average the lowest number of applications per harvested acre, 1.3 and 1.9, respectively. In contrast, the southeastern states average the highest number of applications per harvested acre, ranging from 5.9 in North Carolina to 18.4 in Florida. The number of applications on North Carolina cotton have declined considerably in recent years in comparison to other southeastern states due to the absence of the boll weevil as a result of the eradication effort (Carlson *et al.*, 1987).

CHEMICAL USE

During this century, cotton insect and mite control practices in the United States have evolved from sole reliance on cultural methods to heavy reliance on chemicals to adoption of integrated crop and pest management systems (Ridgway and Lloyd, 1983; Bradley and Agnello, 1986). The use of chemical controls remains as an effective tool to reduce damaging population levels. These compounds generally are toxic to beneficial arthropods and are potentially hazardous to other nontarget organisms if proper application or disposal procedures are ignored. These are important factors contributing to the overall impact that these pests have on agricultural production, thus they need to be examined.

Suguiyama and Osteen (1988) estimated that the average United States cotton harvested acre receives 1.64 pounds of active ingredients for insect and mite control (Table 5). The total amount of active ingredients varies considerably among states, ranging from a high of 7.43 pounds per harvested acre in Florida cotton to a low of 0.34 pounds in Oklahoma. Among the compounds, methyl parathion (average estimate of 0.34 pounds per harvested acre), azinphosmethyl (Guthion®) (0.21 lb.), pyrethroids (0.13 lb.), chlordimeform (Galecron®, Fundal®) (0.12 lb.), propargite (Comite®) (0.11 lb.), and aldicarb (Temik®) (0.11 lb.) accounted for about 63 percent of all active ingredients applied to cotton fields in the United States. Figure 3 shows the average amounts of active ingredients for insecticides and miticides applied to United States cotton for selected years. Since 1977, the shift to the pyrethroids to control bollworm/tobacco budworm has resulted in a significantly smaller amount of insecticides being applied to cotton (Cooke and Parvin, 1983). This is largely due to smaller dosages being required for the pyrethroids. However, longer application intervals due to increased effectiveness and/or longer residual activity may also contribute.

The amount and class of chemicals applied to cotton fields have also changed considerably in recent years. Figure 4 contrasts the quantity of chemical materials by classes between the period prior to 1979 when pyrethroids were not registered for use and the following years when pyrethroids were registered and extensively used. The substantial decline in total amounts of chemical used is noted as the past extensive use of organochlorines (for example: DDT, endrin, and toxaphene) has been proportionately replaced with the use of organophosphates, carbamates and pyrethroids. Several factors have contributed to these changes. They include the development of newer and

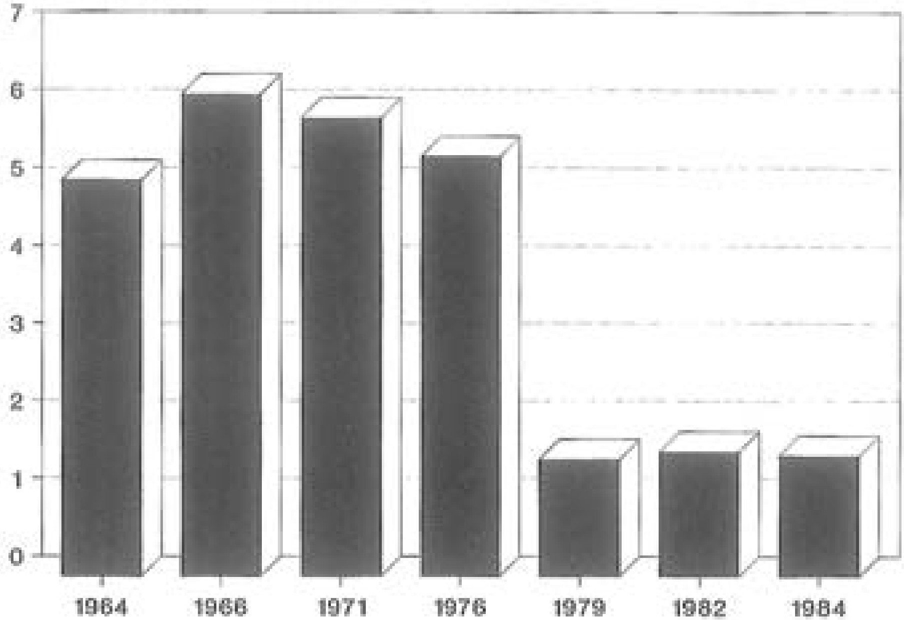

Figure 3. Pounds per planted acre of insecticide/miticide used on cotton 1964-1984. (Source: Economic Research Service, United States Department of Agriculture.)

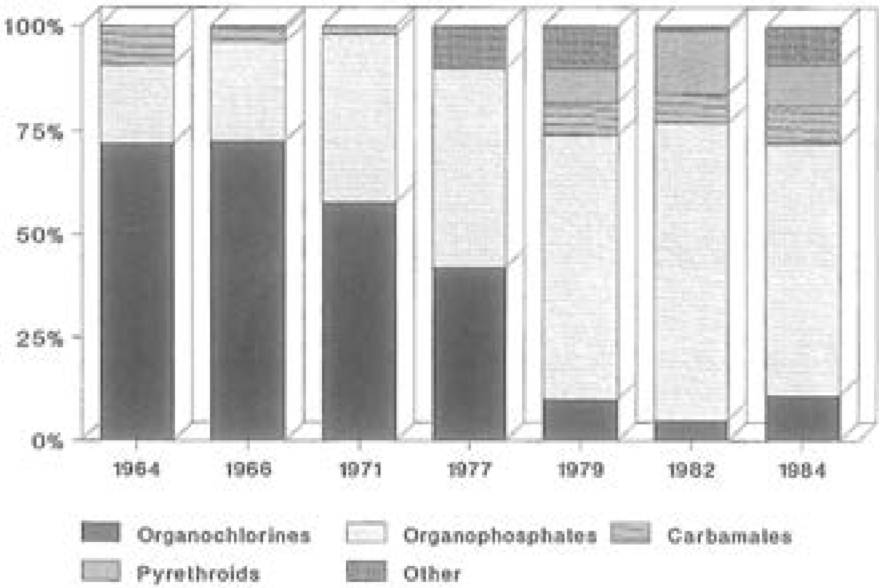

Figure 4. Distribution by chemical class of cotton insecticides/miticides used, 1964-1984. (Source: Economic Research Service, United States Department of Agriculture.)

safer compounds, stricter pesticide regulations, pest resistance, and the extensive efforts of research and extension specialists in promoting integrated crop and pest management practices.

CONTROL EXPENDITURES

Past survey results on expenditures for cotton insecticides and miticides for the 1971-77 period have been carefully reviewed by Cooke and Parvin (1983). Their analysis showed that while insect and mite populations are highly variable, the national per acre cost of insect and mite control has remained remarkably constant. Table 6 shows average estimates of per acre expenditures for insect and mite control for selected years between 1964 and 1980.

Suguiyama and Osteen (1988) estimated average grower control expenditures in United States cotton production to be about $37 per harvested acre, including scouting costs (Table 7[3]). Based on this estimate, the total annual grower expenditures for insect and mite control was approximately $381 million. Bollworm/tobacco budworm and the boll weevil account for over 42 percent of the total insect control expenditures, about $16 out of $37. Cotton grown in the Southeast requires the highest per acre expenditures to control these pests — Florida ($119 per harvested acre), Georgia ($72) and Alabama ($56). The lowest per acre expenditures for these pests are in California ($3), Missouri ($5) and Texas ($5). Also significant are expenditures for pink bollworms in the infested areas of the West. For example, Arizona cotton farmers spend an average of $96 per harvested acre to control primarily pink bollworms.

Per acre grower expenditures for all cotton insects and mites vary considerably among states and areas. The Southeast and Delta states usually report the highest per-acre expenditures for all insect and mite control. Florida farmers spend the most, $145 per harvested acre, while Oklahoma farmers spend the least, about $11 per harvested acre. Estimates of insect control expenditures per harvested acre by species in each cotton production area are reported in Table 8.

COTTON YIELD LOSSES

Yield losses caused by insects and mites have been reported in several studies with significant differences across time (for examples see reports by the U. S. Department of Agriculture, 1965; DeBord, 1977; Schwartz and Klassen, 1981; and Schwartz, 1983). However, estimating yield losses are notoriously difficult to fix on aggregate levels. Survey and experimental methods are used for obtaining replicated loss estimates for adjacent treated and untreated plots. The vexing problem is that such information cannot be easily extrapolated over large areas or average farm conditions because many cultural, physical and environmental factors are important determinants of yield in complex and dynamic crop ecosystems (Carlson and Castle, 1972).

[3]The per acre cost estimate is expressed in 1986 dollars and represents approximately 17 percent of total variable costs per acre of cotton grown in the United States.

In this study, estimates of insect and mite losses in cotton production were obtained from the Proceedings of the Annual Beltwide Cotton-Insect Research and Control Conferences (Anonymous, 1980, 1981, 1983; Head, 1982, 1984, 1985; and King *et al.*, 1986, 1987). The insect and mite cotton loss estimates presented in these annual reports are generated by entomologists and other cotton experts in each of the cotton producing states. These estimates are widely accepted and used by entomologists, extension personnel, pesticide vendors, and cotton producers.

Average production-weighted loss estimates have been summarized for major insect and mite pests. Beltwide loss estimates are shown in Table 9; loss estimates by individual states are shown in Table 10. In the aggregate, 7.7 percent of the annual cotton crop is estimated to be lost to damage despite control measures. Bollworm/tobacco budworm (2.5 percent loss), the boll weevil (1.5 percent), plant bugs (1.6 percent) and spider mites (0.8 percent) are responsible for 65 percent of the total crop loss attributed to insects and mites. The only other species causing significant yield loss is the pink bollworm in the infested areas of the West.

VALUE OF DIRECT DAMAGE

The composite values of damage (yield loss plus control costs) caused by individual species rarely have been reported for cotton pests, with the exception of the boll weevil. Aggregate estimates of economic damage reported in Table 11 are expressed as the sum value of yield losses (from estimates in Table 10) and control expenditures (from Table 7). The calculation of value of yield loss assumes the average market price of cotton to be $0.5844 per pound of lint (1981-84 average). These values represent maximum damage values directly affecting producers alone, since cotton market and other production effects or adjustments in the absence of insect and mite damage are ignored.

The total annual damage caused by all insects and mites on cotton production is estimated to be about $645 million. By species, over half of the damage can be attributed to bollworm/tobacco budworm ($216 million) and the boll weevil ($146 million). Plant bugs also cause significant damage, $76 million. Plant bugs are viewed as serious in California (western lygus bug) and Texas (cotton fleahopper) as well as the Mid-South (tarnished plant bug). The damage caused by the pink bollworm, $71 million, is particularly significant because all damage is concentrated on only six percent of the total United States cotton harvested acreage (Table 1).

AGGREGATE EFFECTS

The continued presence of cotton pests and their associated control measures influence: (a) adjustments in farm cropping patterns (acreage shifts, cultural practices, resistant varieties); (b) the demand for farm inputs (insect control inputs and their efforts on other input use); (c) supply and demand relationships in both the domestic and world market (product price and U.S. comparative advantage); and (d) future production and income stability. As a result, the $645 million crop damage estimate for cotton does not fully reflect the annual impact of insects and mites on total agricultural production.

Several studies have attempted to approximate, either directly or indirectly, the regional and aggregate effects of cotton pests on crop production and marketing (Casey and Lacewell, 1973; Taylor, 1980; Suguiyama and Osteen, 1988). There also are other reports dealing with the effects of pesticide use decisions or areawide pest management programs on crop production. But, because of the complex and interconnected nature of the United States agricultural industry, it is difficult to estimate the effects of producing in the absence of insects and mites, either on total cotton production or on the production of alternative crops.

In one particular study, Suguiyama and Osteen (1988) constructed a scenario in which cotton and other pertinent field crops suffer no damage from insects and mites. As a result, the yield losses and control expenditures were eliminated as output-reducing factors, therefore, yield increased and production costs decreased. Where the absence of insects was restricted to predominant species in cotton and to bollworm and fall armyworm damage in corn, soybean and sorghum, the net annual aggregate impact approached $1.3 billion, or twice the $645 million damage estimate reported earlier for cotton alone[a].

Analytical results generally indicate that the presence of insect and mite pests cause significant changes in cotton planted acreage among production regions. Cotton acreage decreases while soybean, sorghum and corn acreage increases. The Southeast and Delta states, where insect pests cause the greatest direct damage, significantly decrease their cotton plantings. This result is not surprising, since most acreage declines due to pest problems have historically occurred in these regions. Producer income above variable costs are also affected as producers from the southeastern and Delta states, and Arizona suffer the most losses (yield damage and high control costs).

Cotton consumers also lose from lower crop output and thus, higher cotton prices. In turn, lower output and higher prices for fiber alter domestic and foreign cotton markets. Traditionally, the United States has been a residual supplier of cotton in foreign markets; that is, the difference between foreign production and consumption has been met from United States production (National Academy of Sciences, 1975). Furthermore, additional effects may be expected from farm programs since cotton programs have generally included price support or acreage control provisions.

In summary, the annual net domestic aggregate impact of cotton insects and mites on agricultural production involves many significant economic and distributional effects among cotton producers, domestic and foreign, and between cotton producers and consumers.

SUMMARY

Bollworms and tobacco budworms were the most damaging insect pests of cotton, causing direct annual losses of $216 million. The boll weevil ($146 million), plant

[a]The same data estimates were utilized to approximate the direct impact to production and to approximate the net aggregate impact.

bugs ($76 million), pink bollworm ($71 million), spider mites ($64 million), and thrips ($44 million) are also important. Plant bugs and thrips infest a large portion of United States cotton acreage, while the pink bollworm causes heavy damage in the West.

The aggregate economic effects of cotton insects and mites include losses in producer revenues, higher production costs, consumer losses, and net losses to society from wasted resources. Commonly used methods to estimate pest impacts or damages rely on the value of control expenditures plus yield losses. The estimated annual value of direct damage to cotton producers is $645 million, of which about $381 million are chemical control expenditures. More comprehensive analyses suggest that the overall impact from cotton insects and mites has been greater than the above damage estimate.

These reported estimates constitute benchmarks for the assessment of economic impacts caused by cotton insects and mites on United States agriculture. Despite limitations with the data employed in this study, these estimates support current farmer concerns and the need for continued research and educational activities on pest control technologies.

DISCLAIMER

The views presented are those of the authors and do not represent those of any agency or organization. This chapter was written in 1988 and some changes in cotton production and pest control have occurred since then. At the time this chapter was submitted, the senior author was a USDA/APHIS employee.

Chapter 24

APPENDIX

Table 1. Percent of cotton harvested acreage treated one or more times against target pest.

Target pest	Acreage treated																
	AL	AZ	AR	CA	FL	GA	LA	MS	MO	NM	NC	OK	SC	TN	TX	VA	U.S. cotton
	Percent																
BW & TBW[1]	—	73.6	75.0	8.3	100.0	50.0	90.0	52.8	30.0	64.4	98.0	25.0	96.7	50.0	22.8	98.0	34.5
Boll weevil/BW & TBW	100.0	—	55.0	—	100.0	98.8	100.0	37.0	—	—	—	—	—	0.5	6.5	—	19.1
Boll weevil[2]	30.0	32.2	43.9	0.6	100.0	77.1	72.4	49.1	—	—	20.2	7.7	39.0	0.5	11.7	—	20.8
Pink bollworm	—	99.5	—	5.8	—	—	—	—	—	11.3	—	—	—	—	0.6	—	5.8
Pink bollworm/other pests[3]	—	94.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.5
Spider mites	15.0	46.2	—	75.9	2.0	19.4	31.7	21.3	5.0	—	—	—	9.6	2.0	0.9	—	17.0
Thrips	95.0	18.8	98.0	9.4	100.0	87.7	97.6	95.0	100.0	21.3	92.3	2.5	98.3	100.0	24.0	85.0	42.3
Plant bugs[4]	15.0	68.1	34.5	44.4	2.0	29.1	51.2	93.3	50.0	24.5	—	18.7	5.8	75.0	21.8	—	37.1
Fall and beet armyworms	—	—	—	12.3	65.0	19.1	8.8	23.5	1.0	15.5	2.7	1.0	9.6	—	4.3	2.0	7.0
Seedcorn maggot/wireworms	—	—	—	84.8	—	—	—	—	—	—	—	—	—	—	—	—	10.8
Aphids	10.0	—	—	4.7	5.0	29.4	24.4	21.3	5.0	10.7	—	1.7	5.0	2.0	12.4	—	11.0
Whiteflies	—	1.0	—	10.2	2.0	—	—	4.0	—	—	—	—	1.8	—	—	—	1.7
Cotton leafperforator	—	27.1	—	1.2	—	—	—	—	—	—	—	—	—	—	—	—	1.4
Cabbage looper	—	—	—	4.7	2.0	0.9	—	—	1.0	—	—	—	—	—	—	—	0.6
Cutworms	—	2.7	—	4.7	—	—	—	—	—	—	—	—	—	—	0.2	—	0.8
Stink bugs	—	—	—	2.3	—	—	—	—	—	—	—	—	—	—	—	—	0.3
Grasshoppers	—	—	—	—	—	—	—	—	—	15.7	—	3.3	—	—	0.3	—	0.4
All insects and mites[5]	100.0	99.5	100.0	100.0	100.0	99.7	100.0	100.0	100.0	80.7	98.0	63.0	98.3	100.0	56.8	98.0	77.5

— = Unreported or insignificant estimate.

Source: Suguiyama and Osteen, 1988.

[1]Includes the bollworm (BW) and tobacco budworm (TBW).

[2] The acreage treated for the boll weevil in Arizona, California, North Carolina, and South Carolina were estimated prior to completion of cooperative efforts to eradicate the boll weevil from these States.

[3]Other pests include bollworm, tobacco budworm, boll weevil, *Lygus* spp., and stink bugs.

[4]Include *Lygus* spp. and cotton fleahoppers.

[5]Columns may not total 100 due to multiple treatments.

Table 2. Percent of cotton harvested acreage treated one or more times against target pests.

	NC subregions[4]			TN subregions[4]		SC subregions[4]		GA subregions[4]		MS subregions[4]		AR subregions[4]		LA subregions[4]		TX subregions[4]	
Target pest	1	2	3	4	5	6	7	8	9	13	14	15	16	17	18	19	20
								Percent									
BW & TBW[1]	98.0	100.0	85.0	50.0	50.0	99.0	70.0	50.0	50.0	30.0	65.0	50.0	95.0	90.0	90.0	59.0	18.0
Boll weevil/BW & TBW	—	—	—	—	2.0	—	—	80.0	100.0	50.0	30.0	5.0	95.0	100.0	100.0	100.0	49.0
Boll weevil	5.0[2]	45.0[2]	40.0[2]	—	2.0	40.0[2]	27.0[2]	30.0	80.0	85.0	30.0	5.0	75.0	70.0	90.0	98.0	54.0
Spider mites	—	—	—	2.0	2.0	10.0	5.0	10.0	20.0	5.0	30.0	—	—	25.0	80.0	—	—
Thrips	90.0	100.0	70.0	100.0	100.0	99.0	90.0	50.0	90.0	95.0	95.0	98.0	98.0	100.0	80.0	—	20.0
Plant bugs[3]	—	—	—	75.0	75.0	5.0	15.0	15.0	30.0	90.0	95.0	40.0	30.0	50.0	60.0	85.0	90.0
Fall and beet armyworms	2.0	4.0	2.0	—	—	10.0	5.0	5.0	20.0	30.0	20.0	—	—	10.0	—	—	—
Aphids	—	—	—	2.0	2.0	5.0	5.0	20.0	30.0	5.0	30.0	—	—	25.0	20.0	—	10.0
Whiteflies	—	—	—	—	—	2.0	—	—	—	2.0	5.0	—	—	—	—	—	—
Cabbage looper	—	—	—	—	—	—	—	—	1.0	—	—	—	—	—	—	—	—
Cutworms	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.0
All insects and mites[5]	98.0	100.0	85.0	100.0	100.0	99.0	90.0	95.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	97.0

Table 2. Continued

Target pest	TX subregions[6]							OK subregions[6]		NM subregions[6]			AZ subregions[6]			CA subregions[6]	
	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
	Percent																
BW & TBW[1]	100.0	98.0	15.0	10.0	23.0	88.0	75.0	15.0	30.0	30.0	90.0	70.0	45.0	70.0	100.0	95.0	3.0
Boll weevil	100.0	35.0	40.0	10.0	—	—	—	1.0	10.0	—	—	—	—	—	90.0	10.0	—
Pink bollworm	—	—	—	—	—	15.0	75.0	—	—	—	10.0	20.0	95.0	100.0	100.0	100.0	—
Pink bollworm/other pests[4]	—	—	—	—	—	—	—	—	—	—	—	—	45.0	100.0	100.0	—	—
Spider mites	100.0	15.0	5.0	—	—	—	—	—	—	—	—	—	20.0	40.0	80.0	90.0	75.0
Thrips	75.0	15.0	70.0	2.0	33.0	2.0	5.0	1.0	3.0	20.0	10.0	30.0	7.0	20.0	20.0	—	10.0
Plant bugs[3]	100.0	85.0	65.0	5.0	15.0	20.0	15.0	15.0	20.0	15.0	40.0	20.0	60.0	60.0	100.0	100.0	41.0
Fall and beet armyworms	5.0	—	—	—	7.0	5.0	20.0	—	1.0	—	10.0	30.0	—	—	—	50.0	10.0
Seedcorn maggot/wireworms	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	90.0
Aphids	5.0	—	20.0	2.0	18.0	20.0	5.0	1.0	2.0	—	15.0	15.0	—	—	—	—	5.0
Whiteflies	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5.0	95.0	5.0
Cotton leafperforator	—	—	—	—	—	—	—	—	—	—	—	—	—	30.0	30.0	20.0	—
Cabbage looper	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5.0
Cutworms	—	—	—	—	—	—	—	—	—	—	—	—	—	3.0	3.0	—	5.0
Stink bugs	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	40.0	—
Grasshoppers	—	—	—	1.0	—	3.0	—	4.0	3.0	15.0	20.0	20.0	—	—	—	—	—
All insects and mites[5]	100.0	98.0	92.0	15.0	65.0	92.0	85.0	45.0	80.0	60.0	92.0	87.0	95.0	100.0	100.0	100.0	100.0

— = Unreported or insignificant estimate.

Source: Suguiyama and Osteen, 1988.

[1]Includes the bollworm (BW) and tobacco budworm (TBW).

[2]The acreage treated for the boll weevil was estimated prior to completion of cooperative efforts to eradicate the boll weevil from these States.

[3]Include *Lygus* spp. and cotton fleahoppers.

[4]Other pests include bollworm, tobacco budworm, boll weevil, Lygus spp., and stink bugs.

[5]Columns may not total 100 due to multiple treatments.

[6]Map locations of subregions are shown in Figure 1 of chapter 24.

Table 3. Applications per harvested acre, by target pests.

Target pest	Applications per harvested acre																
	AL	AZ	AR	CA	FL	GA	LA	MS	MO	NM	NC	OK	SC	TN	TX	VA	U.S. cotton
	Number																
BW & TBW[1]	—	0.62	1.50	0.22	7.00	1.43	2.59	1.90	0.85	1.42	3.84	0.72	5.75	1.00	0.45	2.74	0.86
Boll weevil/BW & TBW	7.94	—	1.10	—	7.00	6.29	4.88	1.13	—	—	—	—	—	.02	.18	—	.85
Boll weevil[2]	.42	.32	.88	.01	3.00	3.50	1.67	1.57	—	—	.81	.31	2.19	.02	.54	—	.67
Pink bollworm	—	5.02	—	.29	—	—	—	—	—	.13	—	—	—	—	.02	—	.28
Pink bollworm/other pests[3]	—	3.12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.15
Spider mites	.20	.47	—	.99	.04	.32	.48	.39	.10	—	—	—	.15	.02	.02	—	.24
Thrips	1.19	.19	1.42	.19	1.30	1.77	1.19	1.79	1.50	.21	1.20	.04	1.56	2.45	.25	1.15	.62
Plant bugs[4]	.15	.63	.34	.53	.02	.43	.55	1.84	1.00	.35	—	.19	.09	.75	.28	—	.51
Fall and beet armyworms	—	—	—	.22	1.30	.23	.09	.47	.02	.21	.02	.01	.19	—	.04	.02	.11
Seedcorn maggot/wireworms	—	—	—	.85	—	—	—	—	—	—	—	—	—	—	—	—	.11
Aphids	.10	—	—	.08	.05	.58	.24	.43	.05	.13	—	.02	.05	.02	.14	—	.15
Whiteflies	—	.02	—	.28	.02	—	—	.04	—	—	—	—	.04	—	—	—	.04
Cotton leafperforator	—	.27	—	.02	—	—	—	—	—	—	—	—	—	—	—	—	.02
Cabbage looper	—	—	—	.09	.02	.01	—	—	.01	—	—	—	—	—	—	—	.01
Cutworms	—	.03	—	.05	—	—	—	—	—	—	—	—	—	—	.01	—	.01
Stink bugs	—	—	—	.02	—	—	—	—	—	—	—	—	—	—	—	—	.00
Grasshoppers	—	—	—	—	—	—	—	—	—	.35	—	.03	—	—	.01	—	.01
All insects and mites[5]	9.70	10.69	5.24	3.84	18.36	13.05	11.69	9.56	3.53	2.80	5.87	1.32	10.02	4.29	1.94	3.91	4.58

— = Unreported or insignificant estimate.

Source: Suguiyama and Osteen, 1988.

[1]Includes the bollworm (BW) and tobacco budworm (TBW).

[2]Boll weevil applications in Arizona, California, North Carolina, and South Carolina were estimated prior to completion of cooperative efforts to eradicate the boll weevil from these States.

[3]Other pests include bollworm, tobacco budworm, boll weevil, *Lygus* spp., and stink bugs.

[4]Include *Lygus* spp. and cotton fleahoppers.

[5]Columns may not total due to tank-mixed applications for several target pests.

Table 4. Applications per harvested acre, by target pests.

	NC subregions[a]			TN subregions[a]		SC subregions[a]		GA subregions[a]		MS subregions[a]		AR subregions[a]		LA subregions[a]		TX subregions[a]
Target pest	1	2	3	4	5	6	7	8	9	13	14	15	16	17	18	19	20
								Number									
BW & TBW[1]	2.74	6.20	1.62	1.00	1.00	6.08	1.91	0.99	1.46	0.60	2.60	1.00	1.90	2.70	1.80	0.76	0.18
Boll weevil/BW & TBW	—	—	—	—	.10	—	—	3.58	6.46	1.00	1.20	.10	1.90	5.00	4.00	3.00	1.15
Boll weevil	.20[2]	1.80[2]	1.60[2]	—	.10	2.29[2]	1.12[2]	.66	3.68	3.40	.60	.10	1.50	1.40	3.60	7.84	1.97
Spider mites	—	—	—	.02	.02	.16	.09	.18	.33	.10	.54	—	—	.38	1.20	—	—
Thrips	1.15	1.32	.94	2.45	2.45	1.58	1.40	.68	1.84	1.70	1.84	1.47	1.37	1.15	1.50	—	.20
Plant bugs[3]	—	—	—	.75	.75	.08	.30	.15	.45	1.28	2.14	.40	.30	.50	.90	.85	1.80
Fall and beet armyworms	.02	.02	.02	—	—	.20	.05	.08	.24	.60	.40	—	—	.10	—	—	—
Aphids	—	—	—	.02	.02	.05	.05	.20	.60	.10	.60	—	—	.25	.20	—	.10
Whiteflies	—	—	—	—	—	.04	—	—	—	.02	.05	—	—	—	—	—	—
Cabbage looper	—	—	—	—	—	—	—	—	.01	—	—	—	—	—	—	—	—
Cutworms	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.04
All insects and mites[4]	4.76	10.91	4.48	4.61	4.81	10.99	5.26	5.91	13.49	9.11	10.59	4.30	9.07	12.16	13.71	12.61	5.72

Table 4. Continued

	TX subregions[6]							OK subregions[6]		NM subregions[6]			AZ subregions[6]			CA subregions[6]	
Target pest	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
								Number									
BW & TBW[1]	9.00	5.29	0.31	0.12	0.39	2.29	1.50	0.20	0.90	0.68	2.27	1.33	0.61	0.60	1.00	2.85	0.06
Boll weevil	3.00	.99	.70	.20	—	—	—	.04	.40	—	—	—	—	—	.90	.20	—
Pink bollworm	—	—	—	—	—	.30	2.25	—	—	—	.15	.20	2.85	5.70	3.70	5.00	—
Pink bollworm/other pests[4]	—	—	—	—	—	—	—	—	—	—	—	—	.61	2.34	7.40	—	—
Spider mites	2.00	.37	.05	—	—	—	—	—	—	—	—	—	.20	.40	.82	1.53	1.12
Thrips	.75	.13	1.05	.02	.33	.02	.05	.01	.05	.20	.10	.30	.07	.20	.20	—	.10
Plant bugs[3]	2.00	1.25	.81	.05	.17	.30	.15	.15	.20	.20	.70	.20	.60	.60	.74	1.70	.40
Fall and beet armyworms	.05	—	—	—	.07	.05	.20	—	.01	—	.19	.38	—	—	—	.50	.20
Seedcorn maggot/wireworms	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.90
Aphids	.05	—	.20	.02	.22	.26	.05	.01	.02	—	.23	.15	—	—	—	—	.08
Whiteflies	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.10	2.47	.15
Cotton leafperforator	—	—	—	—	—	—	—	—	—	—	—	—	—	.30	.30	.34	—
Cabbage looper	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.10
Cutworms	—	—	—	—	—	—	—	—	—	—	—	—	—	.03	.03	—	.05
Stink bugs	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.40	—
Grasshoppers	—	—	—	.01	—	.06	—	.04	.03	.07	.40	.50	—	—	—	—	—
All insects and mites[5]	16.85	8.03	3.12	.42	1.17	3.50	4.34	.44	1.61	1.15	4.03	3.06	4.33	10.27	15.18	14.99	3.16

— = Unreported or insignificant estimate.

Source: Suguiyama and Osteen, 1988.

[1]Includes the bollworm (BW) and tobacco budworm (TBW).

[2]Boll weevil applications were estimated prior to completion of cooperative efforts to eradicate the boll weevil from these States.

[3]Include *Lygus* spp. and cotton fleahoppers.

[4]Other pests include bollworm, tobacco budworm, *Lygus* spp., and stink bugs.

[5]Columns may not total due to tank-mixed applications for several target pests.

[6]Map locations of subregions are shown in Figure 1 of chapter 24.

Table 5. Pounds of active ingredients of insect and mite pest control chemicals per harvested acre.[1]

Active ingredient	Brand Name	Active ingredients per harvested acre																
		AL	AZ	AR	CA	FL	GA	LA	MS	MO	NM	NC	OK	SC	TN	TX	VA	U.S. cotton
		Pounds																
Acephate	Orthene®	0.028	0.286	—	0.191	0.025	0.183	—	0.122	0.005	—	0.025	—	0.032	0.049	0.018	0.023	0.063
Aldicarb	Temik®	.257	.268	0.245	.187	.026	.132	0.146	.094	.188	0.001	.323	—	.259	.150	.057	.320	.112
Azinphosmethyl	Guthion®	.263	2.432	.356	.029	.850	.598	.078	.143	—	—	—	0.002	.007	.003	.082	—	.208
Carbaryl	Sevin®	—	.027	—	.054	—	—	—	—	—	.061	—	.003	—	—	.002	—	.010
Carbofuran	Furadan®	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.004	—	.002
Chlordimeform	Galecron®, Fundal®	.406	.732	.164	.048	.613	.356	.181	.221	.088	.016	.050	.080	.330	.025	.028	.036	.119
Chlorpyrifos	Lorsban®	.064	—	.017	.263	.030	.069	.033	.246	.001	.005	—	.001	.001	.029	.010	—	.068
Demeton	Systox®	—	—	—	.015	—	—	—	—	—	—	—	—	—	—	—	—	.002
Dicofol	Kelthane®	—	.233	—	.556	—	.010	.097	.029	.010	—	—	—	.058	—	.002	—	.092
Dicrotophos	Bidrin®	.067	.003	.126	.021	.128	.068	.164	.096	.266	.064	.008	.013	.049	.089	.025	.008	.049
Dimethoate	Cygon®, Defend®	—	—	.104	.017	.002	.104	.094	.096	.244	.027	.008	.004	.032	.082	.015	.008	.036
Disulfoton	DiSyston®	.124	—	—	—	.375	.132	—	—	—	—	.027	—	.059	—	.003	.027	.008
Endosulfan	Thiodan®	—	—	—	.023	—	—	—	—	—	—	—	—	—	—	—	—	.003
EPN		—	—	—	—	—	—	—	—	—	—	—	.077	.126	—	.052	—	.029
Lindane		—	—	—	.005	—	—	—	—	—	—	—	—	—	—	—	—	.001
Malathion		.009	.074	—	.017	—	.087	.073	—	—	.210	1.010	.022	1.319	—	.056	—	.060
Methamidophos	Monitor®	—	—	—	.120	—	—	—	.037	—	—	—	—	—	—	—	—	.019
Methidathion	Supracide®	—	.182	—	.015	—	—	—	—	—	—	—	—	—	—	—	—	.010
Methomyl	Lannate®, Nudrin®	—	.077	—	.009	—	—	—	.023	.002	.184	.009	—	.054	—	.017	.009	.017
Methyl parathion		2.124	.838	.275	—	3.000	2.176	.593	.641	—	.080	—	.039	.458	.018	.193	—	.343
Monocrotophos	Azodrin®	.068	.766	—	.037	.034	.188	.173	.050	—	—	—	.017	.218	—	.010	—	.068

Table 5. Continued

Oxamyl	Vydate®	—	—	—	.023	—	—	—	—	—	—	—	—	—	—	.001	—	.003
Phorate	Thimet®	—	—	—	.024	.075	.033	—	—	—	—	.014	—	.027	—	.005	.014	.006
Phosmet	Imidan®	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.000
Phosphamidon	Swat®	—	—	—	—	—	—	—	—	—	—	.008	—	—	—	—	.008	.000
Profenofos	Curacron®	.032	.017	—	.111	—	.017	—	.112	—	—	—	.004	.014	—	—	—	.027
Propargite	Comite®	—	.097	—	.819	—	—	—	.031	—	—	—	—	—	—	.002	—	.113
Pyrethroids[2]		.393	.043	—	—	.030	.559	—	—	.084	—	—	—	.087	—	—	—	.024
Cypermethrin	Cymbush®, Ammo®	—	.283	.096	.026	.546	—	.184	.208	—	.009	.127	.017	.124	—	.021	.091	.064
Fenvalerate	Asana®	—	.059	.030	.022	.490	—	.381	—	—	.097	.116	.014	.173	.101	.013	.082	.042
Flucythrinate	Pay-Off®	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.001	—	.000
Permethrin	Ambush®, Pounce®	—	—	—	.001	.001	.001	—	—	—	—	.038	.027	.035	—	—	.027	.002
Tralomethrin	Scout®	—	.013	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.001
Sulprofos	Bolstar®	—	—	—	.008	.390	.024	.039	—	—	—	—	—	.146	—	—	—	.006
Thiodicarb	Larvin®	.043	—	—	—	.819	.079	.043	.251	.015	—	—	.021	—	—	.004	—	.033
Trichlorfon	Dylox®	—	—	—	.015	—	—	—	—	—	—	—	—	—	—	—	—	.002
Total		3.878	6.430	1.413	2.656	7.434	4.816	2.279	2.400	.903	.754	1.763	.341	3.608	.546	.621	.653	1.642

— = Unreported or insignificant estimate.

Source: Sugaiyama and Osteen, 1988.

[1]Excludes use of microbials, sex attractants, and sulfur. Also excludes active ingredients with less than 0.001 pounds per harvested acre.

[2]In some chemical entries, only an aggregated use for all pyrethroids was provided.

Table 6. Per-acre and aggregate expenditures for insect and mite control in U.S. cotton[1].

Year	Per acre	Total
	Actual dollars	
1964	5.69	83,643,000
1966	6.42	66,126,000
1969	6.79	80,122,000
1971	4.66	57,318,000
1972	7.35	102,165,000
1974	12.35	167,960,000
1976	15.83	183,628,000
1977	24.68	335,648,000
1978	21.49	285,817,000
1979	21.90	304,410,000
1980	25.31	366,995,000

[1]Sources: Starbird, 1974; Krenz et al., 1976; and Economic Research Service, 1984-87.

Table 7. Expenditures per harvested acre for insect and mite control and scouting, by target pests.

Target pest	Expenditures per harvested acre																
	AL	AZ	AR	CA	FL	GA	LA	MS	MO	NM	NC	OK	SC	TN	TX	VA	U.S. cotton
									Dollars								
BW & TBW[1]	—	12.90	9.20	2.62	52.14	10.36	16.70	13.27	4.96	10.27	23.36	6.23	40.26	5.65	3.47	16.56	6.53
Boll weevil/BW & TBW	54.48	—	8.79	—	54.78	49.84	32.04	8.47	—	—	—	—	—	.13	1.31	—	6.01
Boll weevil[2]	1.41	3.47	3.61	.08	11.70	12.25	5.02	6.68	—	—	4.96	1.30	11.11	.08	2.75	—	3.00
Pink bollworm	—	48.42	—	6.29	—	—	—	—	—	.67	—	—	—	—	.10	—	3.13
Pink bollworm/other pests[3]	—	47.86	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.25
Spider mites	1.11	4.53	—	20.78	.35	2.11	3.09	3.70	.42	—	—	—	1.20	.06	.15	—	3.54
Thrips	7.65	1.35	7.13	2.53	7.52	8.36	4.78	5.17	7.08	.88	8.04	.32	8.35	6.60	1.86	7.86	3.12
Plant bugs[4]	.43	7.00	1.10	8.65	.06	.27	1.37	7.24	3.23	1.46	—	.81	.28	1.64	1.04	—	2.89
Fall and beet armyworms	—	—	—	3.03	14.33	1.95	1.18	5.30	.29	1.70	.17	.10	1.53	—	.50	.17	1.28
Seedcorn maggot/wireworms	—	—	—	6.74	—	—	—	—	—	—	—	—	—	—	—	—	0.86
Aphids	.24	—	—	.61	.16	.51	.91	1.78	.18	.50	—	.09	.15	.06	.52	—	0.58
Whiteflies	—	.34	—	3.02	.18	—	—	.23	—	—	—	—	.20	—	—	—	0.42
Cotton leafperforator	—	3.84	—	.49	—	—	—	—	—	—	—	—	—	—	—	—	0.24
Cabbage looper	—	—	—	1.31	.16	.05	—	—	.14	—	—	—	—	—	—	—	0.17
Cutworms	—	.16	—	.56	—	—	—	—	—	—	—	—	—	—	.01	—	0.08
Stink bugs	—	—	—	.30	—	—	—	—	—	—	—	—	—	—	—	—	0.04
Grasshoppers	—	—	—	—	—	—	—	—	—	1.88	—	.14	—	—	.02	—	0.03
All insects and mites	65.32	129.86	29.84	57.02	141.38	85.70	65.10	51.84	16.30	17.37	36.53	8.98	63.08	14.22	11.73	24.59	34.17
Pest scouting	2.75	2.91	3.65	4.92	3.67	3.37	4.93	4.01	2.33	2.69	5.30	1.59	4.22	.72	1.83	5.30	2.81
Total expenditures	68.07	132.77	33.49	61.94	145.05	89.07	70.03	55.85	18.63	20.06	41.83	10.57	67.30	14.94	13.56	29.89	36.98

— = Unreported or insignificant estimate.

Source: Suguiyama and Osteen, 1988.

[1]Includes the bollworm (BW) and tobacco budworm (TBW).

[2]Expenditures for the boll weevil in Arizona, California, North Carolina, and South Carolina were estimated prior to completion of cooperative efforts to eradicate the boll weevil from these States.

[3]Other pests include bollworm, tobacco budworm, boll weevil, *Lygus* spp., and stink bugs.

[4]Include *Lygus* spp. and cotton fleahoppers.

Table 8. Expenditures per harvested acre for insect and mite control and scouting, by target pests.

	NC subregions[1]			TN subregions[1]			SC subregions[1]	GA subregions[1]		MS subregions[1]		AR subregions[1]		LA subregions[1]		TX subregions[1]	
Target pest	1	2	3	4	5	6	7	8	9	13	14	15	16	17	18	19	20
								Dollars									
BW & TBW[1]	16.56	38.03	9.00	5.65	5.65	42.65	12.83	6.80	10.58	3.69	18.39	5.88	11.87	17.46	11.27	5.99	1.22
Boll weevil/BW & TBW	—	—	—	—	.51	—	—	27.73	51.20	6.96	9.27	.80	15.20	32.98	25.31	21.60	8.10
Boll weevil	1.23[2]	11.03[2]	9.81[2]	—	.34	11.51[2]	6.48[2]	2.32	12.86	14.20	2.66	.41	6.17	4.28	10.33	41.16	8.10
Spider mites	—	—	—	.06	.06	1.24	.71	1.05	2.18	.81	5.24	—	—	2.53	7.12	—	—
Thrips	7.86	8.63	6.41	6.60	6.60	8.43	7.37	4.06	8.62	4.49	5.53	6.96	7.26	4.73	5.14	—	.67
Plant bugs[3]	—	—	—	1.64	1.64	.23	.85	.09	.28	4.44	8.74	1.28	.96	1.29	1.98	3.35	6.34
Fall and beet armyworms	.17	.16	.17	—	—	1.63	.41	.59	2.03	6.21	4.81	—	—	1.34	—	—	—
Aphids	—	—	—	.06	.06	.15	.14	.20	.53	.31	2.57	—	—	.93	.73	—	.34
Whiteflies	—	—	—	—	—	.22	—	—	—	.21	.24	—	—	—	—	—	—
Cabbage looper	—	—	—	—	—	—	—	—	.05	—	—	—	—	—	—	—	—
Cutworms	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.34
All insects and mites	25.82	57.85	25.39	14.01	14.86	66.06	28.79	42.84	88.33	41.32	57.45	15.33	41.46	65.54	61.88	72.10	25.11
Pest scouting	5.30	5.30	5.30	.72	.72	4.22	4.22	2.18	3.44	2.97	4.57	3.65	3.65	4.93	4.93	2.05	2.85
Total expenditures	31.12	63.15	30.69	14.73	15.58	70.28	33.01	45.02	91.77	44.29	62.02	18.98	45.11	70.47	66.81	74.15	27.96

Table 8. Continued

Target pest	TX subregions[5]							OK subregions[5]		NM subregions[5]			AZ subregions[5]			CA subregions[5]	
	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
								Dollars									
BW & TBW[1]	79.23	45.14	2.66	0.98	2.80	19.88	13.04	1.59	7.78	5.48	13.13	11.54	—	14.60	13.12	32.32	0.79
Boll weevil	15.54	5.27	3.09	1.10	—	—	—	.17	1.68	—	—	—	—	1.30	12.66	1.42	—
Pink bollworm	—	—	—	—	—	1.86	13.81	—	—	—	.95	.93	33.33	41.55	79.45	108.42	—
Pink bollworm/other pests[4]	—	—	—	—	—	—	—	—	—	—	—	—	8.97	30.32	127.29	—	—
Spider mites	17.55	3.08	.63	—	—	—	—	—	—	—	—	—	3.73	2.10	13.35	24.74	23.78
Thrips	5.91	.68	3.55	.14	2.76	.11	.49	.02	.42	.77	.41	1.29	1.85	.97	2.43	—	1.00
Plant bugs[3]	11.47	4.69	3.00	.18	.59	1.07	.52	.65	.86	.77	3.16	.74	6.34	5.57	12.29	32.52	5.63
Fall and beet armyworms	.63	—	—	—	.82	.63	1.85	—	.13	—	1.39	3.08	—	—	—	7.21	2.77
Seedcorn maggot/wireworms	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7.16
Aphids	.18	—	.77	.07	.78	.37	.18	.05	.11	—	.88	.57	—	—	—	—	.65
Whiteflies	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.67	31.62	1.26
Cotton leafperforator	—	—	—	—	—	—	—	—	—	—	—	—	—	3.91	5.40	8.51	—
Cabbage looper	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.39
Cutworms	—	—	—	—	—	—	—	—	—	—	—	—	—	.14	.31	—	.59
Stink bugs	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5.20	—
Grasshoppers	—	—	—	.06	—	.30	—	.15	.13	.40	2.16	2.69	—	—	—	—	—
All insects and mites	130.51	58.86	13.70	2.53	7.75	24.22	29.89	2.63	11.11	7.42	22.08	20.84	54.22	100.46	267.97	251.96	45.02
Pest scouting	6.80	6.20	3.25	1.26	1.76	2.94	1.84	1.31	1.69	2.69	2.78	2.62	3.18	2.95	2.64	25.00	3.68
Total expenditures	137.31	65.06	16.95	3.79	9.51	27.16	31.73	3.94	12.80	10.11	24.86	23.46	57.40	103.41	270.61	276.96	48.70

— = Unreported or insignificant estimate.

Source: Suguiyama and Osteen, 1988.

[1]Includes the bollworm (BW) and tobacco budworm (TBW).

[2]Expenditures for the boll weevil in North Carolina and South Carolina were estimated prior to completion of cooperative efforts to eradicate the boll weevil from these States.

[3]Include *Lygus* spp. and cotton fleahoppers.

[4]Other pests include bollworm, tobacco budworm, boll weevil, *Lygus* spp., and stink bugs.

[5]Map locations of subregions are shown in Figure 1 page .

Table 9. Cotton yield losses caused by target insects and mites in spite of control measures.

Target pest	Cotton yield losses										1979-86		
	1951-60	1974-76	1979	1980	1981	1982	1983	1984	1985	1986	Mean	Standard deviation	Coefficient of variation
	Percent												
Boll weevil	8.00	2.49	1.40	0.96	1.29	2.36	2.50	0.40	0.98	1.93	1.48	0.68	46.32
BW & TBW[1]	4.00	3.61	3.00	3.07	2.08	2.59	1.70	3.20	2.40	2.20	2.53	.50	19.67
Cotton fleahopper	—	.01	1.40	.54	.46	.44	.40	.30	.37	.86	.60	.34	57.46
Lygus spp.	3.40	.74	1.40	1.28	.78	.76	.70	1.30	.74	.80	.97	.28	28.81
Cotton leafperforator	—	.01	—	.13	.09	.01	—	.10	.01	.01	.04	.05	114.25
Pink bollworm	—	.08	—	.33	.31	.63	.40	.40	.25	.21	.32	.17	53.43
Spider mites	—	.12	.70	1.37	.97	.85	.60	.60	.51	.37	.75	.29	39.42
Thrips	—	.11	.30	.40	.21	.24	1.20	.20	.67	.27	.44	.32	73.88
Other pests[2]	—	.18	.60	.72	.55	.44	.10	.40	1.10	1.06	.62	.31	50.60
All insects and mites	19.00	6.60	8.80	8.73	6.74	8.32	7.60	6.90	7.01	7.76	7.73	.77	9.91

— = Unreported or insignificant estimate.

Sources: Agricultural Research Service, 1965; De Bord, 1977; Anonymous, 1980, 1981, 1983; Head, 1982, 1984, 1985; and King *et al.*, 1986, 1987.

[1]Includes the bollworm (BW) and the tobacco budworm (TBW).

[2]Other pests include fall armyworm, beet armyworm, stink bugs, European corn borer, yellowstriped armyworm, seedcorn maggot, wireworms, cabbage looper, grasshoppers, cotton aphid, cutworms, whiteflies, and Western flower thrips.

Table 10. Cotton yield losses caused by target insects and mites, 1981-84.

Target pest	AL	AZ	AR	CA	FL	GA	LA	MS	MO	NM	NC	OK	SC	TN	TX	VA	U.S. cotton
									Percent								
Boll weevil	5.13	0.67	1.94	—	6.62	3.74	3.65	2.39	—	—	1.83	1.51	4.30	0.82	1.78	—	1.50
BW & TBW[1]	3.81	1.32	2.18	0.38	6.08	3.32	3.80	1.87	2.27	6.06	9.68	8.05	4.90	3.14	3.82	4.96	2.52
Pink bollworm	—	3.27	—	.39	—	—	—	—	—	2.17	—	—	—	—	.10	—	.44
Spider mites	.51	.19	.14	2.56	.11	.13	.39	.09	.21	.57	.14	.30	.27	.89	.28	.82	.78
Thrips	.59	—	.45	.38	.70	.09	.31	.21	.56	2.26	.24	.34	.78	.35	.41	.54	.34
Lygus spp.	.90	1.29	.77	1.16	.15	1.57	.63	1.84	1.24	7.42	.21	.86	.48	3.02	1.50	—	1.32
Cotton leafperforator	—	.29	—	.01	—	—	—	—	—	.12	—	—	—	—	—	—	.03
Other pests2/	.70	.57	—	—	.88	.50	.71	.23	.79	.03	4.98	.38	1.11	.07	.68	—	.44
All insects and mites	11.64	7.60	5.48	4.88	14.54	9.35	9.49	6.63	5.07	18.63	17.08	11.44	11.84	8.29	8.57	6.32	7.37

— = Unreported or insignificant estimate.

Source: Anonymous, 1983; and Head, 1982, 1984, 1985.

[1]Includes the bollworm (BW) and tobacco budworm (TBW).

[2]Other pests include fall armyworm, beet armyworms, stink bugs, European corn borer, yellowstriped armyworm, seedcorn maggot, wireworms, cabbage looper, grasshoppers, cotton aphid, cutworms, whiteflies, and Western flower thrips.

Table 11. Value of damage caused by target insects and mites.

Target pest	Value of damage																
	AL	AZ	AR	CA	FL	GA	LA	MS	MO	NM	NC	OK	SC	TN	TX	VA	U.S. cotton
	Million dollars																
BW & TBW[1]	20.1	10.6	10.8	6.5	2.0	11.2	37.1	28.9	1.7	2.3	4.2	8.4	5.7	4.1	62.3	—	216.1
Boll weevil[2]	21.9	3.9	8.1	.1	1.4	11.7	29.9	24.6	—	—	.8	1.6	2.7	.7	38.1	—	145.7
Pink bollworm	—	57.5	—	11.4	—	—	—	—	—	.6	—	—	—	—	1.5	—	71.0
Spider mites	.9	2.8	.2	47.9	—	.4	2.7	4.0	.2	.2	—	.2	.2	.7	3.6	—	63.9
Thrips	2.9	.7	3.7	6.4	.2	1.4	3.5	5.9	1.3	.7	.7	.4	1.1	2.1	13.4	—	44.1
Plant bugs[3]	1.1	7.7	1.6	20.7	—	.9	2.2	14.6	1.0	2.0	.1	1.0	.2	2.9	20.3	—	76.3
Cotton leafperforator	—	2.8	—	.7	—	—	—	—	—	—	—	—	—	—	—	—	3.6
Other pests[4]	1.2	2.1	2.5	20.4	.3	1.3	4.1	9.5	.6	.3	1.6	.3	.8	.4	12.6	—	57.9
All insects and mites[5]	32.8	89.5	24.8	120.5	3.1	19.6	63.6	83.1	5.2	6.3	7.8	12.5	11.1	11.0	154.4	—	645.4

— = Unreported or damage values less than $0.5 million.

Source: Suguiyama and Osteen, 1988.

[1]Includes the bollworm (BW) and the tobacco budworm (TBW).

[2]The value of damage caused by the boll weevil in Arizona, California, North Carolina, and South Carolina were estimated prior to completion of cooperative efforts to eradicate the boll weevil from these States.

[3]Include *Lygus* spp. and cotton fleahoppers.

[4]Include fall and beet armyworms, wireworms, seedcorn maggot, cotton aphid, whiteflies, cabbage looper, cutworms, stink bugs and grasshoppers.

[5]Columns may not total because expenditures for the boll weevil/bollworm/tobacco budworm were allocated to each target. The total estimated expenditures for scouting have also been included.

Chapter 25

BENEFIT-COST ANALYSIS OF INTEGRATED PEST MANAGEMENT PROGRAMS

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INTRODUCTION

During the last decade interest in the economics of Integrated Pest Management (IPM) has been strong. It has often been argued that there is a need to perform benefit-cost analyses on programs in major crops like cotton. As Reichelderfer (1982) indicates, there is a great deal of enthusiasm for IPM but without concrete economic analyses to support general claims of success, the evidence may be less than convincing. In this chapter, several issues germane to our experience in benefit-cost analysis of IPM cotton programs will be addressed. We will discuss conceptual approaches and apparent paradoxes in measuring benefits and costs, describe the data needs, and examine some examples of studies which have investigated the economics of cotton IPM.

APPROACHES TO IPM EVALUATIONS

IPM approaches to pest control usually involve a systems paradigm (example, pattern, or model) and focus on the development of flexible pest management systems which include the substitution of information for chemical, mechanical and energy inputs. Wetzstein (1988) discusses two pathways to IPM assessments: (a) the integrated crop and pest management approach which emphasizes the system and its component linkages; and (b) the value of information paradigm which focuses on the quality of information, the substitution process, and the sequential nature of decision making as advocated by Antle (1983). This pathway deals with the diffusion of new technologies and differences in the ability to process and use information. The results of economic analyses will be partially dependent upon which of these two assessment approaches are followed. In the United States, the integrated crop and pest management approach has been the predominant choice for empirical work.

WHY BENEFIT-COST ANALYSIS?

The most common analyses of IPM programs focus upon the impacts that IPM adoption has on the per acre yields and costs of production of the adopting farmers.

Because of their incomplete nature, these farm level evaluations are often referred to as partial budgeting studies. While these analyses are useful and are a key first step to more complete examinations, they ignore many of the actual benefits and costs that could determine the true success of the programs. More complete benefit-cost analyses will also examine the effects on aggregate supply and market prices, changes in income distributions, and impacts on non-participating producers. In addition, when benefits accrue to more than one group, information can be generated that is useful in determining appropriate jurisdictional boundaries for sharing in costs and setting regulations. Without the more complete analyses, difficulties are encountered in generalizing beyond the narrow impacts of isolated studies. Due to selection and choice-based sampling biases, generalizing impacts from experiences of voluntary adopters to non-participants who have opted not to adopt the IPM technology should be viewed with caution (Hall and Duncan, 1984). Unfortunately, most of the economic evaluations performed to date are not complete benefit-cost analyses and arguably could be considered as nothing more than a string of case studies (Reichelderfer, 1982).

The effects of IPM programs that are not accounted for in the farm level case study analyses can be divided into intraregional and interregional impacts (Reichelderfer, 1982). The substitution process replacing chemical, mechanical and energy inputs with information and labor can have intraregional consequences upon the economy in which an IPM program has been adopted on a full scale basis. If the acreage of the affected crop does not expand, the demand for the inputs being replaced will drop while yields and/or producers' income will rise. As these changes work themselves through the economy with their associated multiplier effects, they can force redistributions of income and economic activity. The interregional effects can be manifested in two forms. First and primary, as comparative advantages in agricultural production adjust to the changes in yields and costs of production generated by the adoption of the IPM program, resource allocations could be affected and regional shifts in production acreages could result. Secondary effects could surface if the IPM programs in one region impact on migration and population densities of mobile pests in another region.

All of these effects should be considered in a complete benefit-cost analysis of IPM adoption. However, the effects which have the greatest potential to alter conclusions generalized from firm level economic studies are the aggregate supply and market price effects. It is conceivable that as IPM programs either raise yields or reduce production costs, the total supply of the commodity is increased, creating downward pressure on market prices. Due to inelastic demands, aggregate farm incomes actually decline since percentage decreases in farm prices can exceed percentages increases in sales. Hence major benefactors of IPM research and adoption can turn out to be consumers and early adopters.

Finally, IPM impacts on the environment through changes in the quantity and pattern of pesticide use should be documented in a complete analysis. Economic valuations of such changes in pesticide use are difficult to calculate, but displays of quantities of active ingredients of pesticides used with and without the IPM program can still prove to be useful information for policy purposes.

CONCEPTUAL PARADIGMS AND PARADOXICAL ISSUES

It is often proposed that IPM programs will increase farm incomes while reducing the environmental degradation associated with the use of pesticides. However, analytical economic models suggest that this may not always be the case. Taylor (1980) discusses and extends the classical paradoxes that may occur if the adoption of IPM generates higher yields and/or lower production costs at the farm level.

The classical explanation of the process is that as farm level profits to individual producers are increased through higher yields and/or lower production costs, farmers respond by increasing production which results in a new, lower equilibrium market price. Since consumers are not sensitive to price changes, as reflected by inelastic demands, the percentage decrease in price is greater than the percentage increase in sales. As a result, the aggregate income to the group of all farmers declines as the market adjusts to the new technology. Until the market reaches a new equilibrium price level, early adopters will receive higher profits than before. In the end, it is likely that consumers will capture a substantial proportion of the benefits through lower prices, while early adopters benefit until the market has fully adjusted.

Cochrane (1986) supplements this classical paradigm by indicating that in a large degree price support programs of the federal government minimize price adjustments, but the early adopters respond to higher profit levels by expanding and purchasing additional land. This causes land values to rise, which in turn generates higher production costs. The treadmill process then changes the structure of production agriculture in favor of larger farms and may increase the costs of government farm programs.

The classical analysis is predicated, to a certain extent, on the degree of price responsiveness on the part of consumers. This is measured in the price elasticity of demand. Given the rising importance of export markets to United States agriculture, it is often argued that total demands of many commodities are not as elastic as conventional wisdom suggests (Tweeten, 1983). Taylor (1980) extends this classical model by demonstrating that, even under conditions of elastic demands, producer incomes can fall if supply curves reflect marginal costs and the new technology affects supply more at high costs than at low costs.

There is a need to use empirical studies to supplement the analytical models of price and structure adjustments to shifts in supply stimulated by the adoption of new technologies. Without both an analytical and empirical basis, these results cannot transcend from the realm of informed expectations to probable outcomes.

DATA NEEDS

To adequately perform benefit-cost analyses of IPM programs, it is necessary to assemble a variety of information. Foremost on the list is a thorough understanding of the farm level impacts on yields (both quantity and quality), costs of production, and net revenues experienced by known participants as a result of adopting the program. These data are usually expressed in per acre terms. Since slight variations in decision rules and production environments may have significant effects on the economic evaluations of pest control programs, it is essential to include a description of the production setting in the analysis (Reichelderfer, 1982). This provides partial protection against unwarranted generalizations. In addition, alternative pest control programs can affect a farmer's risk in different manners and should also merit attention (Cochran and Boggess, 1988; Horowitz and Lichtenberg, 1993).

To perform regional and national analyses, it is necessary to obtain data on the aggregate effects of widespread adoption. The per acre or farm level benefits must be translated into impacts on the local economy by measuring multiplier effects produced by changes in the mix and magnitude of goods and services exchanged. Part of this aggregation process should focus on the shifts in supply and possible changes in prices of not only the crop being produced but also related goods such as inputs. To accurately assess the latter effects, it is desirable to employ a price endogenous regional or sector model. Significant aggregate effects can also influence distribution of crop production across regions by altering relative profitability and may need to be addressed with a spatial equilibrium model. These more sophisticated models require: (a) data on appropriate multipliers by region and crop; (b) supply and demand specifications (particularly price and cross price elasticities); (c) measures of regional comparative advantage based on relative profitability; and (d) relevant resource constraints.

The cautions on self-selection bias expressed by Reichelderfer (1982) and Hall and Duncan (1984) about identifying differences in characteristics between voluntary participants and non-participants should be heeded in the aggregation process. The multiplication of per acre benefits measured for a small group of early participants by the number of acres historically devoted to the crop to determine potential benefits for an entire region is at best a naive process and should be employed only to provide a crude indication of possible regional effects. Unfortunately, a lack of research resources available for assessments has made this a too frequent necessity.

STUDIES OF REGIONAL AND NATIONAL IMPACTS OF IPM PROGRAMS ON PRODUCER INCOME, CONSUMER SURPLUS AND LOCAL ECONOMIES

Although the incidence of complete economic studies on the impacts that IPM programs may have on the local, regional and state economies is not as frequent as desired, a few analyses do surface in the literature. The difficulties and expense of collecting timely and accurate data pose major problems in closing the gap between what theoretical paradigms suggest be done and what is actually achieved in empirical study. The following survey of the empirical literature will provide a summary of the findings on the aggregate economic impacts of IPM adoption.

ARKANSAS BOLLWORM MANAGEMENT COMMUNITY

Since 1975 in the state of Arkansas, cotton farmers have voluntarily organized bollworm management communities (BMC) in an attempt to manage the populations of bollworm, *Helicoverpa zea* (Boddie) and tobacco budworm, *Heliothis virescens* (F.) over large land areas rather than by the more common field-by-field approaches. The intent is to coordinate control decisions so that all cotton fields in a bollworm management community will be treated within a three-day interval. In 1988, there were approximately 150,000 acres in six bollworm management communities in the state of Arkansas. Formal assessments of the economic impacts of the bollworm management community are found in Parvin *et al.* (1984), Cochran *et al.* (1985) and Scott *et al.* (1983).

Parvin *et al.* (1984) compared the performance of the bollworm management communities to control areas in adjacent counties to identify farm level benefits from participation. Significant differences in yields, insect control costs and net returns per acre were discovered. Yields were increased by 23 pounds of lint per acre; insect control costs were lowered by $1.85 per acre; and net revenue was increased by $18.57 per acre. Cochran *et al.* (1985) use these data to estimate that the bollworm management community program increased producers' incomes in 1984 by $1.5 million and reduced pesticide use by 92,000 pounds of active ingredients.

As an indirect benefit, it was hypothesized that the bollworm management communities function as an effective mechanism for technology transfer and information dissemination. Scott *et al.* (1983) measured the effect that participation in a bollworm management community has on the adoption of all production practices (not just pest management) recommended by the cooperative extension service. It was discovered that participation in a bollworm management community increases the percentage of adoption of the recommended practices by about 11 percent.

TEXAS ROLLING PLAINS UNIFORM PLANTING DATE COTTON SYSTEM

An IPM program designed to control intense infestations of boll weevils and reduce high production costs is the delayed uniform planting date system (UPD) employed in the Texas Rolling Plains since 1973 (Masud *et al.*, 1984; Masud *et al.*, 1985a). By delaying the planting until around May 20, ninety percent of overwintering boll weevils emerge and die before oviposition and feeding sites in the plants are produced. Using data from 27 counties in the years between 1970 to 1981, Masud *et al.* (1984) performed an economic analysis consisting of regressions on per acre yields, partial budgeting and an examination of regional impacts.

A regression model was developed to measure the impact that adoption of the program has upon the farm level yield. The results show that the uniform planting date program increased yields by about 25 pounds of lint per acre, after accounting for the impacts of other factors such as rainfall, temperature, fall freeze dates, and the total number of cotton acres planted in the region. The next step in the analysis was a partial budgeting study that identified the per acre differences in costs of production and net returns between the region's cotton produced under the program and that outside the program. Masud *et al.* (1984) found that total per acre variable costs for the uniform planting date cotton were $5.68 lower and net returns to land, management, overhead and risk were $21.36 per acre higher. The reduction in variable production costs was related to decreases in the use of insecticides, cottonseed and labor. Based upon the coefficients of variation of yields and net returns, risks associated with the program were also less than the conventional control systems in seven of nine years.

The final steps of this analysis consisted of a regional and state impact assessment. The results of the assessment, covering the years of 1970 to 1981, appear in Table 1. The total annual impact for the region and the state in this time period are reported to be $192 million and $305 million, respectively. Included in this figure is the increased value of production resulting from the conversion of land previously devoted to pasture and grain sorghum to cotton as a benefit of the program. If this conversion is not attributed to the development of the uniform planting date program, the regional impact is lowered to $36 million and the state impact becomes $57 million.

Table 1. Annual estimated economic impact of the uniform planting date cotton production system on the Rolling Plains and state of Texas. (Assessment covers the years 1970 to 1981.)

		Impact	
Gross revenue sources	Gross revenue change	Rolling Plains	State
	($ Million)	($ Million)	
Increased gross revenue from existing cotton acres	+15.13	+36.16	+57.04
Gross revenue from land converted to cotton	+91.59	+218.91	+345.31
Gross revenue from sorghum acres converted to cotton	-17.53	-42.76	-63.62
Gross revenue from pasture converted to cotton	-9.45	-20.31	-33.54
Total	+79.74	+192.00	+305.19

AGGREGATE ANALYSIS OF INCREASED BOLLWORM INFESTATIONS ON THE TEXAS HIGH PLAINS

Another study in the same region as uniform planting date program (High Plains of Texas) examined the aggregate economic implications of increased bollworm infestations (Masud *et al.*, 1985b). The per acre effects of bollworm infestations on net returns are presented in Table 2. Prior to 1975 bollworm attacks were of insignificant importance. Since that time bollworm infestations have increased due to large shifts in crop acreage, hot dry weather, increased pesticide use on other crops, decreased beneficial activity and attempts to harvest late maturing bolls.

Table 2. Per acre impact of alternative bollworm infestation levels, Texas High Plains.

Production system	Bollworm infestation level	Reduction in profits
		($ per acre)
Dryland	None	—
Dryland	Light	4.48
Dryland	Moderate	7.62
Dryland	Heavy	8.82
Irrigated	None	—
Irrigated	Light	7.68
Irrigated	Moderate	8.75
Irrigated	Heavy	13.45

Aggregate economic impacts were determined by establishing first a suitable estimate of the number cotton acres affected, categorized by dryland and irrigated production, bollworm infestation level and year. This was accomplished by conducting a survey of 30 representative farms in a 20-county region. Proportions of acres in each category uncovered in the survey were then multiplied by total acreages published by the Texas Crop and Livestock Reporting Service to produce the acres in each category. Reductions in producers' incomes were then calculated by multiplying the estimated loss per acre for each category by the established number of acres and summing across relevant categories. Average annual losses in producers' income during 1979 to 1981 due to bollworm infestations were estimated to be over $33 million. As part of this loss to the bollworm, cotton production was reduced by almost 32,000 bales in the region. An upper limit on potential losses to bollworm resistance was derived by examining scenarios where no insecticides were applied. In this case, average annual production losses are expected to equal 302,489 bales for the Texas High Plains.

TEXAS SHORT-SEASON COTTON SYSTEMS

In a number of regions in Texas, short-season, narrow-row, cotton-production systems were developed to reduce energy and insecticide use by increasing plant densities, accelerating fruiting through water and fertilizer management, and implementing IPM insect control. Economic analyses were performed for the Winter Garden, Lower Rio Grande Valley, Trans-Pecos, and Coastal Bend regions of Texas (Lacewell and Masud, 1988). However, only in the Coastal Bend area was a regional analysis conducted to identify impacts of the program adoption on the regional economy.

In the Winter Garden region, a partial budgeting study revealed that energy and insecticide use on a per acre basis decreased by 33 percent and 27 percent, respectively as a result of the adoption of the short-season system (Sprott *et al.*, 1976). In addition, yields and net returns were increased respectively by 30 percent and 846 percent. While production costs on a per acre basis were increased, the increases in these costs were offset by increases in yields so that costs per pound of lint were actually reduced.

The budget comparisons for the Lower Rio Grande Valley displayed similar patterns (Shaunak *et al.*, 1982). The study examined data from 1973 to 1978 and divided the time period into two intervals (1973 to 1975 and 1976 to 1978). Comparisons to conventional practices were made in both dryland and irrigated systems. Net returns above total costs for dryland systems were increased by $57.69 per acre in 1973 to 1975 and $49.25 per acre in 1976 to 1978 by adopting the short-season, narrow-row practices. In the irrigated systems, the difference between time periods was even more drastic. In 1973 to 1975, the net returns per acre were $12.54 higher with the new IPM technology while in 1976 to 1978, the advantage was estimated to be $93.99.

In the Trans-Pecos region, an IPM short-season program increased profits by $186.50 per acre while lowering per acre production costs by 46 percent, nitrogen by 76 percent, pesticides by 71 percent and irrigation by 25 percent (Condra *et al.*, 1975 as cited by Lacewell and Masud, 1988). However, a decrease in yields of 11 percent was also experienced.

The short-season IPM program developed for the Coastal Bend region was evaluated by Masud *et al.* (1980). Adoption of the short-season production systems, among other factors, led to an expansion of the cotton acreage in the region from 50,000 acres in 1975 to over 300,000 acres in 1980. Short- season IPM programs generated higher yields and net returns. Total insect control costs were reduced by $5.72 per acre and total production costs per pound of lint were decreased as well. Costs of production, on a per pound basis, were calculated to be $0.40 to $0.42 for IPM short-season, $0.46 to $0.50 for typical short-season practices and $0.56 for the long-season conventional production system.

A linear programming model was used to estimate the potential impact on net returns to the region if the IPM short-season program were widely adopted in the Coastal Bend region. The model identified which of several alternative production systems would maximize producers' incomes, given the available acreage of each soil type in the region. The IPM CAMD-E cotton and grain sorghum system resulted in the greatest net return to the region, increasing producers' incomes by $34.2 million over the typical CAMD-E cotton and grain sorghum system.

An estimate of the impact that the IPM program has on the regional and state economies can be derived by multiplying the gross revenues calculated by the linear programming model by an appropriate multiplier. This produces an assessment of the value of the additional sales that are generated by the increased economic activity in the region or state due to the new technology. These estimates are presented in Table 3. It can be seen that within the Coastal Bend region approximately $250 million of additional activity can be attributed to the conversion from the CAMD-E cotton and grain sorghum system to the IPM CAMD-E cotton and grain sorghum system. At the state level this figure is $367.74 million.

Table 3. Impact of short-season IPM production systems in the Coastal Bend region and the state of Texas, 1980.

		Regional impact	
System	Gross revenue	Coastal Bend	Texas
	($ Million)		
1. IPM CAMD-E cotton and grain sorghum	292.88	729.40	1101.65
2. IPM SP-37 cotton and grain sorghum	272.96	679.19	1026.46
3. Typical CAMD-E cotton and grain sorghum	185.79	440.05	668.93
4. Grain sorghum	137.37	300.84	498.65

SOUTHEASTERN BOLL WEEVIL ERADICATION PROGRAM

In 1978, a Boll Weevil Eradication Trial (BWET) program was implemented in Virginia and northeastern North Carolina. During the period from 1978 to 1982, eradication activities directed by the Animal and Plant Health Inspection Service (APHIS) of the USDA covered an area of between 16,000 and 43,000 acres of commercial cotton. The area was divided into several zones. In a northeastern section of the area, boll weevils were eradicated and hence this subarea was labeled the Eradication Zone (EZ). It was surrounded by an 85-mile Buffer Zone (BZ), where insect monitoring and control were fostered to prevent reinfestation of boll weevils in the eradication zone. As a result of the program, boll weevil populations in the buffer zone were reduced below levels normally achieved by farmers in the subarea (Carlson and Suguiyama, 1985). An expanded area and its associated buffer zone south and west of the buffer zone were added to the effort in 1983. This expansion represented a transition from a trial program to an operational eradication program.

Carlson and Suguiyama (1985) identified the benefits and costs and calculated internal rates of return for different groups involved in this boll weevil eradication program. In addition to the eradication and buffer zones, they studied a comparison area to quantify before-and-after changes in net returns, pesticide use, cotton yields and cotton acreage. Public and private program costs were also estimated. It was anticipated that farmers would react to lower insecticide costs, higher yields and program fees by adjusting the amount of acreage planted to cotton. Acreage adjustments were included in the analysis to account for changes in producer' surplus and returns to owners of expanded acreage that might exceed the per acre cost savings generated by fewer insecticide treatments. Changes in the cotton and input prices were ignored as being insignificant due to the fact that the area comprises such a small proportion of United States cotton production and input markets.

Within the eradication zone, insect control costs were reduced from $51 per acre in the before-period to $17 per acre during the program (Table 4). However, not all of this reduction can be attributed directly as a benefit of the eradication program. Insect control costs in the comparison area also declined (by 12 percent) due to lower infestations in the same period. After this adjustment for infestation rates, cost savings due to the program were calculated as $28 per acre. In addition, due to the expansion of cotton acreage as a response to increased profits generated by the eradication program, the value of land not previously devoted to cotton rose. This benefit due to the acreage expansion effect was equal to $8 per acre and raised the total benefits of the eradication program to $34 per acre. It also was estimated that yields were increased from 30

Table 4. Boll weevil eradication benefits: insecticide cost reductions and cotton acreage expansion effects (North Carolina and Virginia).

	Eradication zone	Comparison area	Buffer zone
	($ per acre)		
Average 1974-1977 private insect control costs	51	59	59
Average 1979-1982 private insect control costs	17	52	44
Adjusted eradication insect control cost reduction	28	—	8
Acreage expansion effect	8	—	8
Total benefits to eradication	36	—	16

to 50 pounds of lint per acre due to the program, but since these results were predicated upon experimental plot data and not actual farmer field experiences, yield effects were assumed to be zero to avoid biases in favor of the program.

Eradication program costs, both public and private, were estimated and used in calculating the rates of return for several participating groups. Return on investment when all public and private costs are considered was calculated as 29 percent. Rate of return for the expanded area was estimated at 67 percent. This ignores indirect benefits which might be produced from environmental improvement due to lower pesticide use. Net present values for average growers in the eradication and buffer zones were calculated when only relevant private costs were considered. These values were $240 and $69 per acre, respectively. Net present value figures demonstrate the value of a stream of future benefits net of additional costs, expressed in terms of current dollars. Hence, the average growers in each zone benefited considerably from the boll weevil eradication program.

EARLY APPRAISALS OF NATIONAL BENEFITS OF BOLL WEEVIL CONTROL PROGRAMS

In 1974, the United States Department of Agriculture studied the costs and benefits of three alternative federally sponsored boll weevil control programs (Lacewell and Masud, 1988). The national programs evaluated were based on the: (a) Texas High Plains Boll Weevil Containment Program; the (b) Pilot Boll Weevil Eradication Experiment in South Mississippi, Alabama and Louisiana; and (c) the use of accepted pest management practices on a field-by-field basis. The first program was designed to prevent the spread of boll weevils to uninfested acreage while the second was intended to eliminate the boll weevil completely from the United States. The last program assumed the use of the best field-by-field pest management practices available. The benefits and costs for each program over a 15-year (1974-1988) time horizon were calculated and converted to a common base in terms of present values. Benefit-cost ratios were also derived.

For the High Plains program, a benefit-cost ratio of 16:1 ($273 million in benefits and $17 million in costs) was estimated. A benefit-cost ratio of 3:1 ($1,378 million benefits and $399 million costs) was calculated for the pilot eradication program. Finally, the field-by-field pest management program recorded benefits of $818 million and costs of $68 million for a benefit-cost ratio of 12:1.

The study concluded that the High Plains program represented the best investment given limited funds. With unlimited funds, the eradication program would demand attention since it produces the largest net present value.

NATIONAL AND REGIONAL ANALYSIS OF BOLL WEEVIL CONTROL STRATEGIES

One of the few examples of national evaluations of IPM strategies which examine possible impacts that farm level effects may have on aggregate supply and market prices is the work of Taylor and Lacewell (1977). They examined economic impacts of three boll weevil control strategies at both the regional and national levels. The three control strategies considered were: (a) eradication — the integration of many controls including insecticides for reproduction-diapause control, early stalk destruction, pheromone-baited traps, trap crops, early season insecticide sprays, and massive releases of sterile boll weevils; (b) currently available IPM (1977); and (c) IPM that will be available with 5 to 10 more years of research.

The analysis focused on the estimated effects the adoption of the three alternative strategies would have on consumer surplus, producer surplus and state and federal program costs not transferred directly to producers. Changes in the three performance measures were summed to provide the net social benefits, excluding environmental impacts, associated with each strategy. An interregional activity analysis model of the production of eight crops (cotton, soybeans, corn, sorghum, wheat, barley, rye and oats) in the United States was employed. The model maximizes consumer surplus in 21 consuming regions and producer surplus in 147 producing regions minus transportation costs, subject to resource constraints. It provides a competitive market and spatial equilibrium solution.

Data on the per acre changes in production costs and yields for each strategy were developed from surveys of entomologists in each state who were most familiar with boll weevil control (Pimentel *et al.*, 1976). These data were supplemented by asking the same entomologists to estimate changes in yields and costs if the boll weevil were eradicated.

Results indicate that under these circumstances the present value of changes in consumer and producer surpluses, minus any consideration of transportation costs, for the three strategies are: (a) $1,431 million for currently available IPM; (b) $1,890 million for IPM that will be available in 5 to 10 years; and (c) $1,985 million for eradication. All estimates are in terms of 1973 nominal dollars. However, when non-producer program costs of $176 million for current IPM and $1,062 million for eradication are considered, Taylor and Lacewell (1977) conclude that eradication may not be the optimal strategy for either society or producers. Furthermore, they strongly suggest that, in the aggregate, farmers as landowners would not benefit from the widespread adoption of these programs since land values would fall. Consumers would benefit substantially by lower cotton prices.

The model was also used to identify possible shifts in regional production patterns as national adoption of the alternative controls differentially impacts on relative profitability. In many states no major changes were observed. However, in the following situations significant shifts are predicted: (a) 90 percent increase in Alabama with eradication; (b) 92 percent increase in Arizona with the current IPM; (c) 34 percent increase in Arkansas with the two IPM cases; (d) 14 percent and 46 percent decreases in California with current IPM and eradication, respectively; and (e) 38 percent increase in Louisiana for eradication; and (f) 10 percent decline in Mississippi with eradication.

SUMMARY

While few complete benefit-cost analyses of IPM programs have been performed, the economic studies to date generally suggest that IPM in cotton has had a significant positive effect. Studies of the bollworm management communities of Arkansas, the uniform planting date program of the Texas Rolling Plains, the Texas short-season IPM systems, and the Southeastern boll weevil eradication program display benefits which exceed the costs examined. In many cases, the contribution to regional and state economies was estimated to be hundreds of millions of dollars. This evidence implies that the IPM approach has been successful in altering pesticide use patterns, increasing producer incomes, lowering production costs, and making United States cotton more competitive in world markets.

However, several theoretical concerns and paradoxes have not been conclusively handled in empirical studies. The problem of generalizations based on the experiences of voluntary adopters ignores the problems of self-selection biases. The neglect of the market price adjustments fostered by supply shifts which result from higher per acre yields or lower production costs may produce misleading conclusions. Rather than increasing producers' incomes in the long run, IPM adoption may result in higher land values, more expensive government programs, and lower market prices. Benefits may accrue to consumers and early adopters rather than being uniformly distributed to the group of cotton producers as a whole. Additional and more complete analyses are needed to determine the actual significance of these theoretical concerns.

Chapter 26

ECONOMIC EVALUATION OF INSECT ERADICATION: THE CASE OF BOLL WEEVILS IN THE SOUTHEAST

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INTRODUCTION

The primary organizational form for agricultural pest control activities in the United States is individual farmers taking independent pest control actions on their farms. Of course, social divisions such as farms, counties, and states are not recognized by mobile pests. Crop diseases that disperse in air currents and insects that fly or hitchhike on equipment make property rights difficult to establish by individual farmers. Because of this, collective pest control through volunteer community organizations or mandatory areawide programs may be less expensive and/or more effective, than individual farm pest control. There have been a few studies directed at evaluating the economic returns from particular collective pest control efforts — abatement districts (Carlson and DeBord, 1975), volunteer community programs (Lazarus and Dixon, 1984; Rook and Carlson, 1985) and eradication programs (Johnston, 1975; Carlson, 1975; Taylor *et al.*, 1983). Successful eradication programs are common in some countries for animal diseases, but there are only a few success stories for insect pests; these primarily have dealt with eradication of newly introduced insects, such as various fruit fly species, into an area (Mangle *et al.*, 1986).

The cotton boll weevil, *Anthonomus grandis grandis* (Boheman) is a key pest of cotton in the United States. Cotton farmers expend about $200 million per year for insecticides and miticides. Damage in terms of yield reduction due to insects is estimated to be about 7-20 percent (Ridgway *et al.*, 1983). About two-thirds of the United States cotton growing area is routinely infested with boll weevils. The boll weevil is a major source of yield loss and control cost because it occurs relatively early in the season and insecticide treatments for boll weevil can disrupt natural controls of later insects such as bollworms and tobacco budworms.

The first major boll weevil eradication experiment was in Mississippi during the early 1970s, though successful weevil eradication had occurred in the 1960s in Arizona. The North Carolina-Virginia eradication trial of about 15,000 acres of cotton began in 1978. This area was chosen because it was the northeastern edge of cotton production and the boll weevil was an established major cotton pest. The trial was conducted by the Animal and Plant Health Inspection Service (APHIS) of the United States Department of Agriculture, with financial support being shared as 25 percent federal, 25 percent state government, and 50 percent cotton growers in the trial area. This three-year trial was mandatory for all cotton grown in the original trial area (Figure 1). The trial area was divided into an eradication zone and a buffer zone. The latter area received boll weevil control to achieve non-damaging levels of weevils, but eradication was not expected in the first three years of the trial in the buffer zone. In 1983-85, the program was extended to all cotton in North and South Carolina (about 220,000 total acres). Beginning in 1987, the program was extended to all cotton in Florida, most of Georgia and counties in southeastern Alabama (Figure 1). The most recent expansion is into the remainder of Georgia and Alabama and into Northeastern Mississippi.

Eradication of an established insect species is usually an expensive investment with major uncertainties. With the current limited knowledge of pest population dynamics and migration patterns, and with weather variations, it is necessary to experiment with eradication programs. Regional programs on many operating farms can provide technical and financial information for possible extrapolation to other regions in addition to direct benefits of reduced pest populations. Collective pest control has been assisted in recent years by new technologies such as pheromone traps, sterile insect releases and computerized information systems. Also, there seems to be a need for improvements in institutions to organize decisions and resolve conflicts among farmers. Differences between areas in levels of pest attack, in effects of the program on non-target pests and in resource adjustment costs could prevent technically efficient programs from being adopted.

Economically, we can expect that eradication might be a lower cost alternative to conventional pest suppression when there are significant cost reductions from achieving and maintaining very low pest population levels. The eradication option becomes more attractive compared to annual farm-by- farm pest suppression if one or more of the following conditions occur: (a) significant cost reductions as the geographical area of pest suppression expands; (b) more uniform pest density and benefits of suppression across farms; and (c) when eradication resource are more similar to inputs used for other pests and crops. From a social perspective, an eradication program might also have environmental and health improvement effects, as well as providing principles for other pest control efforts.

This chapter presents data collection and evaluation methods for determining pesticide cost savings, cotton output changes and overall rates of return from boll weevil eradication. The North and South Carolina 1978-1987 eradication program is evaluated first, followed by presentation of results from 1986-1990 for Alabama, Florida

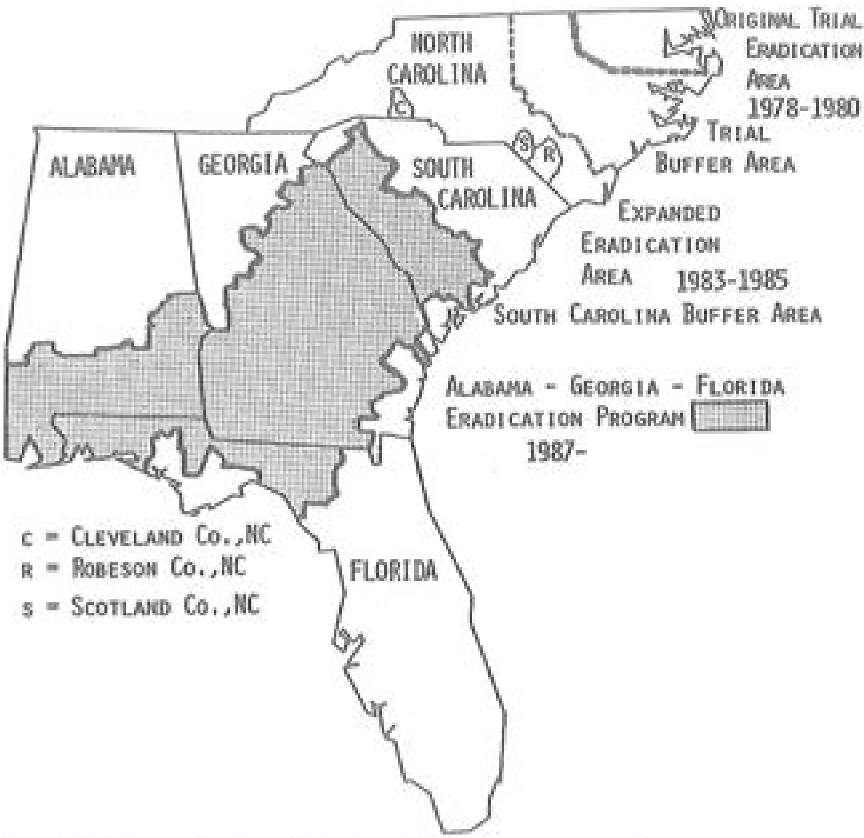

Figure 1. Southeast boll weevil eradication program areas and events.

and Georgia. Some attention is also given to measuring the environmental and informational benefits flowing from the eradication program.

EVALUATION METHODS AND DATA COLLECTION

The basic procedure used to evaluate farmer and overall returns to eradication is to estimate regional changes in: (a) pesticide use; (b) cotton yield; and (c) planted acreage. This is done by comparing regional averages before and after eradication. Before making comparisons, adjustments were made for pest level, weather, technology and changes in crop prices. In the case of pesticide use, a comparison region which did not undergo eradication is used to control for changes in new pesticide technology and pest densities. For cotton yield and planted acreage, linear regression models are developed and estimated to hold constant the effects of weather, technology and crop prices across cotton regions and time periods with and without boll weevil eradication. A more detailed description of the methodology and results is available in Carlson and

Suguiyama (1985) for the trial area, in Carlson *et al.* (1988) for North and South Carolina and Ahouissoussi *et al.* (1993) for the Alabama, Florida and Georgia area.

Changes in benefits (pesticide costs, cotton yield, planted acreage) and eradication costs are compiled by year. Average benefits and costs per acre are used to compute percent rate of return to the eradication investment since most of the costs occur early in the program while benefits are distributed over the future. Standard investment analysis is used assuming a 10 percent interest cost on all funds and contingency costs for maintenance of weevil-free areas.

Data on pesticide use were compiled by personal and telephone surveys of a random sample of cotton farmers. Large proportions of farmers (near 40 percent for the North and South Carolina program) were surveyed to insure that accurate estimates of pesticide use were obtained for all pesticides directed at weevils, bollworms, *Helicoverpa zea* (Boddie), and other pests. Official (USDA Crop Reporting Service) county figures on cotton yield and acreage were used to estimate the changes in yield and area planted. Cost data on eradication program costs and farmer assessments were made available by the APHIS program office and the farmer organization, the Southeastern Boll Weevil Eradication Foundation. Records on farmer balloting for the referenda on the program were made available by the North Carolina Department of Agriculture.

FARMER RESPONSE TO MANDATORY PEST CONTROL

The statutory authority for cooperative pest control by USDA, APHIS is the Incipient or Emergency Control of Pests Act (U.S. Code Section 148-148e) of 1937 and several other cooperative enforcement acts to prevent pest outbreaks. Each state considering mandatory boll weevil eradication has also passed enabling legislation which establishes mandatory cotton producer participation. Following the pattern in North Carolina, states have required a two-thirds approval of all voting cotton farmers prior to implementation of the program. The legislation provides a basis for collection of farmer assessments to fund part of the program, assess penalties, and enable quarantine activities to be carried out. Table 1 shows the percent affirmative votes for the various regions. In six regions the first referendum fell short of the necessary two thirds level, but the average vote has been 82 percent approval on second ballots. The votes represent farmer willingness to assess themselves fees, so they indicate the high value farmers place on the eradication program.

Once an eradication program is approved, farmers can still adjust to the program. Program assessments are based on fees per acre of cotton planted. Farmers can reduce their total assessments by reducing their cotton acreage during the period in the eradication program when fees are high (first two to three years). As will be seen below, this practice has been followed somewhat, but it is limited by farmers' desire to maintain their acreage bases for the federal cotton price support program. Additionally, farmers have been able to reduce program fees slightly by obtaining fee reductions for early fall stalk destruction. Program fees in the California-Arizona boll weevil program are assessed per bale. This could give differences in farmer practices, but has not yet been evaluated.

Table 1. Voting results of boll weevil eradication referenda

State	Year	Cotton Counties	Yes Votes (percentage)
			%
North Carolina	1976	All	76
	1982	Northern trial area	91
	1982	Southern (first referendum)	68
	1983	Southern (second)	79
South Carolina	1982	All (first	64
	1983	All (second)	72
Georgia	1985	All except northwestern (first)	66
	1986	All except northwestern (second)	88
	1992	Northwest (first)	51
	1993	Northwest (second)	97
Florida	1987	All	77
Alabama	1985	Southeastern	67
	1987	Southwestern	78
	1989	Southern (confidence vote)	75
	1992	Northeastern (first)	66
	1992	Northeastern (second)	69
	1992	Central (first)	47
	1993	Central (second)	84
	1993	Northern	82
Mississippi	1993	Eastern	76

The cost-sharing arrangement in the Southeastern boll weevil program has been 70 percent farmer and 30 percent federal funding. Some input from federal and state research, extension and regulatory agencies has also occurred, but only extension costs were included. The 70 percent share paid by farmers is a major change from cost-share arrangements of other insect and animal pest control programs of APHIS. For most programs (grasshoppers, witchweed, animal diseases), farmer assessments were 0-30 percent of costs. Farmers paid 50 percent of program costs in the original 1978-1980 trial. In the expanded program in the Southeast, state appropriations are covering about one-third of the costs in Florida and about thirty-eight percent of the costs in Alabama. Farmers have paid approximately 50 percent of the costs of the Texas High Plains Boll Weevil Containment Program (Lacewell *et al.*, 1974).

PESTICIDE SAVINGS FROM ERADICATION

Three comparison areas are the original eradication area, Robeson and Scotland counties in North Carolina and all of South Carolina for the 1974 to 1987 period (Figure 1). Expenditures for bollworms and total insect control costs including scouting and eradication fees are shown in Figure 2 and Figure 3, respectively. The sharp decline in pesticides directed at boll weevils occurred in the second year of the program (1979 — original trial area, 1984 — expanded program). Bollworm insecticide use declined more gradually following eradication as farmers learned how to utilize natural enemies and take advantage of delays in the onset of in-season pests. All three regions have shown major declines in bollworm expenditures — about 68 percent in the original area, 38 percent reduction in Robeson and Scotland counties and about 33 percent on average for South Carolina.

Total farmer insect control expenditures in constant 1979 dollars for the period before and after eradication are summarized in Table 2. The largest percent reduction in costs (71 percent) was in the original trial area. The total insect control costs for the expanded program in two areas in North Carolina and three areas in South Carolina have fallen by 39 to 53 percent. All absolute reductions are statistically significant except for the two Piedmont areas of Cleveland county, North Carolina and the Piedmont area of South Carolina. These two areas have low weevil infestations, but still show savings of 46 to 53 percent. These low weevil infestation areas are of special interest because many areas in Mississippi, Arkansas and Texas have similar infestations.

Not all the reduction in insecticide use between 1978 and 1987 was due to eradication. During 1978 to 1982, there was a 12 percent decline in cotton insecticide expenditure in the Robeson - Scotland area which was not part of the eradication program. This cost saving was primarily due to introduction of the more effective pyrethroid insecticides. This cost reduction is deducted from all estimates of boll weevil eradication pesticide savings.

Pesticide savings from weevil eradication in other cotton regions may differ from those found in North and South Carolina. However the experience over the 1978-1987 period covers a wide range of conditions. Very high cost situations ($102/acre in the South Carolina buffer area), very low insect control cost situations ($15/acre in Cleveland County, North Carolina), areas with primarily bollworm treatments (South Carolina) and areas with low starting boll weevil populations (original North Carolina-Virginia trial area in 1978) occurred during the eradication experience in this period.

A final aspect of pesticide use reductions is the potential for reduced environmental contamination. Comparing the period prior to eradication to the post-eradication period, there is an average reduction of 5.6 separate applications per year. For the 220,000 cotton acres in North and South Carolina, this is a reduction of about 1.2 million acre applications each year. However, to get to this reduced pesticide use situation there was a higher than average number of diapause applications required in the first two years of the program. Table 3 shows the level of in-season and diapause applications for the expansion program in North and South Carolina. During 1983 there were many more separate applications than either prior to the program or after eradication. This is an investment to obtain the less threatening environmental condition following eradication (1985 to 1987). If environmental contamination is proportional to numbers of pesticide applications, then there are additional benefits to eradication that are not

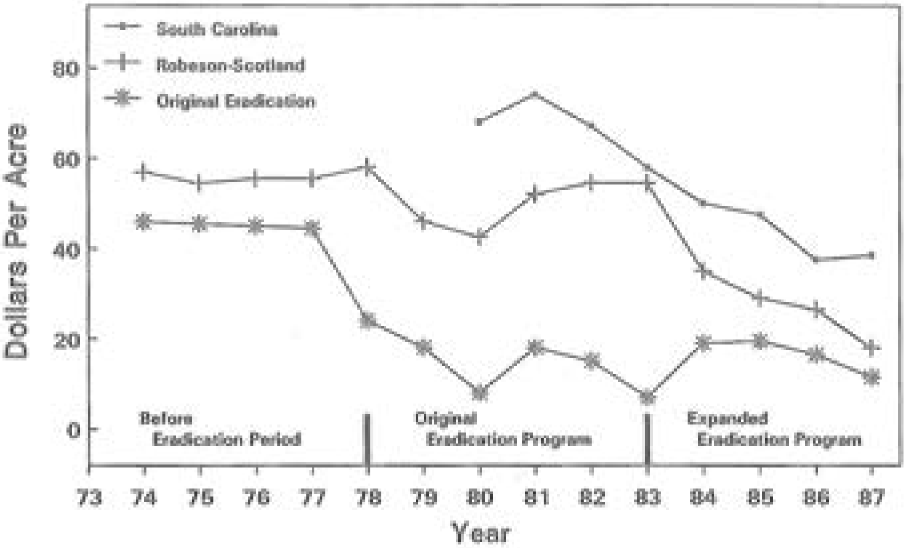

Figure 2. Bollworm control cost per acre (chemical plus application cost), adjusted to real 1979 dollars, 1974–87.

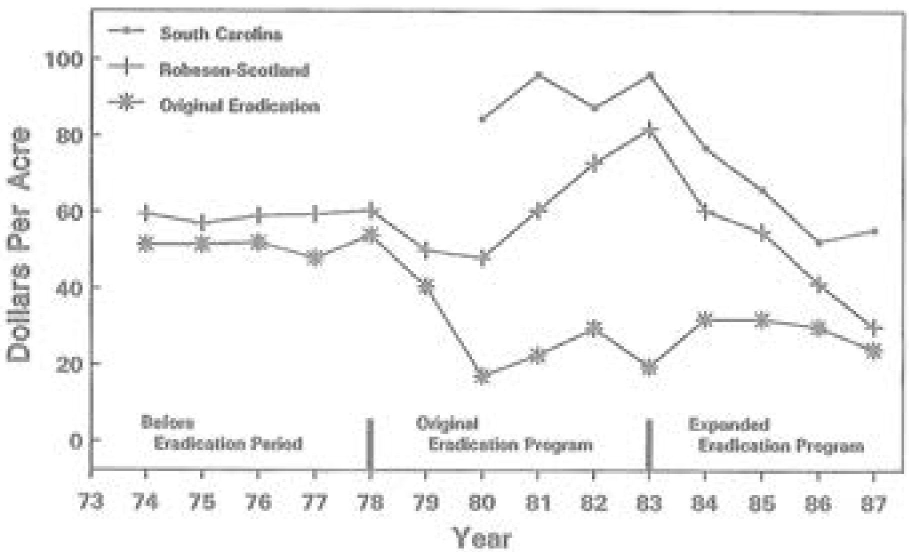

Figure 3. Total insect control cost per acre (chemicals plus application cost plus program fees and scouting), adjusted to real 1979 dollars, 1974–87.

Table 2. Changes in farmer insect control expenditures per acre associated with the boll weevil eradication (BWE) program.[1] (Source: Annual farmer surveys by North Carolina State and Clemson Universities.)

Zone[2]	Average expenditure before BWE program	Average expenditure after BWE program	Percent change	Before-after change (t-values)[3]
Original North Carolina eradication area	$49.41 (1974-77)	$14.54 (1979-87)	-70.56	8.515 *
Robeson-Scotland Counties North Carolina	$55.95 (1974-82)	$33.97 (1983-87)	-39.29	2.222 *
Cleveland County North Carolina	$14.51 (1975-82)	$ 7.77 (1983-87)	-46.46	0.468
South Carolina Piedmont Area	$47.01 (1980-81)	$22.04 (1983-87)	-53.11	1.730
South Carolina Coastal Plain	$83.58 (1980-81)	$50.41 (1983-87)	-39.69	2.250 *
South Carolina buffer zone	$101.93 (1980-81)	$55.78 (1983-87)	-45.27	4.624 *

[1]Expenditures adjusted to 1979 real dollars.
[2]See Figure 1 for locations.
[3]Difference in means using pooled standard deviation, significance at 0.95 = *

Table 3. Average numbers of in-season and program diapause insecticide applications (per field) for the North Carolina and South Carolina expansion programs, 1981-87. (Source: Farmer surveys and APHIS application records.)

Year	Number in-season applications: North Carolina expansion[1]	Number in-season applications: South Carolina expansion[1]	Number of program diapause treatments
1981	8.97	11.10	0.00
1982	11.06	12.80	0.91
1983	8.38	11.10	12.00
1984	5.87	7.30	8.00
1985	4.66	8.90	0.10
1986	5.19	5.56	0.08
1987	4.30	4.50	0.05

[1]See Figure 1 for locations.

Table 4. Summary of savings: benefits of reduced insecticides, area expansion and yield increases for the original area and expansion area from the eradication program.

	Original eradication area	Expansion area North Carolina & South Carolina
Net reduced pesticides	\$28.87[1]	\$30.01[2]
Acreage expansion[3]	\$13.28	\$13.80
Yield effect[4]	\$34.50	\$34.50
Total	\$76.65	\$78.32

[1]1974-1977 to 1979-1987 change adjusted for the \$6 cost savings (12%) achieved over the same period in other non-eradicated area from insecticide improvements. (Carlson and Suguiyama, 1985.)

[2]Insecticide savings which is a cotton area weighted average of \$21.99 for North Carolina Coastal Plains, \$33.17 for South Carolina Coastal Plains, and \$6.74 for North Carolina Piedmont and \$24.97 in the South Carolina Piedmont for an overall Piedmont savings of \$18.89. (from Table 2.)

[3]92 percent acreage expansion multiplied by one-half the cost saving in insecticides.

[4]Based on yield gain of 69 pounds per acre at an assumed long run world price of \$.50 per pound.

captured by the direct pesticide saving costs. The $29 to $30 per acre savings in insecticide costs (Table 4) is an underestimate of the benefits of boll weevil eradication because of the unknown value of environmental and safety gains over the life of the program.

Finally, there may be some contribution of boll weevil eradication to managing insecticide resistance of bollworms and tobacco budworms, *Heliothis virescens* (F.). Because boll weevil eradication reduces early-season use of pyrethroids, there may be less development of resistant populations. Data from 1978 to 1987 shows that in-season treatment for bollworm/tobacco budworm in North Carolina and South Carolina is delayed by an average of eight days. This delay may help reduce selection pressure, especially since 1989 when chlordimeform (Fundal®, Galecron®) use was discontinued. The value of this benefit has not yet been quantified.

COTTON YIELD AND ACREAGE EFFECTS

If farmers can reduce boll damage from other insects when boll weevils have been eradicated, yield increases are an added benefit. A model was specified and estimated using county level yield records from 10 North Carolina, 9 South Carolina and 8 Georgia counties for the 1967 to 1986 period.

The estimated linear regression model is:

$$Y_{it} = \sum \hat{a}_i W_{it} + \sum b_i L_i + 69.23\ BWE - .99\ WORM - 2.7\ WEEVIL + 2.36\ DATE + 603\ PRICE - 2.82\ ACRE, \quad R^2 = .948,$$

where:

Y_{it} = cotton yield in county i in year t;

W_{it} = nine monthly average rainfall and temperature variables, for county i and year t;

L_i = Location or county i dummy variable, one for each county;

$\hat{a}, b_i$ = estimated weather and location coefficients (not shown);

BWE = boll weevil eradication variable (= 1 when county is under eradication in a given year, 0 otherwise);

WORM = Percent worm damage from research check plot in year t;

WEEVIL = Percent weevil damage from research check plot in year t;

DATE = julian date of first insecticide treatment in research check plot in year t;

PRICE = cotton loan rate (Commodity Credit Corporation support price) in year t; and,

ACRE = acreage of cotton planted in year t.

The model includes rainfall variables for each of April through October, and temperature variables for September and October, location variables to reflect soil quality and other factors, bollworm and boll weevil infestation variables, date of first insecticide treatment, county acreage figures to reflect falling land quality as more cotton is planted, a cotton price variable and finally a variable to designate if the county is under eradication or not. That is, the BWE variable takes on a value of one in years 1979 and thereafter for the original eradication counties, and for 1984 and years following for the remaining North and South Carolina counties. The Georgia counties are a non-eradication check area during the 1967 to 1986 period.

The estimated model shows a 69.2 pound lint gain when a county is under eradication and all other factors in the model are held constant. All variables in the model are statistically significant at the 0.95 or higher level except for May rainfall. The overall model explains about 95 percent of the year-to-year and county-to-county yield variation. A sensitivity analysis (Carlson *et al.*, 1988) of this shows that the yield gain from eradication is about one-third smaller when Georgia counties are used as a non-eradication check area compared with analysis of only North and South Carolina counties. This difference probably reflects the fact that improved cotton production technology has increased yield potential separate from the effects of eradication in the past five to ten years.

The price of cotton at the farm level over the past ten years (1975 to 1984) is $0.60 per pound in the Southeast. However, part of the price level is due to the cotton price support program. To reflect scarcity values of cotton, international prices are used, which for the staple length produced in the Southeast is about $0.50 per pound on average for the past 10 years. Therefore, the yield enhancement (69.2 pounds) due to eradication of the boll weevil has a value of about $34.50 per acre.

Because the boll weevil is eradicated from an entire region and not just the current cotton area, there is the potential for returns to a new area which is switched from other crops to cotton production. The amount of crop switching is estimated by a nine-variable, nonlinear regression model (see Carlson *et al.*, 1988 for details). The model specifies county cotton acreage as a function of two boll weevil eradication variables, four crop price variables, a weather variable, time trend and an index variable for the 1983 payment in kind (PIK) program. The model explains 75 percent of the year (1965 to 1986) and county to county (same 27 counties as the yield model) variation in cotton acreage. An estimated 92-percent increase in cotton acreage has occurred in North and South Carolina since the eradication program was completed, holding all other variables in the model constant.

The value of the increase in cotton acreage is estimated to be one-half of the increase in cotton area multiplied by the gain from insecticide savings (Carlson and Suguiyama, 1985). This value is approximately $14 per acre. This is an approximate estimate of the extra net return a farmer would expect as marginal land is switched from some crop like soybean to cotton.

The overall net benefits per acre from eradication for pesticide savings, yield enhancement and new cotton land are shown in Table 4. The pesticide savings are slightly higher in the expansion area of South Carolina and North Carolina compared to the original eradication area. The overall benefits are about $78 per acre. To determine the rate of return from eradication, program costs, expenditures to suppress reinfestations and timing of costs and benefits need consideration.

PROGRAM COSTS

One of the major uncertainties about boll weevil eradication is the likelihood of reinfestation of eradicated areas and the cost of cleanup for these reinfestations. Table 5 shows the cleanup activities for cotton in the original eradication area for the 1981 through 1987 period. The cotton area in column one includes that in the buffer area as well. The reinfestation rate has been from 0 to 22 percent, with very low reinfestation rates since 1983.

Through use of pheromone traps, it has been possible to detect reinfested fields prior to a widespread outbreak from the point sources of reinfestation. Costs of treating fields, adding traps, checking traps and travel expenses are $5 to $50 per treated acre. However, the costs per program acre are very small, especially as the area in the program increases. The likelihood of reinfestation clearly has declined since the distance to the source of large weevil populations was increased by about 300 miles beginning in 1984. The average cost over this seven year period for clean-up activities is about $.94 per program acre (average of final column in Table 5).

The boll weevil eradication program costs and net returns for labor, insecticides, traps and overhead expenditures are shown in Table 6 for the first three years and the average year following the first three years. Both farmer and total program costs are shown. Actual expenditures in 1978, the first year of the trial program, included costs to manage bollworms as well as boll weevils. This part of the costs ($51 per acre) has been deducted since it was not part of the program after the first year, and it would have been required in the absence of the program. The program cost was about $120 per acre for the first three years of the original program. The expansion program was altered and was slightly less expensive. The use of diflubenzuron (Dimilin®) and the release of sterile male insects was not included in the expanded program. Also, the expanded program did not begin until August of the first year with more emphasis on diapause treatments. The third phase of eradication—that is underway in Georgia, Alabama and Florida—is following a similar program and cost structure as the expanded program in South Carolina and southern North Carolina.

The final cost component is the contingency or maintenance fee in the fourth and following years. This figure is currently at $6 per acre in the original eradication area and is at $8 in the expanded program area. Cleanup costs so far have been closer to $1 per acre as shown in Table 5. For the rate-of-return calculations discussed in the following section, it is assumed that this cost is the actual cost up through 1988 and $6, thereafter.

OVERALL NET RETURN TO ERADICATION

The yield and pesticide savings benefits of eradication begin the first year following eradication in the original area. The acreage expansion effects begin the fourth year. In the expanded program, because eradication began in August of the first year, acreage benefits occur in the third year of the program. The net return per acre, considering all

Table 5. Extra costs of clean-up activities in original eradication zone, 1981-87. (Source: Compiled from APHIS records.)

Year	Total acres	Treated acres	Percent area reinfested	Average number of treatments	Total additional cost[1] ($)	Cost per treated acre ($)	Cost per program acre ($)
1981	50095	0	0.00	0	0	0.00	0.00
1982[2]	46003	10144	22.05	6	263,744	26.00	5.73
1983[2]	42435	8563	20.18	2	102,756	12.00	2.42
1984	72747	35	0.05	13	1,767	50.50	0.02
1985	64140	92	0.14	3	1,426	15.50	0.02
1986	56675	0	0.00	0	0	0.00	0.00
1987	61900	15	0.02	0	75	5.00	0.0012

[1]Average variable cost of $3.50 per acre per treatment for pesticides and application, plus an estimated average fixed cost of $5.00 per acre for added traps and pheromone, personnel and travel expenses.
[2]General reinfestation of the original eradication zone occurring as a result of increased acreage in the original buffer area and a period of uncertainty about the expansion of the program.

costs (farmer and federal), are shown (Table 6) for the first three and the typical year after the fourth year for both the original trial area and the expanded program.

The final summary number given in Table 6 is the computed rate of return to the eradication investment in North and South Carolina. This is the rate of interest that will make the present value of all program costs just equal the present value of program benefits. The return is 86 percent for the trial program and 97 percent for the expanded program. To put these figures in perspective, returns on savings accounts or bonds are 2.5 and 7 percent, respectively. For individual cotton farmers who only had to pay 50 to 70 percent of the costs the returns are even higher.

Table 6. Total eradication program and farmer costs and returns.

	Year 1	Year 2	Year 3	Years after program[1]
Original North Carolina/Virginia trial eradication area				
Farmer costs	$21.00	$23.00	$15.00	$ 9.43
Total costs	$42.00	$47.00	$31.00	$ 9.43
Net return	- $42.00	$16.37	$32.37	$66.65
Rate of return = 86%				
North Carolina/South Carolina expansion area				
Farmer costs	$25.47	$25.23	$17.70	$ 9.26
Total costs	$46.96	$31.52	$30.58	$10.99
Net return	- $46.96	$32.99	$47.73	$70.31
Rate of return = 97%				

[1]Average of program and farmer fees for fourth and following years: 1982-1986 for trial area, 1986-1988 for North Carolina/South Carolina expansion area ($/ac).

EVALUATION RESULTS FOR ALABAMA, FLORIDA, AND GEORGIA

An application of the above evaluation methods is the determination of costs and benefits for the Alabama-Florida-Georgia area (Ahouissoussi *et al.*, 1993). Regressions for determining Alabama-Florida-Georgia BWE program affects on producers' yield, insecticide use, and cotton acreage are similar in form to the regressions employed for the North and South Carolina program. Results from these equations covering the pre-eradication period 1986 and 1987 and the eradication period 1988 through 1990 indicate that the BWE program resulted in yield increases of approximately 100 pounds per acre over what they would have been in the absence of the program.

No significant relation was determined between BWE and either insecticide cost or cotton acreage per farm. One explanation for no significance between BWE and insecticide cost was the relatively large increase in other insect pests, particularly beet armyworm, which developed in 1988 through 1990. Unfortunately, not since 1977 was there such a widespread outbreak of beet armyworm. This resulted in a significant increase in insecticide use offsetting any possible gains from decreased costs from BWE.

In terms of planted cotton acreage, since 1989 there is a steady upward tend (Figure 4, USDA). BWE probably explains a portion of this trend along with other factors including low prices for competing crops such as soybeans.

Unfortunately, funding limitations precluded data collection for subsequent years past 1990. With subsequent years data, empirical estimates for insecticide cost savings and acreage response could be derived. In cases characteristic of such funding limitations which precludes data collection essential for evaluation alternative methods are simulation or programming models (Szmedra *et al.*, *1991*, Duffy *et al.*, 1994). For example, a mixed integer programming model developed by Duffy *et al.*, 1994 sup-

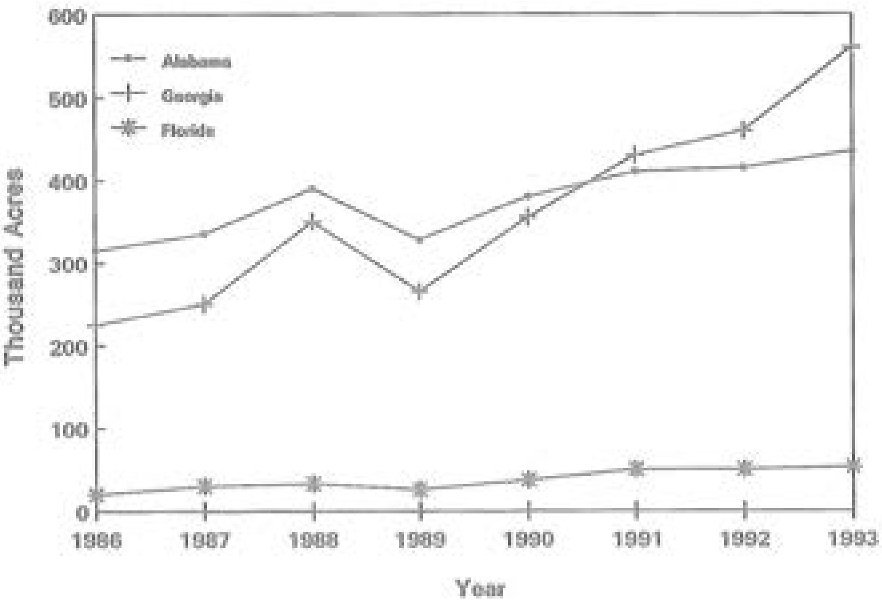

Figure 4. Cotton acreage in the Southeast.

ports the view that BWE is a major factor associated with increased cotton acreage. Their result, for southern Alabama, indicates optimal crop-mix would involve no cotton at all without the yield increase attributed to eradication. By contrast, when the 100 pound yield increase is included in the total yield, cotton is planted extensively.

The five years of data, 1986 through 1990, used for the Alabama-Florida-Georgia BWE evaluation are sufficient for assessing the short-term program impacts. Results indicate a 19 percent rate of return from farmers' investment in the BWE program. Such a return is comparable with a mean of 17 percent which private companies commonly consider as favorable for investment projects. However, this result is significantly less than the 86 and 97 percent rate of return, found in earlier years in North and South Carolina when full farmer and government costs were considered (Table 6).

CURRENT ISSUES

A major concern is how well eradication will work in other areas of the Cotton Belt where the boll weevil is not as major of a pest. Primary research for Northern Alabama, where boll weevil damage is significantly lower compared with the southern region of the state, indicates that the BWE program for farmers who are already producing cotton may not prove as lucrative as for Southern Alabama producers (Duffy *et al.,* 1994). Currently, research on this subject is continuing by agricultural economists in Georgia and Alabama. For other cotton growing regions, the program is expanding into the Mid-South (Mississippi, Louisiana, Arkansas, and Tennessee). The BWE program in the Southwest is almost completed. The only remaining area is 60 miles into Mexico consisting of 3,000 cotton acres. Once this acreage enters the program in 1994 a natural buffer will exist between the Southwestern United States/Northern Mexico and the rest of Mexico. As the BWE program continues to expand there may be some concern that cotton prices might decline with the resulting increased production. However, research based on published elasticities, indicates that the effect of a 100 pound increase in yield for the entire Southeast would be less than a penny a pound, a negligible effect (Ahouissoussi *et al.,* 1993).

SUMMARY

Experimentation with boll weevil eradication in North and South Carolina has led to improvements in organizational and technical features of the program over the 1978 to 1993 period. Eradication of the boll weevil reduces insecticide use in two ways. First, in-season sprays are no longer targeted at the boll weevil, and secondly, greater survival of predators and parasites results in higher mortality of bollworms, tobacco budworms and other pests with reduced need for controlling them with insecticides. The estimated pesticide use reduction from eradication is 40-70 percent (about $30 per acre). Eradication has also encouraged cotton acreage expansion (about 92 percent worth $14 per acre) and increased lint yield by about 15 percent, (69 pounds per acre in North and South Carolina, 100 pounds in the Southeast). Considering the total additional cost of the program (farmer and public expenditures) and total benefits, the rate of return on the eradication investment is estimated to be 97 percent. There are also environmental benefits of the program associated with reduced insecticide use (approximately 5.6 fewer insecticide applications per acre per year). Expansion efforts in Georgia, Alabama, and Florida have been enhanced by knowledge gained in the Carolinas. Eradication efforts in the Southeast will provide information for farmer votes and program plans in the Mid-South region. The decision to undertake an eradication program must weigh the tangible and intangible benefits and costs as indicated in this chapter.

SECTION VII

PERSPECTIVES

Chapter 27

CROP PHENOLOGY AND INSECT MANAGEMENT

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Stoneville, Mississippi

INTRODUCTION

The literature on the principles, concepts, mechanisms and theories of pest management is extensive. The serious reader is referred to publications by (Chant, 1964; Clark *et al.*, 1967; Geier, 1966; Hall and Norgaard, 1973; Knipling, 1966, 1979; Newsom, 1974; Pimentel *et al.*, 1965; Rabb and Guthrie, 1970; Rabb *et al.*, 1974; Stern, 1966; Webster, 1977) and many others. Book I, Cotton Physiology, (Mauney and Stewart, 1986) in The Cotton Foundation Reference Book Series may be equally helpful.

Simulation models have been employed to investigate the many phenomena which interact with the economics of treatment thresholds (For examples Baker *et al.*, 1986; Jones *et al.*, 1979; McClendon *et al.*, 1981; Spurlock and Parvin, 1988; and others). However, from a practical standpoint, little has been done to improve on Headley's (1971, 1972) original articles. Improvements in sampling techniques (Phillips, 1990) and refined estimates of economic threshold are needed (Harris, 1988; Parvin and Harris, 1986). Investigations of the temporal (of or relating to time) aspects of pests, especially multiple pests, have been constrained by their complexity but are needed. The interactions between broad spectrum chemical insecticides, parasites and predators, and economic thresholds require additional study.

Integrated pest management (IPM) system consists of several basic insect control tactics, two of which are: (a) conservation of naturally occurring parasites and predators for pest control, particularly during early season; and (b) judicious use of chemical insecticides (Harris, 1988; Parvin and Harris, 1986). Other control tactics include host plant resistance, cultural control, use of pheromones, diapause treatments, and crop termination tactics. It should be noted here that the relative importance of (or contributing) the various control tactics will vary among different areas in Cotton Belt and between areawide programs versus single farm programs.

The natural parasite and predator component of our current cotton IPM system [(a) above] is based on their efficiency (Ables *et al.*, 1983) and the knowledge that cotton can tolerate early season fruit loss (and other damage) by compensating with other fruit produced later in the season. Treatment thresholds have been established with the view that delayed corrective treatments were better than early preventive measures (Knipling, 1979). Judicious use of chemical insecticides [(b) above], can follow either of two basic but different approaches. From a broad standpoint, pest control procedures can be classed into two categories (Knipling, 1979)—preventive measures and corrective measures. Preventive measures are taken to suppress pests in anticipation of damage even though there is no absolute certainty that damage will occur in a localized area (farm) or selected field. Corrective measures more often are used and involve applying insecticides only where and when insects are causing damage.

Both approaches have merit. The corrective approach is where insecticide treatment is triggered by economic or treatment thresholds. With the prevention approach, insecticide/miticide treatments are used to manage pest populations before they reach threshold levels (Parvin and Smith, 1985).

Since preventive methods of control involve the application of broad spectrum chemical insecticides that can lead to side effects, more and more emphasis is being placed on pest control only where and when the need for the application is necessary. Integrated pest management (IPM) is based upon the close monitoring of plant and insect conditions and the use of control measures where and when necessary with emphasis on methods that permit natural control agents to have their maximum effect in regulating the pest population. However, when control measures are applied, they tend to involve chemical insecticides. Unfortunately, this approach has gained such prominence and has been emphasized in so many technical and popular publications that many people, scientists and nonscientists alike, have the impression that it is the only system having merit (Knipling, 1979). Their general perception is that it is economically unsound and wasteful of resources to develop or undertake preventive control measures (Knipling, 1979).

This chapter attempts to employ the principles of systems analysis (Conway, 1976; de NeuFville and Stafford, 1971; Optner, 1965; Parvin and Tyner, 1974; Watt, 1970) to investigate the interaction between crop phenology[1] and insect/ mite management on cotton.

HISTORY

Scientists engaged in research on insect and mite control methods have been criticized for being too slow to recognize the limitations of the broad spectrum chemical pesticide approach as the solution of insect pest management problems and for the

[1]Phenology is a branch of science that deals with the relationship of climate and periodic biological pheromones on behavior of organisms.

long delay in devoting more of their research efforts to the study and development of alternatives and more acceptable methods (Knipling, 1979). The public sector research/extension community has been credited with entomological irresponsibility (Newsom, 1974) in the development of cotton insect control technology. It has been accused of promoting insect/ mite control techniques that resulted in "count and treat" methods and finally in "treating without counting", so that by the mid 1950s much of the cotton was treated on a "womb to tomb" schedule. This umbrella of protection stimulated several changes in production practices. Varieties were introduced that extended the fruiting season; and other inputs, such as herbicides, fertilizers and water, were increased to take advantage of the protection granted by the insecticides/miticides.

By the early 1970s, it was apparent that we were on another crisis course due to insecticide resistance. The crisis occurred during the mid 70s (especially in 1976 and 1977) and field populations of tobacco budworm, *Heliothis virescens* (F.) on cotton were not controlled despite higher rates of materials and shorter intervals of applications. If new materials had not become available in 1978, the crisis would have been much worse[2]. The introduction of synthetic pyrethroids gave us several years of excellent control.

ATTITUDE OF PUBLIC SECTOR RESEARCHERS/EXTENSION WORKERS

Public sector researchers and extension workers are concerned about the charge of irresponsibility. Many researchers reacted by excluding most preventive measures of insect pest suppression from "acceptable" methods of pest management, i.e., IPM should be comprised only of corrective techniques. However, both corrective and preventive approaches are needed (Knipling, 1979).

Researchers were not irresponsible during the 1950s, 60s and 70s. Once the insecticide technology developed during (and after) World War II was available, there were strong economic incentives (larger and more stable yields, low insecticide costs and increased net returns) to put it into place. Positions by public researchers in the future will have little impact on the next crisis if economic incentives for their positions are not strong. And, as long as insect/mite control is based primarily on chemical pesticides, failures or crises will occur from time to time.

COST-PRICE SQUEEZE OF THE 1980s

In the 1980s growers were caught in a cost-price squeeze. Production costs were up as prices for most inputs increased. Cotton price declined and net returns were drastically reduced. Because of very limited success with increasing cotton net returns by reducing costs, growers were forced to increase yield. Increased yield requires additional inputs (A notable exception is the work reported by Sterling and Haney [1973]).

With the use of additional inputs, growers were forced to lower their treatment thresholds for insect/mite pests so that these pests did not limit yields. From an eco-

[2]Pyrethroids and new organophosphates were available in 1977-78 on a limited basis under a FIFRA Section 18 (Emergency Use) program. They were conditionally registered for use in 1979.

nomic efficiency standpoint, as other inputs are increased, insect/mite treatment thresholds must be reduced or inputs are not being employed correctly (Leftwich and Eckert, 1982; Samuelson, 1961).

CRISIS FOR THE 1990s

Are we on course for another crisis in cotton insect control? Producers are more aware of the benefits of early-season insect control (Anderson *et al.*, 1976; Carter, 1990; Kerby, 1988; Jenkins, 1990; Mauney, 1988: Parvin, 1990a-e; Parvin and Miller, 1986; Smith, 1990). Economic incentives for increased, realized yield and larger net returns through earlier maturity are strong at this time.

Another insect control crisis will occur unless new insecticides/miticides are developed and/or improved strategies for insect/mite management become available soon. And, quite frankly, cotton insect/mite control technology in most of the United States Cotton Belt, into the foreseeable future, will probably depend almost entirely on chemical pesticides.

When the crisis occurs, biological and economic conditions will force the producer to modify his approach to insect/mite management. In the meantime, the increased use of insecticides during early season is sending strong economic messages to the chemical industry to develop new insecticides and sending strong biological messages to the public sector extension/research community to develop improved management strategies.

COMPLEXITY OF PEST CONTROL DECISIONS

Insect and mite pest control decisions are very complex. When long range considerations are included, as most researchers insist they should be, the decisions are more complex.

Clearly all costs should be considered. Early season foliar applications can result in increased numbers of late season applications by inducing secondary pests to major pest status and/or by eliminating beneficial predators and parasites which may result in additional treatments directed toward mid and/or late season bollworm/tobacco budworm. In such cases, the increased cost of the late season program should be considered. Additionally, if the insect control program selected increases the rate of insecticide resistance, a cost should be charged for the change in the level of resistance.

THRESHOLD LEVELS

Generally, the application of chemicals to control cotton insect/mite pests is recommended only if they attain threshold levels. Recommended thresholds are treatment guidelines, not necessarily "true" thresholds. The need to lower or raise a threshold level is influenced by individual conditions on a farm-by-farm or field-by-field basis.

Conceptually, the term, "economic threshold," has meaning to both growers and professional agriculturists. While we may know how to estimate treatment thresholds, we still lack satisfactory estimates of most of the key parameters required (Harris, 1988; Phillips, 1990). Hence, we do not know if our recommended thresholds are correct. And, while individual populations of multiple pests may be at sub-economic levels, indicating no treatment, the combination of all the pests may result in economic damage.

Finally, thresholds should include a temporal aspect. Currently, sub-threshold levels for an extended period of time do not trigger insecticide/ miticide treatment. However, it is known that sub-treatment levels that persist over a period of time may do considerably more damage than a few days with populations slightly above the treatment thresholds.

LONG TERM VS. SHORT TERM CONSIDERATIONS

Public sector agricultural workers tend to be conservative and place more emphasis on long term costs (such as the cost of resistance) than do growers. Many growers mainly are concerned with year-to-year economic survival of their farms. They discount long term considerations. In fact, many growers ignore costs that do not move through the current marketing year. There is no market for resistance. For example, a grower is charged the same unit price for a needed application as for an unnecessary application of the same material that only contributes to resistance. Consequently, growers with considerable funds at risk and the many uncertainties for future years often arrive at different decisions relative to the use of insecticides/miticides than do public sector researchers.

The agricultural research community is beginning to investigate and partially understand the complex interrelationship between early season/mid season insect feeding, the plant's ability to compensate for that feeding, and harvesting economics. With improved and expanded educational activities concerning all aspects of this complex interrelationship, growers will be able to make improved decisions with regard to insect management.

CONSIDERATION OF THE COTTON PLANT

SYSTEMATIC AND PREDICTABLE MANNER OF COTTON GROWTH AND DEVELOPMENT

The cotton plant itself must be considered in insect/mite management decisions. Physiologically, cotton grows and fruits in a systematic and predictable manner. Because it is systematic and predictable, the fruiting sites can be accurately numbered. The main axis and branches have nodes. The first three to nine (usually six) modes of the main axis above the cotyledon leaves usually produce vegetative branches (or no branches). Once fruiting (flowering) begins, each node out each fruiting branch contains a fruiting site (exceptions are extremely rare). Familiarity with the mechanics of plant mapping has increased significantly among growers and others in the last several years. Educational activities of state extension cotton specialists and the Cotton Physiology Education Program sponsored through The Cotton Foundation have made major contributions in this respect.

Because fruiting occurs in a systematic manner, several important fruiting events move up and out the plant in a systematic and predictable manner. In order of occurrence, they are: squares, blooms, green bolls (young green bolls that are subject to insect damage, older green bolls that are generally "safe" from insect damage, and green bolls that are mature in terms of seed and fiber development), and open bolls.

All of these events are important, but the interactions between the events is more important. The research community is just beginning to investigate the relationship between safe/mature green bolls and defoliation and harvesting. An understanding of this relationship and its interaction with insect management decisions will lead to the development of improved cotton production systems and better understanding insect/mite management.

POTENTIAL ECONOMIC VALUES OF DIFFERENT FRUITING SITES

Fruiting forms at different sites do not have the same potential economic value (Jenkins, 1990; Jenkins *et al.*, 1990a,b). The value of a given fruiting site is a function of its average weight (and quality) and the probability it will be harvested. Table 1 gives the dollars per acre value by fruiting site for solid planted cotton in Mississippi. In lower yielding areas of the Cotton Belt, plants may have fewer fruiting branches. Nevertheless, while specific estimates of dollars per acre value by fruiting site may vary by regions (and by varieties within region, and by years) the important trend in value remains unchanged.

There is much valuable information summarized in Table 1. On every fruiting branch, the first fruiting position produces two to ten times more money than the second position.

All first position bolls begin their life as square primordia or baby squares in the terminal (Jenkins, 1990). Every first position boll begins its life in the terminal. No other position fruit does that. Damage to the terminal will affect the first position bolls or the more valuable bolls. In the terminal there are square primordia for the next four nodes or fruiting branches (Jenkins, 1990). Terminal damage can show up as missing first position squares at the next four nodes. And, when observed, will be impossible to correct (Jenkins, 1990).

The best site, 11.1 (e.g. 11th node, 1st position) is approximately 16 times more valuable than site 20.1 (20th node, 1st position) and over 600 times more valuable than site 20.2. Therefore, in simple economic terms, based on the physiology of the plant, we should spend 16 times more money to protect fruiting site 11.1 than 20.1, etc.

Insecticide treatments provide protection for a period of time (The length of the protection period can be influenced by several factors). Sites 11.1 and 9.2 are the same age with a total value of $62.15. Sites 21.1 and 19.2 have a total value of $1.46. The rational grower will spend over 42 times more money to protect sites 11.1 and 9.2 than 21.1 and 19.2. The bottom or early sites are more valuable than the sites near the top of the plant.

Plant stress can cause shedding of fruiting forms and/or interfere with maturation of harvestable bolls fruit from fruiting sites. The major stresses (or causes of stress) are: water stress, nitrogen stress, carbohydrate stress (low solar radiation, etc.) and insect

Table 1. Dollars per acre value by fruiting sites for solid planted cotton in Mississippi[1,2]. (Source: Jenkins [1990].)

Position 3	Position 2	Position 1	Mainstem Node	Position 1	Position 2	Position 3
	$ 0.09	$ 0.91	21			
			20	$ 2.73	$ 0.07	
$0.01	$ 0.55	$ 5.86	19			
			18	$11.44	$ 1.02	$0.09
$0.13	$ 2.09	$17.22	17			
			16	$25.54	$ 4.31	$0.30
$0.62	$ 6.65	$35.28	15			
			14	$41.11	$ 8.11	$0.63
$1.26	$11.00	$42.65	13			
			12	$44.66	$11.47	$1.84
$3.09	$13.36	$44.98	11			
			10	$41.39	$16.22	$2.56
$2.87	$17.17	$38.15	9			
			8	$32.13	$14.98	$3.08
$1.65	$ 7.57	$21.12	7			
			6	$ 8.33	$ 2.99	$0.21
		$36.82	V[3]			

[1]Based on 60 cents price of lint.
[2]Mean values of 8 varieties and 2 years.
[3]Vegetative branch (V).

damage. When the majority of the important fruiting sites are squares, water, nitrogen and carbohydrate stresses are not usually present. Most of the important sites that are lost as squares especially in early season, are lost to insects.

EARLY MATURING/SHORT SEASON CROP

An early maturing crop (with acceptable yield) requires a short squaring period with little or no stress (fruit loss) during the effective squaring period or prior to first bloom. A 135-day crop (an important consideration in most of Coastal Texas, most of the Mid-South and most of the Southeast) is one that allows an early harvest and requires that all the fruit to be harvested develop from the squares from the first four (4) weeks of squaring. With modern varieties and technology this is not difficult if the plant is not stressed. The idea is to rush the plant or crop along to a natural carbohydrate cutout as soon as possible. The easiest and surest way to accomplish this is to set more fruit than the plant can support and allow the plant to decide which sites to abort. The plant will retain the oldest, largest, most valuable fruit and shed the youngest, smallest, least valuable fruit (Mauney and Stewart, 1986).

Physiologically, the plant is designed to handle water, nitrogen and carbohydrate (physiological) stress with minimal damage or delay. At each fruiting site, there is a "valve" (called the abscission "valve" or abscission zone) at the base of the peduncle stem that supports the fruit. With physiological stress, the plant simply closes this "valve" on enough fruiting sites to reduce the stress. Physiologically, this process is part of the genetics of the plant. When the "valve" is shut, nutrients stop flowing to the fruit, and in a few days the fruit aborts (falls off) leaving a well healed scar. With insect damaged fruit, nutrient transfer will continue for several days after damage occurs—a complete waste. And, insects do not always feed on the youngest, smallest, and least valuable fruit. As a matter of fact, during the first few weeks of fruiting (pre-bloom), most of the squares are associated with important sites that are most likely to be harvested. Clearly, from an economic and plant physiology standpoint, the dominant insect management strategy is to assist the plant to retain as much of the early fruit (squares) as possible. Cotton grows in a regular, systematic, and predictable manner thereby enhancing ease of management.

There is another advantage from managing or providing for a high percentage of fruit setting during the first few weeks of fruiting. However, it is difficult to quantify in terms of monetary value or economics. Depending on weather conditions and other factors, many varieties of cotton will get into a "vegetative mode" if fruit are not set on the early sites. In such cases, the grower tends to lose control over management of the cotton plant itself (with respect to vegetative growth and fruit development).

HARVESTING CONSIDERATIONS

Harvesting of cotton is time consuming (Cooke *et al.*, 1991). The failure to harvest a significant portion of a crop can lead to immediate economic disaster in terms of the farm firm's ability to survive. Failure to harvest in a timely fashion or producing the crop in such a manner that maturity is delayed also can create a disaster (Jones *et al.*, 1979; McClendon *et al.*, 1981; Parvin, 1990a,b). Recent improvements in cotton varieties and production practices have greatly increased the potential for earlier maturing cotton with increased yield and returns. Consequently, the timing of the cotton harvest can have a substantial impact upon economic returns—for a given potential yield, timely harvesting, as it affects the producer's ability to initiate and complete harvest at an earlier date, generally will result in a higher yield being realized (Parvin, 1990c).

On the average, mechanical cotton pickers (two-row) in the central area of the Delta region of Mississippi are used to harvest 302 acres with a 50 percent (151 acres) second pick (Parvin and Cooke, 1990). The performance rates (fraction of an hour required to harvest one acre) are: 0.53 hour for first pick and 0.39 hour for second picking. First pick time requirements are 302 acres at 0.53 hours per acre or a total of 160.06 hours for 302 acres. Second pick time requirements are 151 acres at 0.39 hours per acre or a total of 58.89 hours. Therefore, harvest (first and second picks) requires a total of 218.95 hours to complete.

The amount of work that can be accomplished (hours worked per week) is a function of "days fit" (days suitable for harvest) and the number of hours that can be worked per day (Table 2). The number of acres harvested per week is a function of hours worked per week and the performance rate. The pounds of lint that can be harvested per week are related to acres harvested, agronomic yield, and the rate at which yield deteriorates over time (Parvin, 1990d).

Conceptually, in the Mid-South, harvest can be completed in 22 ten-hour days (based on a 2-row picker being able to harvest [1st and 2nd picking] 302 acres in 22 hours). However, due to weather conditions, on the average, first pick requires 29 days and second pick requires an additional 20 days. Or, simply stated, in many years harvest will require more than seven weeks. How a cotton grower views the risks associated with harvest season weather conditions as a function of harvest initiation date affects his decisions on planting dates and on insect control, especially during early season. Delayed maturity lengthens the harvest in terms of calendar days by more than the delay in harvest initiation date.

It is important to note that, in regions of the Cotton Belt with uniformly favorable harvest weather (as may exist in parts of the extreme western portion of the Cotton Belt), the relationship between harvest efficiency, the plant's ability to compensate, and the implications for insect control are much different. Therefore, the appropriate treatment threshold for a given insect pest will vary by regions of the Cotton Belt, due primarily to differences in the severity of weather during the harvest season.

Realized yield is often referred to as commercial, farm or producer yield. The term "economic yield" is also appropriate. These terms embody the concept of harvesting over a lengthy period of time. Research terms like maximum yield, potential yield, agronomic yield and experimental yield embody the concept of rapid sampling, usually less than one day. Extrapolation of experimental yields to farm yields should be done with extreme care. The maturity/harvesting relationship is critical and must be considered carefully in the design, conduct and interpretation of cotton research.

Table 2. Expected days suitable for harvest, hours per day suitable for harvest and acres harvested per week, Mississippi Delta. (Source: Bolton *et al.*, 1961; Cooke *et al.*, 1991; Parvin and Cooke, 1990.)

Dates	Days suitable for harvest	Hours/day suitable for harvest	Acres harvested per week	
			First pick	Second pick
8/28-9/03	4.66	9.11	80	—
9/04-9/10	4.77	9.02	81	—
9/11-9/17	4.88	8.97	83	—
9/18-9/24	4.90	8.88	82	112
9/25-10/01	4.74	8.84	79	107
10/02-10/08	4.72	8.75	78	106
10/09-10/15	4.39	8.66	72	97
10/16-10/22	4.04	8.55	65	89
10/27-10/29	3.59	8.39	57	77
10/30-11/05	2.34	7.91	35	47
11/06-11/12	1.96	7.51	28	38
11/13-11/19	1.44	6.97	19	26
11/20-11/26	1.35	6.60	17	23
11/27-12/03	1.30	6.37	16	21

We have failed to understand the difference between taking yield estimates in small plots and harvesting commercial cotton and have missed the relationship between the timing of the initiation of harvest, length of harvest and realized yield as a percent of agronomic yield.

Even though the cotton plant, in terms of yield potential, may "compensate" for a loss of early fruiting forms by replacing them with a later fruiting form, the consequent delay in maturity would be expected to result in reduced economic returns (Parvin, 1990a,b). Earliness of maturity of cotton is affected by a complex set of factors that complicate both: (a) research design, conduct and interpretation of results; and (b) production management of commercial cotton. Such things as variety (genetics and physiology of the plant); soil type; drainage conditions; fertility practices; weed, insect and disease control practices; and irrigation practices can be managed to enhance earliness of maturity and economic returns. The magnitude of the expected increases in economic returns suggests careful consideration be given to "earliness" and to the lack of compensation in commercial cotton in the development of recommendations and the management of insects in much of the Cotton Belt.

Until recently, the consensus view in the public sector research/extension community was that early season insects in cotton delayed maturity but did not decrease yield.

For cotton grown in small research plots and harvested quickly, the view is true. For commercial cotton, this view is false, because of the difference between small plot experimental yield and producer yield.

Experimental trials using small plots where yields are obtained on a rather instantaneous basis can result in yield estimates in which the cotton appears to have compensated for the early season insect damage or delay in maturity. Such is not the case in commercial cotton due to the length of the harvest season as a function of maturity. Improvement in cotton maturity will increase harvesting efficiency, commercial yield and returns even though agronomic yield in unchanged.

CONSIDERATION OF FRUIT LOSS COMPENSATION

The ability of the cotton plant to compensate for early fruit loss is well known among growers and professional agriculturists. It is a major factor in approaches to insect control or management.

Figure 1 indicates that squaring begins about day 40 (approximately 30 days after emergence), increases to approximately day 75, levels off to day 95 and declines. Since 80 to 95 percent of the fruiting sites will shed their fruit as squares or very small bolls (in the absence of insect damage), the compensation principle states that the early squares (days 40-70) are not important since they easily can be replaced by a small fraction of the large number of squares being formed after day 70 (during the heavy fruiting period, days 75-95). Because of this relationship, treatment thresholds for early season insects which damage squares (or other plant parts) have been kept artificially high, avoiding insecticide treatments and enabling beneficial insects to increase in early season so that they can aid in the control of bollworm/tobacco budworm in mid and late season.

The phenological events summarized in Figure 1 are relatively simple but have important implications for insect control. Much of the Cotton Belt is confronted with a 135-day effective growing season. For the Mid-South this translates to a planting day of May 1 and a harvest initiation date of about September 15. Consequently, the mature/open boll period can only extend from relative day 100 to day 135 (35 days). Therefore, all the harvestable bolls must occupy fruiting sites that were squares on days 40 to 70 (30 days). The difference in the 35-day open boll period versus the 30-day effective squaring period is partly due to lower temperature during late season.

If stresses remove enough squares from the fruiting sites that developed during the first 30 days of fruiting (days 40 through 70) so that the resulting green bolls do not induce a natural carbohydrate cutout early enough to end the open boll period by day 135, then the season is extended. Extension of the season dictates that the effective squaring period must be extended. If 20 additional days of squaring is required (days 70 through 90), then the open boll period is extended to days 135 though 160 (25 days). In simplest terms, this means that the bolls that were opened during days 100 through 135 are subjected to an additional 25 days of exposure to the environment and can suffer deterioration in weight and quality.

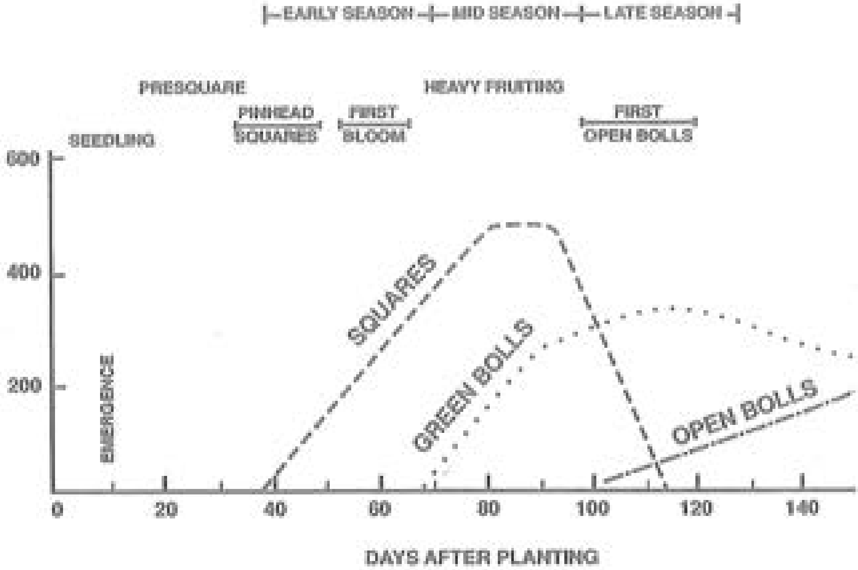

Figure 1. Seasonal development of cotton.

It is important to note that regions with a longer growing season and uniformly favorable harvest weather can extend the season and allow the plant to compensate for the early damage. However, the longer season may require the application of additional inputs such as: herbicides, insecticides, irrigation water, fertilizer, etc. And, if compensation must be attempted in regions with deteriorating harvest weather, per acre harvesting costs will also increase.

Delayed maturity will extend the growing season and delay the initiation of harvest. Additionally, because of the relationship between days suitable for harvest and the passage of time during the harvest season, the harvest season will be lengthened in terms of calendar days. Consequently, harvesting efficiency will be reduced and harvesting costs will be increased. And, because of additional exposure of some of the open bolls to deteriorating environmental conditions, commercial yield and quality will be lowered, resulting reduced returns.

It is not a question of insects causing direct yield losses; rather, it is insect damage resulting in the same or equivalent yield just a little later, i.e., a delay in maturity with full yield compensation. The delay in the initiation of harvest simply means that commercial or realized yield as a percent of agronomic or produced yield is reduced (Parvin, 1990b).

The process is best explained by looking again at our most important research data—yield. Even though we tend to use all yield terms as synonyms, and even though we have considerable research data indicating full compensation to early (and mid-season) damage, we now are beginning to understand that commercial cotton (in most of the United States Cotton Belt) cannot fully compensate because of the length of the harvest season and our deteriorating weather as the season progresses. Or conversely, our research data indicates full compensation because we took our yield estimates quickly and full compensation is not possible in commercial cotton because of the lengthy harvest season, harvest season weather, and harvesting cost. Yield compensation requires additional time. Time in and of itself has economic value. Compensation at the expense of time carries a cost.

EXAMPLE

The cost of delayed maturity and/or the value or earliness will differ by regions of the United States Cotton Belt. Because of the declining gradient in "Days fit" and "Hours/day" (columns 2 & 3 of Table 2), the cost of delay will be larger in absolute terms than the value of earliness.

Table 3 provides an estimate of the value of 14-day earliness (advancement in maturity) at Stoneville, Mississippi and at Moree, New South Wales (Australia).

Clearly, two weeks of earliness is desirable at Stoneville and at Moree but for very different reasons. For example, the increase in yield and quality amounts to 51 percent of the total value at Stoneville but only 14 percent at Moree. This is due to differences in the severity of harvest weather at the two locations. Other differences shown in Table 3 are a function of harvesting equipment cost, interest rate and soils.

Table 3. Summary of the estimated value of 14 days of earliness for cotton at Stoneville, Mississippi vs. cotton at Moree, New South Wales, Australia. (Source: Parvin, 1990f; Parvin, 1991.)

	Value per acre	
	Stoneville	Moree
	$US	$US
Decrease in interest charge of production loan	2.86	8.04
Increase in interest earned on net margin	0.62	2.70
Decrease in picker fixed cost	9.04	23.53
Decrease in variable irrigation cost	9.00	10.12
Decrease in insect control cost	16.01	17.41
Improvement in soil compaction	40.00	60.00
Sum	77.53	121.80
Increase in yield	52.20	14.79
Increase in quality	23.88	4.52
Sum	76.08	19.31
Total	153.61	141.11

IMPLICATIONS

The current debate over alternative methods of insect control was never over late season insect pests but concerns the best method of controlling early season insect pests within a commercial cotton production system in selected portions of the Cotton Belt. Late season insect pests tend to have definite generations within the cotton growing season, and the consequences of their damage is relatively easy to understand, i.e., compensation is no longer an issue. Much good research has been conducted on late season insects and our treatment threshold levels for these pests ar probably about as they should be. But, when the economic threshold is uncertain or unknown or is impractical to measure, as appears to be the case with most early season insect pests (Harris, 1988), the grower may opt to use a preventive application during early season with the expectation that it will: (a) enhance maturity; (b) result in reduced late season insecticide applications; and (c) increase harvesting efficiency, realized yield and returns.

When the cotton plant is managed in concert with its genetic makeup, management strategy tends to be more successful. In parts of the Cotton Belt—with 130-140- days to make the crop, with deteriorating weather as the harvest season is extended, and with treatable levels of early season insect pests in most fields in most years—the preferred approach to cotton management (based primarily on harvest economics and plant physiology) currently includes as a subcomponent the preventive approach to insect management during early season and a shift to the corrective approach for mid and late season. Growers, in parts of the Cotton Belt where it can be successfully utilized, are opting for this approach.

Intuitively, all parties involved (growers, consultants, researchers, extension workers, industry representatives, etc.) would prefer a corrective or threshold approach for early, mid and late season. However, the authors of this chapter believe the final decision rests with the grower. A few researchers (Barker, 1982; Carter, 1990; Harris, 1988; Parvin, 1990; Parvin & Harris, 1986; Parvin & Miller, 1986; Mauney, 1988; Smith, 1990) are beginning to address this complex area.

Preventive techniques need not conflict with IPM. Used correctly they can improve the effectiveness of IPM. Preventive approaches to insect management should be employed if, and only if, they are clearly superior to corrective approaches. Many growers have demonstrated a preference for the short run benefit of the harvesting economics associated with early maturity and its interaction with early season insect control versus late season insect control. Researchers are moving in that direction. For example, the current Mid-South Resistance Management Plan (Phillips, 1990) recommends the preventive use of an in-furrow insecticide applied at planting. Early maturity is now the key component of the Mid-South Resistance Management Plan.

The authors of this chapter recommend the consideration of resistance management program of the type suggested by Leigh (1989) and Wilson (1989) for secondary pests. It is a futuristic idea whose time has come. It is time to begin to move away from farm-by-farm or field-by-field approaches to insect management. Because they impact only a portion of the population, they are doomed to be needed year after year and in time, will fail (Knipling, 1979). We must move toward sustainable techniques which will reduce the pesticide load in the environment over time and which may need to include preventive techniques to lower original or temporary pest populations to levels suitable for management with current or modified IPM. Preventive techniques will be less controversial or more acceptable in areawide pest management programs. We should always remember that today's approaches will be unacceptable tomorrow.

SUMMARY

The current debate is over the early season insect control sub-component of the overall cotton insect management system. There is no significant disagreement concerning the use of thresholds to treat mid to late season insect pests.

Early season treatment has generally been discouraged because of the insecticide resistance and secondary pest(s) problems encountered in the recent past when cotton insecticides were widely used in a scheduled program. Even though the cotton plant may "compensate" for a lost early crop by replacing it with a later crop in terms of yield potential, the consequent delay in maturity (loss of time) can: lengthen the harvest season; reduce harvesting efficiency; increase harvesting costs; and lower commercial yield, quality and returns. Economic considerations of the interactions between crop phenology and insect management are the key to understanding these complex phenomena.

Chapter 28

ENVIRONMENTAL ISSUES

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INTRODUCTION

In the 1970s cotton growers made certain adjustments in their farming practices because of decisions handed down by the administrator of the United States Environmental Protection Agency (EPA). The most comprehensive adjustments were those associated with agricultural pest control operations. These adjustments eventually resulted in a decrease in the total amount of chlorinated hydrocarbon pesticides released into our environment. During the intervening years, agricultural regulators also implemented numerous agricultural worker and consumer safety protocols. However, as with most agricultural commodity producers, cotton growers continue to rely on pesticides to a greater or lesser extent depending on geographic location and current site-specific pest management practices. In addition, our current knowledge and research progress suggest that the present methods of cotton crop protection will continue to be based largely on synthetic organic pesticides through the remainder of the 20th Century. And, since the utilization of crop protection materials exposes both man and the environment to the hazards associated with pesticides, agriculture will remain under scrutiny as a non-point source of probable pesticide pollution.

The pesticide group of greatest concern with respect to worker safety is the organophosphates, but environmental concerns have shifted focus from the persistent chlorinated hydrocarbons to the soil-applied pesticides as potential groundwater contaminants. Current issues include the potential environmental and health impacts surrounding pesticide use patterns, groundwater protection, pest resistance and risk significance. These issues and some problems surrounding them will be discussed in this paper, but the issue of groundwater protection will be the first priority of federal and state authorities for the foreseeable future.

PESTICIDE USE PATTERNS

In the 14 major cotton-producing states, there are about a dozen arthropod pests that are of economic concern. Those that attack the squares and bolls are considered the most damaging, although leaf feeders can reduce yield if they destroy too much foliage. Seedling pests can make it necessary to replant parts of a field, while whiteflies and aphids are more apt to reduce lint grade than yields. Some pests such as the boll weevil, *Anthonomus grandis grandis* (Boheman), potentially are present in all the cotton-producing states. A few pests are relatively new and/or are of concern to certain geographic areas, such as thrips, or in North Carolina, the European corn borer, *Ostrinia nubilalis* (Hübner) (King *et al.*, 1986). The choice of control material for these pests has included just about every major family of insecticides ever developed. Some of the first pest control attempts were with calcium arsenate. Later the chlorinated hydrocarbons were utilized, followed by organophosphates, carbamates, formamidines and now the pyrethroids. Bottrell and Adkisson (1977) have summarized the historical pesticide use patterns of insect pest control in cotton that may have created our present day environmental concerns.

Doutt and Smith (1971) describe the development in the late 1940s of a new philosophy towards pest control, that of expediency. Up until the 1940s, field observations of organismal interaction led to tremendous amounts of energy being directed towards biological and cultural control of crop pests. Then, in the late 1940s, synthetic organic pesticides became available. They proved effective on most all the pest insects. Suddenly, crop yields could be maximized through utilization of these synthetic organic pesticides. The new synthetics also created an opportunity for entomological crop protection specialization. By picking a pest and a crop and concentrating on insect control utilizing synthetic chemicals, commercial (private) insect/crop consultants quickly carved out an area of expertise in their jurisdictions. Entomologists designed calendar-based insecticidal pest control practices for crop yield maximization. Then, unexpected pest resistance and secondary pest control problems developed that had to be solved. From this era of expediency emerged new opportunities for pest control advancement through an understanding of insect pheromone biology and chemistry, pest resistance, pest management, agroecosystem modeling, insect behavior, pathology and physiology. Perhaps these advancements were ordained by the use and misuse of the first synthetic organic pesticides.

Now 50 years later, yield enhancement programs are being designed around the new broad spectrum pyrethroids. These "new" programs may eventually be negated by the same insecticide-resistant pest strains, secondary pest outbreaks, and environmental quality problems experienced earlier if correct judgment is not employed by growers, consultants and industry, communicating and working together.

REGISTRATION AND REGULATIONS

REGISTRATION

The registration process is the only effective way to regulate pesticide use patterns. At the national level, the Environmental Protection Agency (EPA) has built into the registration process three mechanisms that scrutinize pesticides for potential adverse health effects and for potential to reach groundwater. They are: (a) new chemical registration process; (b) reregistration or the registration standards process; and (c) the amendment to existing registrations process. In addition, the EPA can utilize the Ground Water Data Call-In option to determine which of the most used pesticides have the potential to reach groundwater under actual use conditions (Creeger, 1986). Many pre-1983 registered products and public domain products need toxicity studies done before the re-review can begin. Some will need environmental fate data. Thus, the older chemicals will be required to meet the same scrutiny as new chemicals regarding chronic health effects and groundwater pollution. Whether or not a company chooses to provide the data necessary for reregistration most likely will depend on the market profitability of that product.

Insecticide and nematicide residues in the soil occur as a result of: (a) fall-out after crop spraying; (b) incorporation of plant residues in the soil; or by (c) direct treatment. The persistence of these chemical materials depends on their stability and biodegradability, all of which in turn are influenced by soil type, micro-organism populations, pesticide formulation and method of application. Not only does the grower have to consider these factors when planning a plant-back schedule but these same factors have to be considered by regulatory officials when evaluating the potential of a pesticide to reach groundwater.

Likewise, the effects of pesticides on non-target organisms are also an issue of regulatory and environmental concern. Any pesticidal effects to non-target organisms at field-applied rates will be governed by the stage of crop development, the climate, and the distribution and behavior of the non-target arthropod population itself. Generally, organophosphates are considered broad spectrum insecticides that are also toxic to mammals and birds. The pyrethroids, however, have a relatively low dermal toxicity to mammals and birds at field-applied rates, with birds being less sensitive to pyrethroids than mammals (Hill, 1985). Invertebrate organisms, such as the parasitic wasps and predacious mites, are acknowledged in very few regulations governing pesticide use compared to the honey bee. Honey bees are important pollinators of many high value crops, and commercial pollination and honey production are agricultural industries to be protected. Although pyrethroid toxicity to bees may be of little concern at field application rates (Hill, 1985), they should be considered comparable to the organophosphate compounds in impact on beneficial insects.

The regulatory concerns of pesticide impact on non-target organisms can be mitigated somewhat through application technique. A potential advance in the technology of precision application of pesticides is represented by controlled droplet application. Controlled droplet application offers the potential of reduced environmental contamination and better operator safety if fundamental questions on droplet transport and disposition are actively pursued (Bals, 1987). Full development of this technology deserves the cooperative implementation effort of both industry and government. Other aspects of pesticide use that can either create or mitigate regulatory concerns are: (a) proper management of insecticidal equipment, especially chemigation equipment; (b) accurate calibration; (c) correct mixing rate for proper pesticide concentration; (d) swath coverage so as to avoid water areas; (e) the use of qualified consultants to scout for field pests; and (f) the use of alternate classes of pesticides when feasible.

REGULATIONS

It has been suggested that, between resistance and escalating costs for pesticide development, registration and reregistration, insecticides are becoming an endangered resource for cotton production (Frisbie, 1987). Despite thinking to the contrary, legislation and regulations are implemented because of a demonstrated need. A need for safe drinking water in California resulted in Proposition 65, the "Safe Drinking Water and Toxic Enforcement Act of 1986." Under this Act the Governor can declare any chemical as a health hazard if it is a carcinogen or reproductive toxicant. Among the first chemicals named in 1987 were aramite, dibromochloropropane (DBCP), ethylene oxide, arsenic, and arsenical compounds. Methyl bromide was added in 1993. Likewise when the air concentration of methyl parathion exceeded established thresholds for health effects, California identified it as a toxic air contaminant in 1993. In response to air quality concerns, California now prohibits the selling or use of weed oil in certain counties.

There was a demonstrated need for The Endangered Species Act of 1973. This Act was reauthorized in 1985 and requires all federal agencies to insure that their action will not jeopardize endangered or threatened animal or plant species and their habitats. Under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the EPA must protect endangered and threatened species. The compliance date for cotton was February 1, 1988. EPA, however, has postponed implementation of the program due to suggestions from various sources. If and when the program is ever implemented, certain pesticides most likely will be restricted from use in areas where endangered species exist. Some of these pesticides which are used in cotton are paraquat, parathion, aldicarb (Temik®), azinphos-methyl (Guthion®), Cypermethrin (Ammo®, Cymbush®), Fenvalerate (Pydrin®), and profenofos (Curacron®). If the program is implemented, it is obvious that some cotton producers in all states will have to make land use adjustments.

ENVIRONMENTAL AND BIOLOGICAL RISKS

The issues of risk assessment, significance, and management are current topics in regulatory circles. From a public health standpoint, we possess the technology to maintain an environment virtually free of pest-transmitted diseases. Public health is maintained in part through the use of insecticides to reduce the incidence of malaria, yellow fever, encephalitis, and other arthropod-transmitted diseases. This same technology provides the food and fiber we all need for longer, more productive lives and now provides economic control of pests at levels of less than 10 parts per million of active ingredient per acre rather than pounds of active ingredient per acre.

Nevertheless, even as field application rates decrease, our ability to detect synthetic organic materials has increased at a rate faster than our scientific assessment of associated risk, its management, or the public's perception of risk. And as these refined analytical techniques revealed even smaller levels of pesticide residues in our food and environment, the health consequences of exposure were refocused in an attempt to explain chronic health concerns ranging from cancer to birth defects. Thus, the numbers characterizing trace contamination of our environment need a significant understanding for appropriate regulatory response and public perception. For example, there is uniform interest in groundwater protection, but considerable differences exist among parties in setting acceptable limits for detected chemicals in groundwater. Some will not accept any level or limit for chemicals in groundwater, while others recognize that naturally occurring water is not pure and that some limit to assure high quality is reasonable (Summer and Stevens, 1986). Some believe that, in order for the public ever to perceive the difference between the analytical finding and acute and chronic health significance, the government must establish numerical groundwater standards (Ehart *et al*., 1986). EPA's Office of Drinking Water has set some Maximum Contamination Levels (MCLs) as established standards of what is safe water (Summer and Stevens, 1986). These MCLs function in the same way as food tolerances do. However, there is the question of public trust in government officials. Recent survey results reveal that 63 percent of those asked disagreed with the idea that if the government allows "small amounts of chemicals in water," the water is safe to drink (Ehart *et al*., 1986). In an effort to address these concerns, a regulating agency's response to the public can make for curious circumstances. The California State Water Resources Board's list of "Criteria for Selection of Priority Chemicals" places public concern before chronic and acute human toxicity potential. The Board seems to react to public opinion before it initiates evaluation of potential human toxicity problems. The logic is if there is difficulty in establishing a cause-effect relationship between the detected chemical and long-term health effects, then responsible precautions should be taken since it is prudent to err on the side of caution (Cohen, 1986). Thus, there is a need to bridge the void between analytical detection and public perception by risk assessment and management.

Risk significance is an issue clouded by a lack of data on certain pesticides and poor communications between scientists, manufacturers and the media. When the issue of groundwater contamination is raised, the investigative focus by the media usually is on pesticides simply because it is assumed we have more data on them than on other classes of chemicals. Yet when a pesticide is discovered in groundwater at parts per million or parts per billion, there are no definite answers to questions about potential health effects. Now the investigation becomes clouded. Because data are lacking, a risk is perceived. Media and public focus immediately shift from the pesticide to the analytical finding (the mere presence of the chemical). Lacking evidence to the contrary, they assume that since these products are poisonous, even small amounts are undesirable in our ground or surface waters. Sometimes there is a great disservice to the public when media reports focus on the detection and gloss over the health effects associated with that detected level. At other times the public is misinformed when media, through ignorance, report the toxicology of a substance on study animals but fail to mention the existence of legally enforceable EPA standards and thereby imply that the water is unsafe to drink (Newby and Rouk, 1986). Thus, it is necessary that the quantitative estimates of risk made by the risk assessor be communicated in a way understandable to the risk manager, the regulatory decision makers, and the public (Colthern, 1986). Otherwise, when scientists are unable to assess the health significance of parts per million or billion, the public justifiably demands no-risk protection from their elected representatives. Because the public is not well informed on technical issues, an unknown health assessment provides a reaction rather than informed opinion. In response, laws are passed and regulations are written to mitigate future analytical findings in an attempt to restore the no-risk environment. This scenario reaffirms the belief that risk assessment is a scientific endeavor but that the decision of risk significance and risk management should be left to societal judgment (Smith, 1986).

GROUNDWATER PROTECTION

Concern about groundwater contamination from pesticides has resulted in use restrictions or regulations at both the federal and state levels. This turns out to be the least costly and most effective approach to alleviating groundwater pollution. The United States Environmental Protection Agency hopes to prevent future chemical contamination of groundwater resources by promoting state groundwater protection programs and by requiring more rigorous pesticide registration requirements, especially on the potential for leaching. Promulgating these regulations has been especially exasperating for lawmakers who have had to listen to evidence, testimony and opinion stating that less than one percent of the ground water is polluted, that this number will decrease in a couple of decades, and that groundwater moves so slowly that there is adequate time to achieve a management plan for the future (Cohen, 1986). Contrasting views state that we are just seeing the tip of the iceberg. They state that contamination may turn out to be greater than now realized, given the lag time for chemicals to reach groundwater from the expanded use of synthetic organic chemicals in manufacturing since 1940. Others are of the opinion that we cannot wait for health effects data to come in; the contaminants must be removed now (Cohen, 1986). Although there are nine existing federal ground water protection programs ranging from FIFRA's pesticide policy to the Nuclear Wastes Policy Act, consultants in Michigan believe that a state level policy approach for groundwater protection offers the greatest promise for immediate protection (Libby and Kovan, 1987). Local legislative responses have been in acts such as the Wisconsin Ground Water Law, and the birth defects and groundwater protection bills in California. The birth defects bill mandates review of all pesticide data for possible deficiencies regarding potential health effects, while the groundwater protection bill, known as the Pesticide Contamination Prevention Act prohibits or restricts pesticide use through the establishment of pesticide management zones for those pesticides with a high potential for leaching. Established in 1990 and identified by township, range and section, applied pesticides must meet specific numerical values for water solubility, hydrolysis, soil absorption and aerobic soil metabolism.

Groundwater contamination by pesticides is usually associated with spills, runoff, accidents and use patterns. Normally, pesticides are dissipated by photochemical, microbial or chemical degradation, or by leaching. Those herbicides, insecticides and nematicides susceptible to leaching are subject to regulation. Pesticides that remain in solution have the greatest chance of making it to groundwater compared to those that are less soluble or insoluble in water or that are retained by the soil. There are records of contamination of groundwater by illegal pesticide use, improper discharge of unused pesticide mixtures or rinse water, and accidents, (Cohen, 1986), all of which are few in number.

Detections of herbicides and insecticides/nematicides in groundwater are about equal in those states that have surveyed for contamination. Aldicarb (Temik®) has been detected in groundwater in eleven states in addition to New York, California, Florida and Wisconsin (Cohen *et al*., 1986). However, it has not been found in groundwater in association with cotton despite its extensive use in that crop (Leser, 1986; Cai *et al*., 1993). The fact that it is soil-applied makes aldicarb's continued use questionable especially in areas with a perched water table and sandy soil. The short-lived pyrethroid insecticides have not been found in groundwater, although residues were found in fish and invertebrates (Bennett *et al*., 1983). Documented adverse health effects associated with a specific contaminant acquired by drinking pesticide-contaminated groundwater are difficult to develop, although there are documented health risks associated with ingesting groundwater having excess leached nitrate from nitrogen fertilizer, sewage or feedlots (Kamrin, 1987).

Public health and environmental concerns will continue when new technology is utilized without adequate substantiating data on the potential long-term effects simply because experimentation in time and place is not adequate enough to be predictive (Bradley and Agnello, 1986). Creative mitigation solutions to groundwater pollution problems may involve fundamental land use patterns proposed by those unfamiliar with agricultural production issues. The authority and procedures (zoning laws) for directing the private use of land are in place and well established (Libby and Kovan, 1987). Only through group articulation can a reasonable approach compatible with current and developing agricultural practices and technology be reached on the issue of groundwater protection.

WORKER SAFETY

Organophosphate insecticides are popular crop protection chemicals because of their high efficacy and relatively low environmental persistence. There exists, however, the potential for adverse exposure to farm workers from handling farm chemical pesticides. Over thirty workers became ill in California in 1984 while applying organophosphates. Most of these illnesses are associated with dermal absorption resulting from spills or application mists (Meinders, 1985). Farm worker safety is addressed by the pesticide label, mandatory protective clothing, and required education and training programs stressing safe handling and application of pesticides. Other safety aspects include closed systems for mixing pesticides, and the actual posting in California fields of reentry times after application of specific pesticides.

The potential acute and chronic health effects that could result from pesticide residues on cotton are of concern. For example, field evaluations in California of the health safety of twelve chemicals (six organophosphate insecticides, three synthetic pyrethroid insecticides and three defoliants) found that the measured residues on bolls at harvest did not pose an inhalation hazard to cotton harvest workers (Maddy *et al*., 1984). And the airborne levels of the harvest-aid paraquat declined rapidly both temporally and spatially, but residues on cotton plants at harvest were comparable to those downwind from a sprayed field (Seiber *et al.*, 1983).

The residual life of a pesticide is also influenced by the carrier. All of the tested pyrethroids and some of the organophosphates in a cottonseed oil carrier had their residual life greatly enhanced compared to those pesticides applied in an aqueous solution, thus indicating a need to evaluate worker reentry times when different carriers are used (Ware *et al.*, 1983). However, there is need for common understanding between researchers and regulatory officials regarding the actual versus potential exposure risks for farm workers. The EPA model for exposure assumes 100 percent absorption, but mixer-loader studies indicate that less than 10 percent of the "actual" exposure was absorbed (Nye, 1986).

The environmental, biological and economic complexity of production decisions is evident when the agricultural pest control practices incorporated in the field can be of worker health significance in the gin or the mill (cottonseed or textile). Several researchers have found relationships between insect infestation and aflatoxin contamination. Aflatoxin is a secondary metabolite of the common soil fungus *Aspergillus flavus*. Aflatoxin is sometimes found on lint and is considered to be an animal health risk and could be a human health risk (Maddy *et al.*, 1983). It has been observed that as the level of pink bollworm infestations increased, so did the mean amount of aflatoxin (Russell *et al.*, 1976 and Widstrom, 1979). It may be that insect injury to cotton locules (locs, locks) slows the rate of boll opening, thus maintaining higher moisture in the boll which is ideal for aflatoxin elaboration by the soil fungus.

In another study concerning worker safety, three different arsenical harvest-aids were analyzed in cotton lint and seed but were found not to be significantly above the pre-application levels after eight days (Mastradone and Woolsen, 1983). However, Columbus (1987) discovered a good correlation between defoliant left on lint and the amount of gin cleaning and drying — the less foreign matter in the lint, the lower the defoliant.

From these selected examples, it is evident that as long as chemicals are to be used for production agriculture, we can expect federal and state regulatory authorities to continue pesticide monitoring and to specify safety requirements for agricultural workers at all production levels. These safety concerns also should address the proper selection, handling and storage of protective clothing as outlined by Laughlin and Gold (1987), as well as protective devices, training sessions, medical monitoring where appropriate, and reentry requirements. For applicators and mixers/loaders, continued training and certification will be necessary as the EPA continues to assign restricted use labels to pesticides. Regulatory agencies have begun to enforce the requirements of the 1992 Federal Worker Protection Standard (Code of Federal Regulations, Title 40, Part 170) when pesticides with labeling that refers to the Worker Protection Standard are used. Any agricultural pesticide user and/or an employer of agricultural workers or pesticide handlers is required to provide to those employees information about exposure to pesticides, protections against exposures to pesticides, and ways to mitigate exposures to pesticides.

TOXICITY

Toxicity can be viewed as the inherent capacity of a compound to produce a harmful effect (Bohmont, 1981). The toxicity of a pesticide depends on the: (a) chemistry of the compound, (b) target or non-target organism, (c) method and duration of exposure, and (d) inherent ability of the target organism to metabolize the toxic compound into innocuous compounds before the pesticide can harm the target organism. Using standard test procedures, a relative measure of toxicity among pesticides has been established. Although there may be potential for injury to the skin or eyes from a compound, the most familiar measure of toxicity is the LD_{50}, or the acute oral lethal dose in milligrams, that kills 50 percent of the test animals. Since this number is based on the weight in kilograms of the test organism, a lower number means the compound is more toxic. The chlorinated hydrocarbon dicofol (Kelthane®) is generally considered less toxic (LD_{50}=809 mg/kg) than is the organophosphate monocrotophos (Azodrin®) whose LD_{50} is 20mg/kg. Some newer pesticides are now subject to a data call-in for existing data gaps that would help to assess acute and chronic toxicity risks. Most are of the organophosphate group. Standard health studies to assess the potential of pyrethroids to cause cancer have shown that at very high dose levels of 3,000 to 6,000 ppm, the pyrethroid molecule does not have carcinogenic properties (Litchfield, 1985).

In order to use the more toxic pesticides, the potential hazard to agricultural workers has to be mitigated. Hazard is the combination of toxicity and exposure. Mitigation occurs through different pesticide formulations (granular vs. liquid or dilute vs. concentrate), application equipment (enclosed cabs and closed mixing systems), and applicator training and experience. Currently, organophosphates, carbamates and pyrethroids are the most commonly used insecticides on cotton. All of these pesticides overlap as to their relative toxicity or potential hazard to agricultural workers. Some pyrethroids [cypermethrin (Ammo®, Cymbush®), LD_{50}=251mg/kg] are more toxic than some organophosphates [acephate (Orthene®), LD_{50}=945mg/kg]. Thus, when handling concentrates, there would be no health safety advantage of a pyrethroid over an organophosphate as far as the mixer/loader is concerned. The safety advantage of the pyrethroids is evident to field applicators and workers since their normal application rates are less than 0.15 pounds active ingredient per acre. This safety is always compromised when, for instance, a pyrethroid/organophosphate mixture is recommended.

PEST RESISTANCE

Resistance problems historically have been solved by the discovery of pesticides with a new chemistry or with a new mode of action. Perhaps the current bollworm/tobacco budworm resistance phenomenon will be addressed through the development of a transgenic strain of cotton or genetically engineered pesticides based on pesticidal toxins (Micinski *et al*., 1992 and Brumley, 1987). New compounds and techniques could offer new dimensions for cotton pest control, but thinking such as this places blind reliance on the ability of technology to bail us out of a predicament that could be avoided with correct thinking. We know that resistance development in insects is a population phenomenon. It develops due to selection pressures, like pesticides, on the pre-existing genes that impart resistance. These genes occur in a population at a certain frequency and their expression is determined by both biological and operational factors. We have no control over the biological factors such as generation turnover, gene dominance and migration. But we can manipulate some of the operational factors such as the chemistry and persistence of pesticides (Graves, 1987). Resistance can be managed in each producing area with correct thinking and careful planning of an annual pest control strategy similar to that practiced for cotton production in Australia, Egypt and in some areas of the United States. (Denholm and Rowland, 1992). Resistance management strategies include pesticide selection, utilization of short-season cotton varieties, irrigation and fertilizer management, planting date, row spacing and plant growth regulators to remove immature bolls (Henneberry, 1987; Clower, 1987; Denholm and Rowland, 1992).

Resistance to pyrethroid insecticides in the United States was first detected in 1985 in Texas (Plapp and Campanhola, 1986). Before that, there was evidence of pyrethroid resistance by the diamondback moth, *Plutella xylostella* (L.), in Thailand and Malaysia, by the beet armyworm, *Spodoptera exigua* (Hübner), in South and Central America, and by a *Helicoverpa* species. in Australia. Today, researchers are monitoring resistance and suggesting ways to prolong the biological activity of the pyrethroids in general. Local area studies found that the economic advantages of early maturing varieties in the Rio Grande Valley of Texas were the potential reduction of pesticide use by over one million pounds and an increase in net returns (Sprott *et al*., 1975). Short-season cotton requires less inputs for insect control (0-24 percent less) and can have higher yields (0-25 percent) than the longer seasoned varieties (Norman and Henneberry, 1987).

With potential resistance problems looming, it is alarming that statements have been made pronouncing reliance on pyrethroids for bollworm, *Helicoverpa zea* (Boddie)/tobacco budworm, *Heliothis virescens* (F.), control in the event that pest problems develop as the result of early-season insecticidal controls (Ratchford *et al*., 1987). Pesticide selection and use rates should be considered in terms of potential effects both long range (resistance, environmental contamination) and short range (capabilities of the insecticides available) (Luttrell and Reed, 1986). Resistance management through thoughtful selection of pesticides appropriate for early-season pest control may avoid tobacco budworm problems. Clower (1987) has observed that use of pyrethroids early in the season triggers the resistance selection process, especially in Mid-South early fruiting cotton. Graves *et al*.(1991) documented seasonal changes in frequency of pyrethroid-resistant moths. This information combined with cultural practices may prolong the useful life of pyrethroids in cotton.

For early-season thrips management, varietal pubescence or delayed planting may be a consideration. Cotton producers in the high wheat producing Rolling Plains area in Texas adopted a uniform delayed planting date to combat boll weevil and may secondarily be controlling thrips because the thrips have dispersed by the time cotton is susceptible (Leser, 1986). Pesticide resistance in bollworm/tobacco budworm may be delayed by avoiding the temptation to apply pyrethroids during the early stages of crop development. A reasonable pest management program of organophosphates and carbamates for early-season pest control and pyrethroids mid- to late-season may prolong the useful life of the pyrethroid insecticides.

Some thought as to this direction is coming from the Pyrethroid Efficacy Group (PEG), an organization whose purpose is to establish technical recommendations for pyrethroids and to extend the useful life of these insecticides. The United States contingency of this group met with manufacturers after resistance was confirmed in the tobacco budworm. With the exchange of pest control ideas, the pyrethroids can be a long and useful tool in cotton pest management. The success of resistance management will depend on a high level of cooperation within and between the agrichemical industry, production consultants and growers (Denholm and Roland, 1992) and with the realization that resistance management is just one other aspect of an integrated pest management philosophy. That there will always be a need for managed pesticide use is well illustrated by the recent appearance in several cotton producing states of the pesticide-resistant silverleaf whitefly, [*Bemisia argentifolii* (Bellows and Perring)], formerly recognized as strain B of the sweetpotato whitefly [*Bemisia tabaci* (Gennadius)].

SUMMARY

Preservation of the quality of our environment and natural resources, especially the quality of our surface and ground water, are important and sensitive issues today and always will be. Yet, on a worldwide basis, chemical pesticides will continue to be the primary tool against the threat of disease and famine well into the twenty-first century. Therefore, proper use of these tools will always be under the scrutiny of the public and regulatory officials. Knowing the health and environmental risks of these pesticides as well as their benefits mandates that common sense and correct thinking be practiced when using them. In order to insure continued safe use of these tools, there must be meaningful communication among the respective concerns of commodity producers, regulatory officials, industry and the public. The current environmental issues in cotton production are no different than they were thirty years ago. The chemical names have changed but the problems of environmental pollution, pest resistance problems, worker safety, residues and secondary pest outbreaks are still with us. Why, with such demanding pesticide use and registration regulations, are we still faced with thirty year old problems? Will they ever be resolved? They will probably never be completely resolved until science and technology show us how to produce agricultural commodities without the use of pesticides. And they will not be solved immediately because of our cultural heritage regarding the legal and administrative processes. These processes guarantee fairness to all through open hearings where government's role is to arbitrate among competing interests. Are more regulations to be expected then? Yes. Continued public demands for health safety and a quality environment will add more restrictions on pesticides used for commodity production and perhaps limit the total amount of pesticides applied. In fact, Pimentel (1993) reports that the results of a feasibility study suggest a legislated 50 percent reduction in pesticide use would be possible without compromising crop yield or substantially increasing food costs. This restriction may seem utopian but through focused lobbying efforts by agenda-driven nescience groups, similar restrictions will be proposed for legislative action in all the agricultural producing states. But are more regulations really needed? Wartenberg (1988), in commenting on the aldicarb (Temik®) incident in New York, believes the existing power already allocated to various regulating agencies is sufficiently broad-based to address the problem. The pesticide registration and health agencies, both federal and state, already have the prerogative to demand additional data on compounds with questionable health properties or to restrict or ban pesticides likely to cause environmental contamination. Health authorities can close contaminated wells or conduct sampling programs or implement health studies. The only thing needed for efficient pesticide management is sufficient coordination among these regulatory agencies and coordinated input from commodity producers. The public, regulatory officials and growers will always be concerned for the quality of our environment and the implications pollution may have for our present and future living standards. "We don't inherit the land from our ancestors, we borrow it from our children" is wisdom and good philosophy from the old Pennsylvania Dutch farmers that can be shared by all agricultural commodity producers.

Chapter 29

WORKING TOGETHER: ROLES OF PRIVATE CONSULTANTS, INDUSTRY, RESEARCHERS, EXTENSION, AND GROWERS

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INTRODUCTION

The transfer of technology in developing and using cotton insect and mite control methods encompasses a complex and challenging system that probably is as good an example as one can find of the interactions between private and public components in the American economic system. Development of control technology moves from the conceptual level through a vast array of bench scientists, field researchers, pilot programs, and extension demonstration and education programs before reaching the final advisor and user. It may originate and/or be developed by industry, the USDA Agricultural Research Service, various state agricultural experiment stations, and various other less structured "discoverers" of new technology.

Technology transfer usually involves numerous cooperative efforts between the various entities in the agricultural research and development business. When a control technology is proven effective, it is offered in the market, possibly as the only effective method of control, but usually as one of several methods competing for the cotton grower's attention and dollars in his pest control budget. Information and advice on all the available technology reaches the final user through many routes provided by industry (basic manufacturers and dealer/distributors), the Cooperative Extension Service, and to an increasing extent, by professional crop consultants. Various federal and state regulatory agencies help insure proper use of products and quality of services. Other professionals may be involved in the application of a selected control technique, such as the aerial applicators who play an essential role in effective cotton insect and mite pest control. The final user is usually a fairly sophisticated cotton producer who, within the constraints of public health and safety considerations, will use a pest control method if it works effectively and is cost effective.

The complex interactions involved in this process of insect and mite control technology transfer are illustrated in Figure 1. This diagram may serve as a guide for the following discussions of how various public and private sectors work in the process of discovering, developing, marketing and using cotton insect and mite control technology.

HISTORICAL BACKGROUND

THE LAND GRANT SYSTEM

The land-grant system of higher education functioning in concert with mission oriented agricultural research and extension education and demonstration programs has been the foundation of America's unique success in agricultural production. The minds which conceived and fought for the system may not have realized its ultimate value, but it has proved to have been a grand scheme with which this nation has built the world's most productive agricultural industry. It was based on the idea that American productivity and quality of life can be directly influenced by the scholarship of the University and a dynamic linkage to its people by an Extension Service. It was designed to help solve society's problems, to respond to public needs, and to educate the nation's young people. The idea was unique in its time and continues to be highly successful in achieving its goals.

For the first 150 years of life as a free nation, the United States was almost exclusively agricultural. A century ago the nation's leaders were primarily concerned with the establishment of a reliable food supply. The country was truly an agrarian society; farming was a way of life. In 1920 about 6.4 million people were engaged in farming. In 1930, as we moved into an industrial society, still some 25-30 percent of the population was engaged in the production of food. During this period crop yields were almost equal worldwide. Differences among the United States, England, India, and Argentina were not readily perceptible. But over the next 50 years, United States productivity soared. Corn yields quadrupled, milk production per cow more than doubled and overall farm productivity increased about 2.5 times. This resulted from technology and public education — the Land-Grant concept.

This concept has been particularly well applied in cotton insect and mite control across the Cotton Belt. When technology has been developed by the research compo-

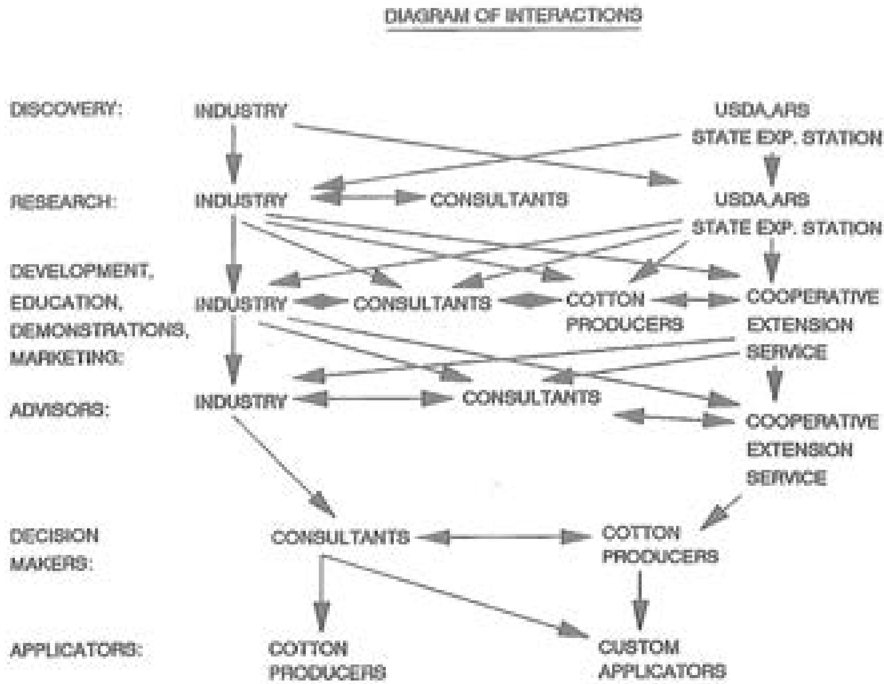

Figure 1. A schematic description of the interactions with regard to insect pest management among the various public and private groups within the cotton industry illustrating the complexities of these relationships.

nent of the system, the cooperative extension service has been diligent to develop education programs to take the new methods to the field.

PRIVATE INDUSTRY

Another key player in cotton insect and mite control is the pest management industry. Correctly referred to as the "pesticide industry" for many years, this industry is participating in innovative discovery and development of new concepts for products and services in insect and mite pest management for the twenty first century.

Devastation of cotton by the boll weevil, *Anthonomus grandis grandis* (Boheman), across most of the Cotton Belt during the first half of this century resulted in research of numerous methods of weevil control. Minimally effective cultural control methods and difficult to apply inorganic insecticides that gave only slightly better control were the cotton producers' only defense against the boll weevil during most of these years. During the 1940s the organic chemical industry began to produce organochlorine compounds such as DDT, BHC, chlordane, dieldrin, endrin and toxaphene, which were highly effective against boll weevil and other cotton pests. These chemicals appeared to have provided "the" solution to cotton insect pest problems, effectively and permanently. However, insects and mites had survived many millennia in a hostile environment and they soon showed capability to adapt to these chemicals. Insecticide resistance has become a well known fact of life and private industry is responding by searching not only for new chemistry but also for new approaches to managing insect and mite pests of cotton. Since the 1970s, greater emphasis by industry has been given to development of biological insecticides such as the bacterium, *Bacillus thuringiensis,* and to development of chemicals that disrupt insect growth, development and behavior. These new chemicals include insect growth regulators, pheromones and semiochemicals. Private industry is also active in various stages of research, development and marketing of insect traps, attracticide devices, insect confusion products, parasites and predators for field release, and other new products and services.

Biotechnology is probably the area in which private industry has the greatest potential to change cotton insect control in the future. Cotton plants containing genes from *Bacillus thuringiensis* have been engineered to produce the endotoxin at sufficient levels to control lepidopterous pests including bollworm and tobacco budworm. Cotton varieties containing this trait are in advanced stages of development and some agronomically acceptable cultivars will be availabale for the 1996 planting season.

The goal of private industry is the development of products that meet the needs of the cotton grower. In addition to synthesizing and developing pesticides (chemical and biological agents), and other products, and manufacturing and distributing the products, the industry participates in training on proper use of products including integration of a product's use with other pest management tactics. These activities are done in cooperation with public organizations and the consulting profession.

PRIVATE CONSULTANTS

Private consultants have become important insect pest management advisors for cotton growers in recent years and their role continues to grow in importance. Private consulting in cotton pest control probably can be considered a new profession. Significant growth in numbers of individuals in the profession did not occur until the early 1950s. Earlier accounts of private consulting indicate a few individuals here and there contracted with the larger and more progressive cotton producers as early as the 1930s. In those days, the boll weevil was a major pest in most of the Cotton Belt and there were few effective control methods available for a consultant to recommend. Calcium arsenate dust was an inferior insecticide that was also difficult to apply. Application technology was in its infancy. A few cultural methods such as early planting and stalk destruction helped but had limited effectiveness against the boll weevil. Under such circumstances, private consulting in cotton insect control was not a very appealing career. This was the situation in cotton insect control until the late 1940s and early 1950s, when organochlorine insecticides were first produced.

There were probably several interacting reasons for growth of the private agricultural consultant profession in cotton country. Numerous pests such as boll weevil, bollworm, tobacco budworm, thrips, aphid, spider mite, pink bollworm, *Lygus,* fleahopper, cotton leafperforator and other pests cause significant problems requiring professional attention in cotton.

Lack of availability and quality of other sources of advice also contributed to the need for private consultants. Quality here is not used in reference to the general competence and importance of county and state extension personnel or pesticide salespeople, but refers to special skills and training in entomology and insect control. County agents were much more likely to be trained in animal science or dairy science than in entomology, and, even if they had a degree in entomology, their time for scouting and advising individual growers on cotton insect problems was limited. Some of the most competent entomologists in the business have worked in sales and technical service for chemical companies and pesticide dealers but their time for individual growers is limited and their primary job is to promote and sell product.

Circumstances in cotton production that developed in the late 1940s and during the 1950s were opening up a niche for the private entomology consultant. Remedies for cotton insect problems, principally chemical insecticides, became available and development of new ones mushroomed. Federal, state, and industry researchers developed better methods of how and when to use these products. Complications of insecticide resistance and secondary pest outbreaks, inherent in chemical insect control regimens, became apparent. Entrepreneurial entomologists began to move in to fill the niche.

Reduced federal and state funding for agricultural research and extension services, and changing societal needs have placed new demands on the state universities. Consequently, the land-grant system has been less able to respond to the needs of the cotton producer. These producers, if they can satisfy their needs through other (private) sources, seem willing to pay for services and information formerly provided through tax supported public agencies. By recognizing these entrepreneurs as complimentary and synergistic, rather than antagonistic and threatening, the land-grant system can remain relevant to society and to the individual producer.

In some states, the local research and extension personnel helped develop the private sector, the agricultural consultants, and continue their support through cooperative educational programs.

There has been a significant change to more use of private consultants in the final steps of technology transfer, but this has not diminished the role of the cooperative extension service. Consultants and other clients continue to heavily depend on the Cooperative Extension Service.

COOPERATIVE EFFORTS

The relationship between extension, state and federal research, consultants, pest control advisors (PCA's), private industry, and the cotton producer is important. This relationship has strengthened within the last few years and will continue to improve. Figure 1 is a schematic description of the interaction between the various public and private groups within the cotton industry. It illustrates the complexities of these relationships and the need for continued improvement in communication and cooperative efforts among the sectors represented. With product usage becoming more complex and economic thresholds and other field monitoring technology changing rapidly, it is increasingly important for all segments to work together. The control of pests in cotton, whether insects, mites, weeds or diseases, is important for maximum yields and quality crops. There are public and private groups of people and companies working together to help the cotton producer manage his pests while protecting the environment.

There are numerous examples of cooperative programs where research, extension, industry, consultants and growers have cooperated to bring new technology to practical application. Two such programs will be discussed here to illustrate by specific example how the system of cooperation has worked. One such technology that has been applied across most of the Cotton Belt is a boll weevil control tactic called "reproduction-diapause control". The second widely applied technology is "pyrethroid resistance management".

BOLL WEEVIL REPRODUCTION-DIAPAUSE CONTROL PROGRAMS

Term "reproduction-diapause control" refers to a boll weevil control technique that is directed to a vulnerable period in late season when interruption of reproduction and prevention of diapause can be achieved with insecticide applications.

Research in boll weevil infested states across the Cotton Belt showed reproduction-diapause boll weevil control to be an effective method of suppressing boll weevils during the early and middle part of the cotton growing season by limiting the number of winter survivors. Consequently, many integrated pest management (IPM) systems were based on effective community-wide reproduction-diapause boll weevil control programs.

A symposium during the 1983 Cotton Insect Research and Control Conference, Beltwide Cotton Production Research conferences, was entitled "A Decade of Extension Cotton Integrated Pest Management 1972-1982" (Young, 1983). The objectives of the federally funded cotton pest management program were to assist growers in developing effective, economical, and environmentally-sound pest management practices that involve combinations of chemical, cultural, and biological control methods; with emphasis on early planting trap crops, delayed in-season insect control, early post-harvest crop destruction, chemical diapause control (of boll weevil), pheromones, and other technologies as appropriate (Blair, 1983). One of the greatest changes in cotton insect pest management observed during this ten-year period was the increase in acreage scouted by private consultants, up from 401,500 acres in 1972 to over 2.2 million acres in 1982 (Lambert, 1983). The number of private consultants involved in cotton insect management increased during this period from 66 in 1972 to 571 in 1982, and many chemical companies started promoting integrated pest management concepts in their advertising and other product promotion activities (Head, 1983). Benefits of IPM during the ten-year period included improved quantity and quality of scouting (monitoring pest populations), greater use of beneficial insects, greater reliance on thresholds for timing insecticide applications as needed, reduced number and rates of insecticide applications, and millions of dollars in economic benefits across the Cotton Belt (Smith, 1983).

The effective transfer of reproduction-diapause boll weevil control technology from research to cotton growers by the cooperative extension service was particularly important during the early 1970s because of resistance in bollworm/tobacco budworm to both organochlorine and organophosphate insecticides. Reduced in-season insecticide applications against boll weevil was essential for certain bollworm/tobacco budworm management tactics such as utilizing natural enemies to control early generations in cotton. Consultants who practiced integrated pest management adopted the practice for their clients in boll weevil infested areas. The pesticide industry participated in the demonstration efforts and positioned certain products to fit the integrated insect pest management concept of which reproduction-diapause boll weevil control was the basic tactic. The ovicide, chlordimeform, (Fundal®, Galecron®) was introduced into the cotton insecticide market during the early 1970s and was particularly suited for use in the insect management programs upon which cotton producers were dependent at the time.

During this period when growers recognized the acute need for careful management of their insect control resources and turned increasingly to private consultants for expert advice, a cooperative relationship between extension service specialists and private consultants became important. Their roles were intrinsically linked and synergistic. The private agricultural consultant professionals, in fact, became important clients of the cooperative extension service.

INSECTICIDE RESISTANCE MANAGEMENT

Highly effective pyrethroid insecticides became available toward the end of the 1970s decade and by 1980 cotton growers across the Cotton Belt had begun to rely heavily on these products to control their most serious insect pests. A few problems occasionally occurred following pyrethroid applications, i.e. cotton aphid, spider mites, and whitefly infestations might be flared. However, these problems seemed minor compared to earlier difficulties with resistant tobacco budworms. Several pyrethroid products were soon developed, registered, and introduced into the cotton insecticide market. Competition was keen and price was lowered. Vigilance regarding integrated pest management strategies was relaxed. Dependence on natural enemies for bollworm, *Helicoverpa zea* (Boddie)/tobacco budworm, *Heliothis virescens* (F.), control became less important to growers. Entomologists who knew the history of resistance in cotton insect pests and the mode of action of the pyrethroids began early in the 1980s to issue warnings about the probability of pyrethroid resistance with continued prevalent use of the products in cotton insect control.

The reality of pyrethroid resistance in tobacco budworm occurred with field control failures in Texas in 1985 and in the Mid-South states of Arkansas, Louisiana, and Mississippi in 1986 (Graves *et al.*, 1991). The significance of these events was immediately recognized by consultants, researchers, and extension entomologists in Texas and the Mid-South.

A group of consultants operating in the Brazos River Valley and the Winter Garden areas of Texas developed and implemented an insecticide resistance management plan which was widely used with great success.

Following the 1986 tobacco budworm control failures with pyrethroids in the Mid-South, J. R. Phillips of the University of Arkansas named a Pyrethroid Task Force for the Tri-State area of Arkansas, Louisiana, and Mississippi. This group of 16 entomologists met in Greenville, Mississippi on November 6, 1986 to initiate development of a Pyrethroid Resistance Management Plan for the Mid-South. J. B. Graves of Louisiana State University was asked to act as facilitator for the group and he drafted a tentative Pyrethroid Resistance Management Plan for the group's consideration. During this meeting the Pyrethroid Task Force made slight revisions to the draft and recommended the plan for adoption by the three Mid-South states represented. The plan was adopted by the entomologists representing the three states for promotion and use starting with the 1987 cotton growing season. The plan has been modified several times since 1987 and has become an Insecticide Resistance Management Plan rather than a Pyrethroid Resistance Management Plan. The original plan consisted of the following three basic components: (a) avoid late planting and establish a healthy, vigorous stand of cotton; (b) control insects during the period from planting to June 30 in order to allow production of a crop in 120-140 days, but avoid use of pyrethroids during this period; and (c) use pyrethroids as needed during the period of July 1 through the end of the season. As levels of pyrethroid resistance in tobacco budworm increased the pyrethroid use window was narrowed to mid-season and growers were advised to use organophosphate insecticides in late season. Full rates, short intervals and mixtures with other insecticides were advised when tobacco budworms were present in the infestation (Personal communication, J. B. Graves, Louisiana State University, Baton Rouge).

The insecticide resistance management plan developed by the Tri-State Pyrethroid Task Force, and subsequent modifications, has been widely promoted, advocated, accepted and used by researchers, extension entomologists, consultants and cotton producers across the Cotton Belt where pyrethroid resistance has occurred in tobacco budworm.

Insecticide resistance management has strong support in industry. An Insecticide Resistance Action Committee (IRAC) represents manufacturers of all insecticides and exists to extend the useful life of insecticides. An international organization of pyrethroid insecticide manufacturers known as the Pyrethroid Efficacy Group (PEG) is a major supporter of pyrethroid resistance management efforts worldwide. A subcommittee known as PEG/US has supported the pyrethroid resistance management efforts in the United States with members (pyrethroid manufacturing and marketing companies) making major contributions in personnel and funds (Graves *et al.*, 1991).

The efforts of a broadly based and often administratively unstructured consortium of industry and people interested in avoiding or delaying development of pyrethroid resistance in cotton insects, especially tobacco budworm, appears to have been successful. The evidence is circumstantial but intensive monitoring activity across the region shows a decline in pyrethroid resistance in tobacco budworm during the time when use of pyrethroids is discouraged. The level of success notwithstanding, the insecticide resistance management activities across the Cotton Belt of the United

States, as well as around the world, are excellent examples of working together between all segments of the cotton insect management profession.

SUMMARY

The various entities which develop and transfer cotton insect technology are synergistic in their interrelationships, both through cooperative efforts and through an inherent system of checks and balances. Through it all is a continually evolving array of information, services, and products available to the system's clients and customers — the world's cotton farmers. The system has done an excellent job of screening this flow of information and technology and discarding that which proved to be inferior and promoting that which proved to be effective. The result is a top quality delivery system — the best information, the best service, the best line of products.

The future will bring greater demands for "working together" by all segments of the cotton insect and mite pest management delivery system. Public opinion and legal requirements will continue to increase demands for assured environmental safety and human health protection. Highly adaptable insect and mite pests will continue to evolve defenses against control tactics. Pest management will become more complex and implementation of effective and safe pest management tactics will require more knowledge and superior judgement.

Working together involves interaction of federal, state, industry and self-employed professionals on farms, at grower meetings, in special training workshops and a myriad of other training opportunities, including the mecca of cotton information exchange and technology transfer, the Beltwide Cotton Production and Research Conferences. These annual Beltwide conferences epitomize the concept of diverse segments of the industry working together to support and promote the interests of the entire cotton industry, including improved insect and mite pest management.

Chapter 30

COTTON INSECT MANAGEMENT: A LOOK TO THE FUTURE

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INTRODUCTION

Integrated pest management (IPM) is the most logical, ecologically as well as environmentally, approach for arthropod population management presently and in the foreseeable future. IPM, which is based on coordinated use of multiple tactics to keep arthropod pest damage below economic injury levels, is focused on long-term sustainability. History has shown that unilateral use of single tactics, that typically offer only short-term, quick-fix solutions for pest problems, often result in disastrous consequences, i.e., resistance to insecticides and acaricides, pest resurgence, secondary pest outbreaks, and environmental concerns. (Newsom 1975, Luckmann and Metcalf 1982, Rabb *et al.*, 1984, Graves *et al.*, 1991a).

Because IPM is resource management under an umbrella of sound ecological practices, it requires little thought to discern how complicated it is to develop and maintain economically and environmentally acceptable arthropod management systems. By the time increments for a control system are researched, tested and found to be adequate, the cropping scheme may have changed substantially. For example, an increase in a particular crop's acreage or a decrease in another alters the ecosystem, often causing a substantial change, quantitatively and qualitatively, in insect and mite populations. Moreover, weather patterns shift, new technology becomes available, additional regulations are enacted, sociological changes occur, marketing expectations may not be realized, international interactions occur and so on, *ad infinitum.* Despite these complications, future IPM systems ultimately must evolve to address pest complexes rather than just individual pests (Newsom 1980, Phillips *et al.*, 1989).

FUTURE COTTON IPM SYSTEMS

Future cotton IPM systems will of necessity be different when one considers: (a) the dynamic nature of cotton production systems; (b) the ever present threat of insecticide and acaricide resistance; (c) the slow rate of development and registration of new, efficacious compounds; (d) the general public expectations for an abundant supply of a variety of wholesome food and quality fiber; (e) the incredibly complex and self-serving national and international political systems dictating agricultural program development; (f) the environmental concerns such as endangered species, water quality, worker protection, and wetlands; and (g) the improvement of plants and animals by genetic engineering.

Development, refinement and adoption of sophisticated IPM systems that will be needed in the future cannot be fully realized without increased commitment of personnel and resources for interdisciplinary research, more trained IPM practitioners to implement IPM programs on individual farms and greater cooperation among cotton producers, researchers, extension personnel, private agricultural consultants, universities, USDA, ARS, industry and regulators, etc. (Newsom, 1975; Huffaker *et al.*, 1978, Smith 1978, Phillips *et al.*, 1989).

Financing the level and intensity of research and development required to evoke a significant change in our present arthropod management strategies challenges the most astute leadership. The assumption that federal and state governments will increase support to land grant institutions and the USDA, ARS may be unrealistic (Huffaker *et al.*, 1978). Cotton "Check-Off" funds seem to be one practical method for providing necessary funding.

Regardless of how sophisticated technology becomes or how effective it may be in the research phases of the program, a well-trained cadre of personnel must be in place in the field to implement the new technology at the user level. Producers cannot be expected to understand all the technical ramifications of the various disciplines involved in complex IPM systems. Land grant institutions must accept the challenge of educating IPM practitioners that are capable of implementing highly sophisticated IPM programs involving every facet of cotton production (Newsom 1975; Huffaker *et al.*, 1978; Smith, 1978, Phillips *et al.*, 1989).

A cooperative atmosphere must be pervasive in developing IPM and production systems. Everything possible should be done to stimulate cooperation and effective interdisciplinary research within the academic community as well as the USDA, ARS. Cooperation among extension personnel, consultants, industry, regulators and, most importantly, cotton producers, enhances the implementation of IPM. Cooperative extension service personnel will be unable to meet all the demands expected of them, because no individual has all the expertise required. Undoubtedly, private agricultural consultants will become an indispensable entity in the adoption of new IPM programs. These consultants are key individuals in any arthropod management venture. County extension personnel should be glad to have them in their area assisting producers with insect, disease, and weed and nematode problems (Newsom, 1975; Phillips *et al.*, 1989).Our emphasis on the need for interdisciplinary cooperation should not be interpreted as an attack on the need for agricultural disciplines. We are simply trying to emphasize the fact that perhaps the lines of the disciplinary fields should be less sharply focused and the lines of interdisciplinary cooperation more sharply focused (Newsom, 1975).

IPM CONSTRAINTS AND OPPORTUNITIES

Eight of the many important areas covered in preceding chapters of this book are discussed below in relation to, and with emphasis on, future research and development of new technologies for cotton insect and mite management systems.

1. SAMPLING PROCEDURES. For many years, we have relied primarily on the sweep net and examination of individual plant parts to assess pest populations. These sampling procedures are not only slow but often lack precision for many pests. More rapid and more precise methods for sampling arthropod populations are desperately needed. We must broaden our vision in seeking improved sampling technology (Kuno, 1991; Hutchins, 1993; Pedigo, 1993).

Pheromones undoubtedly will have an increased role in sampling technology (Campion, 1994; Ingram, 1994; King, 1994; Smith and Harris, 1994). However, quantification of catch data from pheromone-trapping devices must become much more precise and timely. The development of sensors that can detect the presence of insects does not seem unreasonable. Perhaps in the future, permanent sensors could be placed in fields and the information gathered fed to a model for assessment and evaluation. Portable sensory devices may be a more realistic expectation for the near future.

Whatever the technology developed, it must be far more precise and timely than presently available. If we are to initiate action on numbers, then we must have an accurate means to determine those numbers. To reemphasize, little if any significant improvements in our existing pest management systems for cotton insects, or for any insect, will be realized until more dependable, precise and timely insect sampling techniques are developed. Adequate assessment of beneficial organism populations is equally important as is the assessment of pest complex populations.

2. ECONOMIC INJURY LEVELS. The greater the emphasis placed on managing insect populations, the greater precision must be for assessing the potential loss from a given population density. In addition, these population density thresholds must be based to a large degree upon the expectations of the cotton producer and his financial situation. We must provide him with the technology that apprises him of what a population of pest insects means with regard to potential yield and quality losses. The producer then must decide if he is willing to take the loss or initiate the necessary control strategies. The same type information must be forthcoming for the beneficial insect and mite populations. The producer must be apprised of the levels of natural enemies including expected impact on pest species and their damage. Some computerized advisory systems already have been developed that aid producers in making treatment decisions (Gutierrez and Wang, 1984; Naegele *et al.*, 1985; Mumford and Norton, 1994).

We must develop a much improved data base for the interaction of pest species with various cotton cultivars. The database must be developed around an ability to understand and interpret growth and fruiting patterns of the cotton plant. We already know that the cotton plant provides indicators of such important phenological events as fruit set, fruit retention and "cutout". There can be much more improvement in economic injury levels once we understand better the biology and physiology of the cotton plant (Reynolds *et al.*, 1982; Wilson, 1993; Matthews, 1994). Economic injury levels for pest complexes also must be developed. One approach already being used is to lump pests that cause similar damage together, *i.e.*, defoliators and pests causing fruit loss. (Newsom, 1980; Newsom and Boethel, 1985).

3. AREAWIDE PARTICIPATION. Data are available to show that with some pest species, e.g., boll weevil, tobacco budworm, bollworm and pink bollworm, the larger the area involved in a management program, the more effective the program (Newsom, 1975, 1980; Frisbie, 1985). Substantial planning and coordination are required in areawide programs, but the results justify the effort. Within an areawide approach, there are a number of production practices that need coordination. Three of these practices are covered below.

Variety Selection—Variety selection is the initial step to an effective IPM system. If the variety is beyond the producer's capabilities for planting, in-season cultural practices, and harvest, then an IPM approach is severely handicapped. In selecting the variety, a producer must consider the following points: resistance to pests, earliness, soil type, equipment capabilities for planting and harvesting, irrigation, and a general understanding and commitment to IPM procedures. Under some conditions, it may be advisable to have more than one variety in a single operation. However, the more uniform the fruiting characteristics, the more effective IPM tactics might be for any given area (Newsom, 1975, 1980; Matthews, 1989; Graves, 1994).

Uniform Planting Date—One should avoid late planting. Insect and mite population densities are generally highest during late season and the likelihood of encountering populations tolerant or resistant to commonly used pesticides is greatest. Uniform planting aids in synchronizing the occurrence and management of major pests such as the bollworm, tobacco budworm and boll weevil, as well as improves the efficiency of terminating the crop (Newsom, 1975, 1980; Reynolds *et al.*, 1982; Graves, 1994).

Late Season Crop Management—Irrigation and fertilization must be properly managed to mature the crop in a timely manner. Producers often lose many of the early bolls (which are heavier and higher in quality) while trying to mature and harvest late-season bolls. Additionally, early crop maturity reduces overwintering arthropod pest populations and pesticide use. The final phase of late season crop management involves prompt crop residue destruction, which further reduces pest populations by depriving them food and overwintering sites (Bagwell and Tugwell, 1992; Graves, 1994).

4. CROP RATIOS AND SEQUENCES. As far back as the late 1800s, crop ratios and sequences have been implicated in promoting as well as attenuating pest population densities (Gould and Stinner, 1984, Rabb *et al.*, 1984). Obviously, some arthropods are more manageable using this concept than others. For example, the boll weevil, bollworm/ tobacco budworm complex, pink bollworm, and the sweetpotato whitefly have life and seasonal histories responding favorable to large area management of crop ratios/sequences (Butler and Henneberry, 1994; Ingram, 1994; King, 1994; Smith and Harris, 1994).

If research proves that a certain crop sequence or ratio may be utilized to lessen the hazard of infestation by a major pest species, then we believe it would be a sound IPM tactic to do so. Convincing farmers to adopt this approach would be difficult because the profits from producing various commodities vary widely. Perhaps subsidies or other forms of inducement could be used to promote this pest management approach.

5. MIGRATION AND DISPERSAL. Many aspects of the biology and ecology of arthropod pests of cotton insects remain to be elucidated. In terms of information needed to design effective IPM programs, one of the greatest needs is a better understanding of their movement. Local and long range movement of both pest and beneficial species affects almost every facet of arthropod pest management. For example, pesticide resistance management plans, eradication programs, areawide control programs, and quarantine programs must be based on a clear understanding of migration and dispersal of pest species. Management of pests migrating long distances may require international cooperation. On the other hand, chemical control of pests that are stationary or move very little on the host plant can be obtained by complete coverage of the host plant or the use of systemic pesticides (Rabb, 1985; Butler and Henneberry, 1994; Ingram, 1994; King, 1994; Smith and Harris, 1994).

6. HOST PLANT RESISTANCE. Considerable research has been conducted in cotton to develop plants that are resistant to damage by insect and mite pests. This research has been fruitful. Resistance traits to the major pests have been identified and incorporated into high-yielding cotton varieties (Bird, 1985; Gannaway, 1994). In our opinion, if the available insect plant host resistance technology for several pests, such as tobacco budworm, bollworm, and tarnished plant bug, were implemented on an areawide basis, it would serve to reduce greatly overall population pressure by these pests. This in turn would decrease the need for insecticides ultimately resulting in reduction of risks of insecticide resistance development, environmental damage, destruction of beneficial organisms, and the threat of elevating secondary pests or innocuous organisms to primary pest status.

Several constraints have slowed the adoption and use of arthropod plant host resistance. First, research and extension personnel have not focused enough on plant host resistance to insect and mite pests as an answer to pest management. To the contrary, we have generally "gone with the flow" to rely too heavily on the use of insecticides and miticides. Next, the major seed companies that supply virtually all seed used by cotton producers strive for increased yield first and foremost in their variety development programs (Bridge, 1990). This emphasis on yield as the "bottom line" is fueled by the maximum yield mind set of producers and is based on the assumption that cheap and effective insecticides and miticides will always be available. In our opinion, synthetic chemical insecticides and miticides are a declining resource that are likely to be fewer in number and more expensive in the future (Phillips *et al.*, 1989; Graves, 1994). To add to the problem, most of the current commercial varieties of cotton have been developed under a complete canopy of insecticides. Thus, many of today's varieties are not as resistant to most pests as were varieties a decade or two ago. Recent emphasis in commercial cotton breeding has been on earliness (Bridge, 1990). This has indirectly benefitted IPM systems by markedly reducing the time period of risks to insect and mite damage. As the availability of effective insecticides and miticides decline, we are confident that host plant resistance will play a major role in the future in IPM programs.

7. APPLICATION TECHNOLOGY. One area of technology greatly limiting IPM programs and resulting in considerable environmental damage is the process of applying insecticides and miticides (Hall, 1991). When one considers that approximately 7.5 milligrams of cypermethrin (AMMO®, CYMBUSH®) is all that is required to kill 95 percent of a population of tobacco budworms, even up to 50,000 per acre, if it were applied directly on the pest, it seems incomprehensible that we must apply over 3,500 times this much to achieve approximately 95 percent field control. In fact, it is not unusual for 50 percent of a pesticide applied with an airplane to fail to reach the intended target, the cotton plant (Willis and McDowell, 1987). In addition to the actual application process, the effectiveness of insecticides is often negatively affected by the practice of adding other pesticides, adjuvants, fertilizers and minor elements (Long *et al.*, 1992). Conversely, synergism and other interactions among pesticides occasionally result in phytotoxicity. We are greatly encouraged by the formation of an application systems research group at the USDA, ARS Jamie Whitten Delta States Research Center at Stoneville, Mississippi. This group should advance the science of application technology, which has remained almost unchanged in the United States over the past several decades.

8. CHEMICAL CONTROL AND RESISTANCE MANAGEMENT. Insecticides and acaricides historically have been the primary means of population management for arthropod pests of cotton (Newsom and Brazzel, 1968; Matthews, 1994). The principal factors contributing to the predominance of chemical control include: (a) the large arthropod pest complex which, directly or indirectly, may lower yield and quality of cotton; (b) the lack of effective biological control agents for the boll weevil, a key pest of cotton; (c) the rapid action and efficacy of insecticides and miticides in relation to other suppression components; and (d) the relatively low cost of insecticides and miticides. Deleterious aspects of chemical control such as environmental contamination, acute and chronic toxicity to non-target organisms, pest inducement and resurgence, and insecticide resistance remain as serious constraints.

The continued availability of effective and economical insecticides and acaricides is in question because of: (a) the rapid development of resistance by arthropods to chemicals used for their control (Georghiou, 1990); (b) the increasingly stringent and costly federal and state registration and reregistration requirements; (c) the relatively short effective patent life of new chemicals; and (d) the difficulty in discovering new leads for chemicals with novel modes of action. These developments have increased the cost of developing and registering a new chemical (current estimates range from $50 to $180 million) to such an extent that some companies are no longer active in pesticide research and development (Szczepanski, 1990). In the future, it appears that only a few very large companies will be financially able to compete in the agricultural chemical arena. This trend is already underway and the expected outcome is fewer, more expensive insecticides and acaricides.

Let us reiterate that IPM is the most logical and ecologically sound approach to arthropod population management. Because insecticides and acaricides are generally used in IPM programs only when other control measures (biological, cultural, physical and regulatory) fail to keep pest populations below acceptable thresholds, the availability of effective insecticides and acaricides is necessary for most of these programs to succeed (Phillips *et al.*, 1989; Graves, 1994). Thus, the usage of the declining arsenal of chemicals registered for control of the arthropod pests of cotton must be managed to impede resistance development (Sawicki, 1989; Leonard *et al.*, 1994). Insecticide and acaricide resistance management (IRM) must become an essential part of IPM.

Very importantly, IRM is supported by the chemical industry (Riley, 1989; Hope, 1993). The Mid-South (sometimes referred to as the Tri-State Area) and Texas insecticide resistance management plans represent the first attempts at IRM in cotton in the United States; their initial success is encouraging (Anonymous, 1986; Plapp, 1987; Graves *et al.*, 1991b). Increased research concerning the best utilization of available resources is imperative. Information on how to best use available insecticides and acaricides (*i.e.*, mixtures, alternations, mosaics, rates and timing) will be necessary to ensure effective pest control.

Novel insecticides with modes of action different from presently available chemicals or novel approaches in chemical control are desperately needed because IRM only delays resistance development in most situations. Current research thrusts on insect endocrinology (especially juvenile hormones, hormone inhibitors and biologically active peptides), entomopathogens, allelochemicals, light sensitive porphyric compounds, avermectins, nitroguanidines, pyrroles, phenylpyrazoles and spinosyns offer great hope for the future (Sparks *et al.*, 1993; Graves *et al.*, 1995). Similarly, recent biotechnological breakthroughs in genetic engineering that permit incorporation of foreign genes into insects and plants present new opportunities in arthropod pest management. An excellent example is the development of cotton varieties expressing the gene for *Bacillus thuringiensis* (Bt) (Perlak *et al.*, 1990). Bt cotton has been shown to give excellent control of tobacco budworm, bollworm and pink bollworm (Jenkins *et al.*, 1993).

SUMMARY

Integrated pest management (IPM) is the most logical, ecologically and environmentally, approach for insect population management now and for the foreseeable future. IPM must be based on coordinated use of multiple tactics to keep insect and mite pest damage below economic threshold. Because insecticides are primarily used in IPM programs when other control measures (biological, cultural, physical and regulatory) fail to keep pest populations below acceptable thresholds, the availability of effective insecticides and acaricides is necessary for most of these programs to succeed. However, total dependence on insecticides and acaricides or any other single approach for long term insect management is unrealistic.

Cotton IPM of necessity will be different in the future when one considers: (a) the dynamic nature of cotton production systems; (b) the ever present threat of insecticide and acaricide resistance; (c) the slow rate of development and registration of new, efficacious insecticides and acaricides; (d) the general public expectations for an abundant supply of a variety of wholesome food and quality fiber; (e) the incredibly complex and self-serving national and international political systems dictating agricultural program development; (f) the environmental concerns such as endangered species, water quality, worker protection, and wetlands; and (g) the improvement of plants and animals by genetic engineering.

Some important ancillary issues that will shape IPM in the future are: (a) funding for IPM and agricultural production research; (b) training of IPM practitioners; (c) emphasis on interdisciplinary research; (d) advent of private agricultural consultants; and (e) the roles of the land grant university system, the cooperative extension service, and the federal research and extension programs.

Some present constraints on IPM that provide great challenges for refinement of future IPM programs are: (a) inadequate and inefficient insect and mite sampling procedures; (b) poorly defined economic injury levels; (c) lack of areawide insect population management programs; (d) insufficient information on crop productions systems; (e) lack of knowledge of insect migration and dispersal; (f) underutilization of host plant resistance; (g) antiquated application technology; (h) loss of insecticides due to resistance, regulation, cost of development and difficulty in discovering new insecticidal and acaricidal chemistry; and (i) lack of acceptance of insecticide and acaricide resistance management strategies.

The challenges facing insect and mite management in cotton in the future will be numerous and difficult to surmount. However, we remain optimistic that all challenges will serve as great opportunities to improve and refine present management systems.

LITERATURE CITED

Abdel-Bary, A. A., S. M. Hassan, and K. Mohamed. 1968. Susceptibility of some cotton varieties to insect infestation. I. Infestation by thrips. Cotton Grow. Rev. 45: 296-305.

Abdel-Gawaad, A. A. W., F. H. El-Gayar, A. S. Soliman, and O. A. Zaghlool. 1973. Studies on *Thrips tabaci* Lindeman. X. Mechanisms of resistance to *Thrips tabaci* L. in cotton varieties. Z. Angew. Entomol. 73: 251-255.

Ables, J. R., J. L. Goodenough, A. W. Hartstack, and R. L. Ridgway. 1983. Entomophagous arthropods, pp. 103-128. *In* R. L. Ridgway, E. P. Lloyd, and W. H. Cross (eds.), Cotton Insect Management with Special Reference to the Boll Weevil. USDA Agr. Handb. No. 589.

Ables, J. R., S. L. Jones, and D. W. McCommas Jr. 1978. Response of selected predator species to different densities of *Aphis gossypii* and *Heliothis virescens* eggs. Environ. Entomol. 7: 402-404.

Ables, J. R., B. G. Reeves, R. K. Morrison, R. E. Kinzer, S. L. Jones, R. L. Ridgway, and D. L. Bull. 1979. Methods for the field release of insect parasites and predators. Trans. ASAE 22: 59-62.

Abro, G. H., R. A. Dybas, A. St J. Green, and D. J. Wright. 1988. Toxicity of avermectin B1 against a susceptible laboratory strain and an insecticide-resistant strain of *Plutella xylostella* (Lepidoptera: Plutellidae). J. Econ. Entomol. 81: 1575-1580.

Abu-El-Haj, S., M. A. H. Fahmy, and T. R. Fukuto. 1979. Insecticidal activity of 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane (DDT) analogues. J. Agric. Food Chem. 27: 258-260.

Adams, C. H., W. H. Cross, and H. C. Mitchell. 1969. Biology of *Bracon mellitor*, a parasite of the boll weevil. J. Econ. Entomol. 62: 889-895.

Adams, C. J., C. A. Beasley, and T. J. Henneberry. 1987. Pink bollworm spring emergence related to weather parameters, pp. 276-281. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Adams, J. R., E. A. Stadelbacher, and G. J. Tompkins. 1979. A new virus-like particle isolated from the cotton bollworm *Heliothis zea*. 37th Ann. Proc. Electron Microscopy Soc. Amer. 52-53.

Adams, M. E. 1986. Altering insect brain chemistry, pp. 163. *In* USDA Yearbook of Agriculture.

Adams, M. E., and T. A. Miller. 1979. Site of action of pyrethroids: Repetitive "backfiring" in flight motor units of house fly. Pestic. Biochem. Physiol. 11: 218-231.

Adams, M. E., and T. A. Miller. 1980. Neural and behavioral correlates of pyrethroid and DDT-type poisoning in the house fly, *Musca domestica* L. Pestic. Biochem. Physiol. 13: 137-147.

Addor, R. W., T. J. Babcock, B. C. Black, D. G. Brown, R. E. Diehl, J. A. Furch, V. Kameswaran, V. M. Kambl, K. A. Kremer, D. G. Kuhn, J. B. Lovell, G. T. Lowen, T. P. Miller, R. M. Peevey, J. K. Siddens, M. F. Treacy, S. H. Trotto, and D. P. Wright Jr. 1992. Insecticidal pyrroles: Discovery and overview, pp. 283-297. *In* D. R. Baker, J. G. Fenyes, and J. J. Steffens (eds.), Synthesis and Chemistry of Agrochemicals III. American Chemical Society, Washington, D.C.

Adkisson, P. L. 1962. Timing of defoliants and desiccants to reduce populations of the pink bollworm in diapause. J. Econ. Entomol. 55: 949-951.

Adkisson, P. L. 1964. Comparative effectiveness of several insecticides for controlling bollworms and tobacco budworms. Tex. Agr. Exp. Sta. MP. 709.

Adkisson, P. L. 1965. Present status of insecticide resistance in certain geographical populations of bollworms in Texas. Tex. Agric. Exp. Stn. PR-2358.

Adkisson, P. L. 1968. Development of resistance by the tobacco budworm to endrin and carbaryl. J. Econ. Entomol. 61: 37-40.

Adkisson, P. L. 1969. How insects damage crops, pp. 155-164. *In* How crops grow — a century later. Conn. Agr. Exp. Stn. Bull. 708.

Adkisson, P. L. 1986. Integrated pest management. Bull. Entomol. Soc. Amer. 32: 136-141.

Adkisson, P. L., C. F. Bailey, and R. L. Hanna. 1964a. Effect of the bollworm, *Heliothis zea* on yield and quality of cotton. J. Econ. Entomol. 57: 448-450.

Adkisson, P. L., R. J. Hanna, and C. F. Bailey. 1964b. Estimates of the numbers of *Heliothis* larvae per acre in cotton and their relation to the fruiting cycle and yield of the host. J. Econ. Entomol. 57: 657-663.

Adkisson, P. L., C. F. Bailey, and A. Niles. 1966. Internal clocks and insect diapause. Science 154: 234-241.

Adkisson, P. L., and S. J. Nemec. 1966. Comparative effectiveness of certain insecticides for killing bollworms and tobacco budworms. Texas Agric. Exp. Sta. Bull. 1048.

Adkisson, P. L., and S. J. Nemec. 1967. Effectiveness of certain organophosphorus insecticides against chlorinated hydrocarbon-resistant bollworm and tobacco budworm larvae. J. Econ. Entomol. 60: 268-270.

Adkisson, P. L., and S. J. Nemec. 1967. Insecticides for controlling the bollworm, tobacco budworm and boll weevil. Tex. Agric. Exp. Stn. MP-837.

Adkisson, P. L., G. A. Niles, J. K. Walker, L. S. Bird, and H. B. Scott. 1982. Controlling cotton's insect pests: a new system. Science 216: 19-22.

Adkisson, P. L., O. T. Robertson, and L. C. Fife. 1962. Planting date as a factor involved in pink bollworm control, pp. 16-20. *In* D. F. Martin, and R. D. Lewis (eds.), A summary of recent research basic to the cultural control of pink bollworm. TAEX MP-579.

Adkisson, P. L., E. S. Vanderzant, D. L. Bull, and W. E. Allison. 1960. A wheat germ medium for rearing the pink bollworm. J. Econ. Entomol. 53: 759-761.

Agee, H. R. 1986. Laboratory-reared boll weevils (Coleoptera: Curculionidae) are visually impaired. J. Econ. Entomol. 79: 900-902.

Agnew, C. W., and W. L. Sterling. 1981. Predation of boll weevils in partially-open cotton bolls by the red imported fire ant. Southwest. Entomol. 6: 215-219.

Agnew, C. W., and W. L. Sterling. 1982. Predation rates of the red imported fire ant on eggs of the tobacco budworm. Prot. Ecol. 4: 151-158.

Agnew, C. W., W. L. Sterling, and D. A. Dean. 1981. Notes on the Chrysopidae and Hemerobiidae of Eastern Texas with keys for their identification. Southwest. Entomol. Suppl. 4: 1-20.

Agnew, C. W., W. L. Sterling, and D. A. Dean. 1982. Influence of cotton nectar on red imported fire ants and other predators. Environ. Entomol. 11: 629-634.

Agudelo, F., and L. A. Falcon. 1977. Some naturally occurring insect pathogens in Colombia. Turrialba 27: 423-424.

Ahouissoussi, N., M. Wetzstein, and P. Duffy. 1993. Economic returns to the boll weevil eradication program. J. Agric. Appl. Econ. 25:

Akesson, N. B., and R. Gibbs. 1988. Precision and safety with PARIS: Some basic challenges for areial application. NAAA-ASAE 88-8008:

Akesson, N. B., and W. E. Yates. 1974. The use of aircraft in agriculture. Food and Agriculture Organization of the United Kingdom, Rome, Italy.

Akhurst, R. J., and W. M. Brooks. 1984. The distribution of entomophilic nematodes (Heterorhabditidae and Steinernematidae) in North Carolina. J. Invertebr. Pathol. 44: 140-145.

Albertos, S. C. 1974. Studies on diapause induction and development of the pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae), under controlled conditions. Ph.D. Thesis, University of California, Riverside.

Aldrich, J. R. 1985. Pheromone of a true bug (Hemiptera-Heteroptera): Attractant for the predator, *Podisus maculiventris*, and kairomonal effects, pp. 95-119. *In* T. E. Acree, and D. M. Soderlund (eds.), Semiochemistry: Flavors and Pheromones. de Gruyter, Berlin.

Aldrich, J. R. 1988a. Chemical ecology of the Heteroptera. Annu. Rev. Entomol. 33: 211-238.

Aldrich, J. R. 1988b. Chemistry and biological activity of pentatomoid sex pheromones, pp. 417-431. *In* H. G. Cutler (ed.), Biologically active natural products: potential use in agriculture. ACS symposium series no. 380. American Chemical Society, Washington, DC.

Aldrich, J. R. 1995. Chemical communication in the true bugs and parasitoid exploitation, pp. 318-363. *In* R. T. Carde, and W. J. Bell (eds.), Chemical ecology of insects II. Chapman and Hall, New York.

Aldrich, J. R., M. S. Blum, H. A. Lloyd, and H. M. Fales. 1978. Pentatomid natural products: chemistry and morphology of the III-IV dorsal abdominal glands of adults. J. Chem. Ecol. 4: 161-172.

Aldrich, J. R., J. P. Kochansky, and C. B. Abrams. 1984. Attractant for a beneficial insect and its parasitoids: pheromone of the predatory spined soldier bug, *Podisus maculiventris* (Hemiptera: Pentatomidae). Environ. Entomol. 13: 1031-1036.

Aldrich, J. R., W. R. Lusby, B. E. Marron, K. C. Nicolaou, M. P. Hoffmann, and L. T. Wilson. 1989. Pheromone blends of green stink bugs and possible parasitoid selection. Naturwissenschaften 76: 173-175.

Aldrich, J. R., J. E. Oliver, W. R. Lusby, J. P. Kochansky, and J. A. Lockwood. 1987. Pheromone strains of the cosmopolitan pest, *Nezara viridula* (Heteroptera: Pentatomidae). J. Exp. Zool. 244: 171-175.

Alfiere, A. 1929. The introduction of a parasite [*Microbracon kirkpatricki* (Wilk.)] of the pink bollworm into Egypt. Soc. Roy. Entomol. d'Egypte Bull. 1928: 52-56.

Allen C.T., and J. W. Norman Jr. 1982 - 1983. Management of cotton insects in the Lower Rio Grande Valley of Texas. Tex. Agric. Ext. Serv. B-1210.

Allen, C.T, W. Multer, and P. Glogoza. 1985. Pink bollworm management program in Texas. Texas Agric. Ext. Ser. Bull. 1151.

Allen, C. T., W. L. Multer, R. R. Minzenmayer, and J. S. Armstrong. 1987. Development of pyrethroid resistance in *Heliothis* populations in cotton in Texas, pp. 332-335. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Allen, C. T., and J. W. Norman Jr. 1982. Management of cotton insects in the Lower Rio Grande Valley of Texas. Texas Agric. Ext. Serv., B-1210.

Allen, C. T., and J. W. Norman Jr. 1983. Management of cotton insects in the Lower Rio Grande Valley of Texas. Texas Agric. Ext. Serv. B-1210.

Allen, G. E., B. G. Gregory, and J. R. Brazzel. 1967. Field evaluation of the *Heliothis* nuclear polyhedrosis virus into a biololgical control program for cotton. J. Econ. Entomol. 59: 1333-1336.

Allen, G. E., B. G. Gregory, and T. L. Pate. 1967. Field evaulation of a nuclear-polyhedrosis virus in the control of *Heliothis zea* and *Heliothis virscens* on cotton. J. Invertebr. Pathol. 9: 40-42.

Allen, R. M., H. Tucker, and T. A. Wilson. 1960. Leaf crumple virus disease of cotton in Arizona. Plant Dis. Rep. 44: 246-250.

Almand, L. K., W. L. Sterling, and C. L. Green. 1976. Seasonal abundance and dispersal of cotton fleahopper as related to host plant phenology. Texas Agr. Exp. Sta. Bull. 1170.

Altieri, M. A., W. J. Lewis, D. A. Nordlund, R. C. Gueldner, and J. W. Todd. 1981. Chemical interactions between plants and *Trichogramma* sp. wasps in Georgia soybean fields. Protection Ecology 3: 259-263.

Altman, D. W., D. M. Stelly, and R. J. Kohel. 1987. Introgression of the glanded-plant and glandless-seed trait from *Gossypium sturtianum* Willis into cultivated upland cotton using ovule culture. Crop. Sci. 27: 880-884.

Ames, B. N. 1989a. Mutagenesis and carcinogensis: Endogenous and exogenous factors. Environ. Mol. Mutagenesis 14 (Suppl. 16): 66-78.

Ames, B. N. 1989b. Endogenous oxidative DNA damage, aging, and cancer. Free Rad. Res. Comm. 7: 121-127.

Anderson, J. M., R. R. Bridge, A. M. Heagler, and G. R. Tupper. 1976. The economic impact of recently developed early season cotton strains on firm and regional cropping systems and income, pp. 98-100. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Anderson, M. I. 1986. Low and slow. Calif. Farmer Publ., Co., San Francisco.

Anderson, R. A., and M. F. Schuster. 1983. Phenology of the tarnished plant bug on natural host plants in relation to populations in cotton. Southwest. Entomol. 8: 131-136.

Anderson, T. E. 1984. Distribution of the European corn borer, *Ostrinia nubilalis* (Hubner) (Lepidoptera: Pyralidae) as related to oviposition preference of the spring-colonizing generation in eastern North Carolina. Environ. Entomol. 13: 248-251.

Anderson, T. E., J. R. Babu, R. A. Dybas, and H. Mehta. 1986. Avermectin B1: Ingestion and contact toxicity against *Spodoptera eridana* and *Heliothis virescens* (Lepidoptera: Noctuidae) and potentiation by oil and piperonyl butoxide. J. Econ. Entomol. 79: 197-201.

Andrawes, N. R., and H. W. Dorough. 1967. Metabolic fate of carbaryl-naphthyl-C14 in boll weevils and bollworms. J. Econ. Entomol. 60: 453-456.

Andreadis, T. G. 1987. Transmission, pp. 159-176. *In* J. R. Fuxa, and Y. Tanada (eds.), Epizootiology of insect diseases. John Wiley & Sons, Inc., New York.

Andres, L. A. 1957. An ecological study of three species of *Tetranychus* (Acarina: Tetranychidae) and their response to temperature and humidity. Ph.D. dissertation, University of California, Berkeley.

Andres, L. A., V. E. Burton, R. F. Smith, and J. E. Swift. 1955. DDT tolerance by lygus bugs on seed alfalfa. J. Econ. Entomol. 58: 509-513.

Andrews, G. L. 1981. Optimum insect management trial, pp. 41-44. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Andrews, G. L., F. A. Harris, P. P. Sikorowski, and R. E. McLaughlin. 1975. Evaluation of *Heliothis* nuclear polyhedrosis virus in a cottonseed oil bait for control of *Heliothis virescens* and *H. zea* on cotton. J. Econ. Entomol. 68: 87-90.

Andries, J. A., J. E. Jones, L. W. Sloane, and J. G. Marshall. 1970. Effects of super okra leaf shape on boll rot, yield, and other characters of upland cotton, *Gossypium hirsutum* L. Crop. Sci. 10: 403-407.

Angus, T. A., and P. Luthy. 1971. Formulations of microbial insecticides, pp. 623-636. *In* H. D. Burgess, and N. W. Hussey (eds.), Microbial control of insects and mites. Academic Press, London.

Anisimov, A. I. 1988. Investigations on sex linked recesssive lethal mutations as a possible mechanism for the genetic control of lepidopterous pests, pp. 65-76. *In* Modern insect control: nuclear techniques and biotechnology. Proc. Symp. Vienna, 1987, IAEA Vienna.

Anonymous. 1901. Save the cotton crop. Kill the boll weevils. Circular of the Eagle Printing Company. (June 1, 1901)

Anonymous. 1947-1987. Annual Conference Report on Cotton Insect Research and Control. USDA, ARS Vol. 1-40.

Anonymous. 1958. A report of the findings and a detailed supplemental statement on the boll weevil problem and research and facility needs to meet the problem. Prepared by The Working Group on Boll Weevil Research Problems appointed by The Office of Secretary, USDA in response to congressional requests for a report and proposals.

Anonymous. 1975. Pest control: an assessment of present and alternative technologies. I. Contemporary pest control practices and prospects: the report of the executive committee. National Academy Sciences, Washington, D.C.

Anonymous. 1976. Aerial application of agricultural chemicals. Mississippi Cooperative Extension Service. 973:25, Miss. State, MS.

Anonymous. 1977. Review of the pink bollworm program. USDA Task Force, USDA Plant Protection and Quarantine, Animal and Plant Health Inspection Service.

Anonymous. 1981. Biological evaluation report (Appendix A). Beltwide boll weevil/control insect management programs. USDA, Science and Education Administration, Washington, DC.

Anonymous. 1981. Possibilities for the use of biotic agents in the control of the whitefly, *Bemisia tabaci*. Biocontrol News and Information 2: 1-7.

Anonymous. 1981. The delphi: insecticide use and lint yields. Appendix E. USDA Economic Research Service, ERS Staff Report AGESS 810507.

Anonymous. 1982. Oklahoma Agriculture 2000 Report. Oklahoma State University, pp. 142-143.

Anonymous. 1984a. 37th Annual Conference Report on Cotton Insect Research and Control. USDA, ARS.

Anonymous. 1984b. Integrated pest management for cotton in the Western Region of the United States. Univ. of Calif., Berkeley, Div. Agric. Sci., Publ. 3305.

Anonymous. 1986. Cotton entomologists seek to delay pyrethroid resistance in insects. MAFES Res. Highlights 49: 8.

Anonymous. 1988. Cotton management guide. Rhone-Poulenc Agricultural Company, 2 T.W. Alexander Drive, Research Triangle Park, N.C.

Anonymous. 1988. Farm chemicals handbook. Meister Publishing, Salem.

Anonymous. 1989. The great boll weevil conspiracy. Agrichemical Age 6-7.

Anonymous. 1990a. Timing is of the essence. Agrichemical Age 34: 16.

Anonymous. 1990b. News. Agrichemical Age 34: 20.

Antle, J. M. 1983. Sequential decision making in production models. Amer. J. Agr. Econ. 65: 282-290.

Argenine, J. A., J. M. Clark, and H. Lin. 1992. Genetics and biochemical mechanisms of abamectin resistance in two isogenic strains of Colorado potato beetle. Pestic. Biochem. Physiol. 44: 191-207.

Armes, N. J., D. Jadhav, G. Bond, and A. King. 1992. Insecticide resistance in *Helicoverpa armigera* in South India. Pestic. Sci. 34: 355-364.

Arnaud Jr., P. H. 1968. A host-parasite catalog of North American Tachinidae (Diptera). Misc. Pub. 1319.

Arthur, F. H., and J. L. Zettler. 1991. Malathion resistance in *Tribolium castaneum* (Coleoptera: Tenebrionidae): Difference between discriminating concentration by topical applications and residual mortality on treated surfaces. J. Econ. Entomol. 84: 721-726.

Aruga, H. 1971. Cytoplasmic polyhedrosis of the silkworm—historical, economical and epizootiological aspects, pp. 3-21. *In* H. Aruga, and Y. Tanada (eds.), The cytoplasmic-polyhedrosis virus of the silkworm. University of Tokyo Press, Tokyo.

ASAE. 1983. Safety devices for applying liquid chemicals through irrigation systems. Engineering practice EP409, Agric. Engrs. Yearbook of Standards. ASAE, St. Joseph, MI.

Ashley, T. R. 1979. Classification and distribution of fall armyworm parasites. Fla. Entomol. 62: 114-123.

Askari, A., and J. M. Stern. 1972. Biology and feeding habits of *Orius tristicolor* Hemiptera (Heteroptera) Anthocoridae. Ann. Entomol. Soc. Amer. 65: 96-100.

Atim, A. B., and H. M. Graham. 1984. Predation of *Geocoris punctipes* by *Nabis alternatus*. Southwest. Entomol. 9: 227-231.

Awad, T. M., and S. B. Vinson. 1968. The pickup and penetration of ulv and emulsifiable concentrate malathion formulations by tobacco budworm larvae. J. Econ. Entomol. 61: 242-245.

Bache, D. H., and S. Uk. 1975. Transport of aerial spray. II. Transport within a crop canopy. Agric. Meteor. 15: 371-377.

Bacheler, J. S. 1988. Cotton production guide: insect scouting. CPG No. 13. January. North Carolina Agricultural Extension Service.

Bacheler, J. S. *Heliothis* management in North Carolina with subeconomic boll weevils levels, pp. 183-184. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bacheler, J. S., and J. R. Bradley Jr. 1975. Effect of temperature on development and mortality of the boll weevil egg stage. Environ. Entomol. 4: 319-320.

Bacheler, J. S., J. W. Jones, J. R. Bradley Jr., and H. O. Bowen. 1975. The effect of temperature on development and mortality of boll weevil immature stages. Environ. Entomol. 4: 808-810.

Bagwell, R. D., and N. P. Tugwell. 1992. Defining the period of boll susceptibility to insect damage in heat-units from flower, pp. 767-768. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bailey, J. C. 1981. Growth comparison of *Heliothis virescens* (F.) larvae fed white, yellow and orange pollen, pp. 79. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bailey, J. C. 1982. Influence of plant bug and leafhopper populations on glabrous and nectariless cottons. Environ. Entomol. 11: 1011-1013.

Bailey, J. C., B. W. Hanny, and W. R. Meredith Jr. 1980. Combinations of resistant traits and insecticides: effect on cotton yield and insect populations. J. Econ. Entomol. 73: 58-60.

Bailey, J. C., F. G. Maxwell, and J. N. Jenkins. 1967. Mortality of boll weevils in squares of genotypically different lines of cotton. J. Econ. Entomol. 60: 1279-1280.

Bailey, J. C., A. L. Scales, and W. R. Meredith Jr. 1984. Tarnished plant bug (Heteroptera: Miridae) nymph numbers decreased on caged nectariless cotton. J. Econ. Entomol. 77: 68-69.

Bailey, S. F. 1938. Thrips of economic importance in California. Calif. Agr. Exp. Sta. Circ. 346.

Baker, D. N., J. D. Hesketh, and W. G. Duncan. 1972. Simulation of growth and yield in cotton. I. Gross photosynthesis, respiration, and growth. Crop. Sci. 12: 431-435.

Baker, D. N., J. R. Lambert, and J. M. McKinion. 1983. GOSSYM: a simulator of cotton crop growth and yield. S. C. Agric. Exp. Stn. Tech. Bull. 1089.

Baker, E. W., and A. E. Pritchard. 1953. A guide to the spider mites of cotton. Hilgardia 22: 203-234.

Baker, R., M. Borges, N. G. Cooke, and R. N. Herbert. 1987. Identification and synthesis of (Z)-(1'*S*,3'*R*,4'*S*)(-)-2-(3',4'-epoxy-4'-methylcyclohexyl)-6-methylhepta-2,5-diene, the sex pheromone of the southern green stinkbug, *Nezara viridula* (L.). Chem. Commun. 414-416.

Baker, T. C., R. T. Staten, and H. M. Flint. 1990. Use of pink bollworm pheromone in the southwestern United States, pp. 417-436. *In* R. L. Ridgway, R. M. Silverstein, and M. N. Inscoe (eds.), Behavior-modifying Chemicals for Insect Management: Applications of Pheromones and Other Attractants. Marcel Dekker, Inc., New York.

Baldwin, J. L., J. S. Tynes, J. B. Graves, G. Burris, and S. Micinski. 1993. Control cotton insects. Louisiana State Univ. Coop. Ext. Service Pub. 1083.

Ballard, W. W. 1951. Varietal differences in susceptibility to thrips injury in upland cotton. Agron. J. 43: 37-44.

Ballou, H. A. 1919. The poisoning of the boll weevil. Agric. News. 18: 122-123.

Bals, T. E. 1987. Economical pesticide application: the reasons for controlled droplet application, pp. 133-138. *In* G. B. Beestman and D. I. B. Vander Hooven (eds.), Pesticide formulations and application systems: Vol. 7. American Society for Testing and Materials, Philadelphia.

Banks, W. A., B. M. Glancy, C. E. Stringer, D. P. Jouvenaz, C. S. Lofgren, and D. E. Weidhaas. 1973. Imported fire ants: eradication trials with mirex bait. J. Econ. Entomol. 66: 785-789.

Barber, G. W. 1936. Method of rearing corn earworm larvae. J. Econ. Entomol. 29: 1175-1176.

Barber, G. W. 1936. *Orius insidiosus* (Say), an important natural enemy of the corn earworm. USDA Tech. Bull. 504.

Barber, G. W. 1937. Seasonal availability of food plants of two species of *Heliothis* in eastern Georgia. J. Econ. Entomol. 30: 150-158.

Barbour, K. S. 1988. *Acrosternum hilare* (Say) in cotton: a study of direct and indirect feeding damage. M.S. Thesis, North Carolina State University, Raleigh.

Barfield, C. S., P. J. H. Sharpe, and D. G. Bottrell. 1977. A temperature-driven developmental model for the parasite *Bracon mellitor* (Hymenoptera: Braconidae). Can. Entomol. 109: 1503-1514.

Bariola, L. A. 1978. Suicidal emergence and reproduction by overwintered pink bollworm moths. Environ. Entomol. 7: 189-192.

Bariola, L. A. 1983. Survival and emergence of overwintered pink bollworm moths (Lepidoptera: Gelechiidae). Environ. Entomol. 12: 1877-1881.

Bariola, L. A. 1985. Evidence of resistance to synthetic prethroids in field populations of pink bollworms in Southern California, pp. 138. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bariola, L. A., and T. J. Henneberry. 1987. Prep and Dropp for pink bollworm and boll weevil control in Arizona and Southern California, pp. 340. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bariola, L. A., T. J. Henneberry, and T. Meng Jr. 1986. Plant growth regulators for pink bollworm and boll weevil control, pp. 235-238. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bariola, L. A., J. C. Keller, D. L. Turley, and J. R. Farris. 1973. Migration and population studies of the pink bollworm in the arid West. Environ. Entomol. 2: 205-208.

Bariola, L. A., D. L. Kittock, H. F. Arle, P. V. Vail, and T. J. Henneberry. 1976. Controlling pink bollworms: effects of chemical termination of cotton fruiting on populations of diapausing larvae. J. Econ. Entomol. 69: 633-636.

Bariola, L. A., and P. D. Lingren. 1984. Comparative toxicities of selected insecticides against pink bollworm moths. J. Econ. Entomol. 77: 207-210.

Bariola, L. A., R. L. Ridgway, and J. R. Coppedge. 1971. Large scale test of soil applied aldicarb for suppression of populations of the boll weevil. J. Econ. Entomol. 64: 1289-1284.

Barker, G. L. 1982. Equation for estimating cotton preharvest losses. Trans. ASAE. Vol. 25.

Barnes, W. W., and G. W. Ware. 1965. The absorption and metabolism of C14-labeled endosulfan in the house fly. J. Econ. Entomol. 58: 286-292.

Barrow, D. N. 1894. Experiments in width of rows and distance. Louisiana Agric. Exp. Stn. Bull. 28.

Barthel, W. F. 1961. Synthetic pyrethroids. Advan. Pest Control Res. 4: 33-41.

Bartlett, A. C. 1967. Genetic markers in the boll weevil. J. Hered. 58: 159-163.

Bartlett, A. C. 1985. Guidelines for genetic diversity in laboratory colony establishment and maintenance, pp. 7-17. *In* P. Singh and R. F. Moore (eds.), Handbook of Insect Rearing. Elsevier, New York.

Bartlett, A. C. 1985. Movement and longevity of laboratory-reared pink bollworm moths. Cotton, a College of Agriculture Report, Series P-63, Coop. Ext., Agric. Exp. Stn., Univ. Arizona, Tucson.

Bartlett, A. C. 1988. Induction and use of sex linked lethal mutations in the pink bollworm, pp. 85-96. *In* Modern insect control; nuclear techniques and biotechnology. Proc. Symp. Vienna, 1987, IAEA Vienna.

Bartlett, A. C., and L. J. Lewis. 1987. Response of the pink bollworm (Lepidoptera: Gelechiidae) to long-term selection for the inability to diapause. Ann. Entomol. Soc. Amer. 80: 797-803.

Bartlett, A. C., and P. D. Lingren. 1984. Monitoring pink bollworm (Lepidoptera: Gelechiidae) populations using the genetic marker sooty. Environ. Entomol. 13: 543-550.

Bartlett, A. C., W. C. Randall, and J. E. May. 1983. Allozyme variation among populations of boll weevils in Arizona and Mexico. Southwest. Entomol. 8: 118-130.

Bartlett, A. C., and W. W. Wolf. 1985. *Pectinophora gossypiella*, pp. 415-430. *In* P. Singh, and R. F. Moore (eds.), Handbook of Insect Rearing, Vol. 2 Elsevier, New York.

Bartlett, B. R. 1956. Natural predators. Can selective insecticides help to preserve biotic control? Agric. Chem. 11: 42-44, 107-109.

Batko, A. 1964. On the new genera: *Zoophthora* gen. nov., *Triplosporium* (Thaxter) gen. nov., and *Entomophaga* gen. nov. (Phycomycetes: Entomophthoraceae). Bull. Polon. Acad. Sci. Ser. Sci. Biol. 12: 323-326.

Baumhover, A. J. 1966. Eradication of the screwworm fly, an agent of myiasis. J. Amer. Med. Assoc. 196: 240-248.

Beards, G. W., and F. E. Strong. 1966. Photoperiod in relation to diapause in *Lygus hesperus* Knight. Hilgardia 37: 345-362.

Beasley, C. A. 1990. Effects of extent and time of irrigations on winter survival and spring emergence patterns of pink bollworm, pp. 186-189. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Beasley, C. A. 1991. Winter irrigation reduces spring emergence of pink bollworm moths, pp. 943-944. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Beasley, C. A., T. J. Henneberry, C. Adams, and L. Yates. 1985. Gossyplure-baited traps as pink bollworm survey, detection, research and management tools in southwestern desert cotton growing areas. Calif. Agric. Exp. Sta. Bull. 1915.

Beck, S. D., and F. G. Maxwell. 1976. Use of plant resitance. *In* C. B. Huffaker, and P. S. Messenger (eds.), Theory and practice of biological control. Academic Press, New York.

Beckham, C. M. 1957. Hibernation sites of the boll weevil in relation to a small, Georgia Piedmont cotton field. J. Econ. Entomol. 50: 833-834.

Beckham, C. M. 1963. Seasonal occrrence of hibernation in the boll weevil. Mimeograph Series N.S. 164, Univ. Ga., Ga. Agric. Exp. Stn.

Beckham, C. M. 1970. Effect of nitrogen fertilization on the abundance of cotton insects. J. Econ. Entomol. 63: 1219-1220.

Beckham, C. M. 1970. Influence of systemic insecticides on thrips control and yield of cotton. J. Econ. Entomol. 58: 1118-22.

Beckham, C. M., and L. W. Morgan. 1960. On the flight distance of the boll weevil. J. Econ. Entomol. 53: 681-682.

Beegle, C. C., H. T. Dulmage, D. A. Wolfenbarger, and E. Martinez. 1981. Persistence of *Bacillus thuringiensis* Berliner insecticidal activity on cotton foliage. Environ. Entomol. 10: 400-401.

Beevers, M., W. J. Lewis, H. R. Gross Jr., and D. A. Nordlund. 1981. Kairomones and their use for management of entomophagous insects: X. Laboratory studies on manipulation of host-finding behavior of *Trichogramma pretiosum* Riley with a kairomone extracted from *Heliothis zea* (Boddie) moth scales. J. Chem. Ecol. 7: 635-648.

Bell, A. A., and R. D. Stipanovic. 1977. The chemical composition, biological activity and genetics of pigment glands in cotton, pp. 244. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bell, A. A., R. D. Stipanovic, C. R. Howell, and M. E. Mace. 1974. Terpenoid aldehydes of *Gossypium*: isolation, quantitation, and occurrence, pp. 40-41. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bell, K. O., and W. H. Whitcomb. 1964. Field studies on egg predators of the bollworm, *Heliothis zea* (Boddie). Fla. Entomol. 47: 171-180.

Bell, M. R. 1983. Microbial agents, pp. 129-151. *In* R. L. Ridgway, E. P. Lloyd, and W. H. Cross (eds.), Cotton Insect Management with Special Reference to the Boll Weevil. USDA Agr. Handb. No. 589.

Bell, M. R., and T. J. Henneberry. 1980. Entomopathogens for pink bollworm control, pp. 76-81. *In* H. M. Graham (ed.), Pink bollworm control in the Western United States. USDA, ARM-W-16.

Bell, M. R., and R. F. Kanavel. 1975. Potential of bait formulations to increase effectiveness of nuclear polyedrosis virus against the pink bollworm. J. Econ. Entomol. 68: 389-391.

Bell, M. R., and R. F. Kanavel. 1977. Field tests of a nuclear polyhedrosis virus in a bait formulation for control of pink bollworm and *Heliothis* spp. on cotton in Arizona. J. Econ. Entomol. 70: 625-629.

Bell, M. R., and R. F. Kanavel. 1978. Tobacco budworm: development of a spray adjuvent to increase effectiveness of a nuclear polyhedrosis virus. J. Econ. Entomol. 71: 350-352.

Bell, M. R., and C. L. Romine. 1980. Tobacco budworm: Field evaluation of microbial control in cotton using *Bacillus thuringiensis* and a nuclear polyhedrosis virus with a feeding stimulant. J. Econ. Entomol. 73: 427-430.

Bell, M. R., and C. L. Romine. 1982. Cotton leafperforator: effect of two microbial insecticides on field populations. J. Econ. Entomol. 75: 1140-1142.

Bell, M. R., and C. L. Romine. 1986. *Heliothis virescens* and *H. zea*: Dosage effects of feeding mixtures of *Bacillus thuringiensis* and a nuclear polyhedrosis virus on mortality and growth. Environ. Entomol. 15: 1161-1165.

Bellows Jr., T. S., T. M. Perring, R. J. Gill, and D. H. Headrick. 1994. Description of a species of *Bemisia* (Homoptera: Aleyrodidae). Ann. Entomol. Soc. Am. 87: 195-206.

Benedict, J. H., D. W. Altman, E. S. Sachs, W. R. Deaton, and D. R. Ring. 1991. Field performance of cotton genetically-modified to express insecticidal protein from *Bacillus thuringiensis*. III. College Station, TX, pp. 577. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Benedict, J. H., D. W. Altman, P. F. Umbeck, and D. R. Ring. 1992. Behavior, growth, survival, and plant injury by *Heliothis virescens* (F.) (Lepidoptera: Nocutidae) on transgenic *B t* cottons. J. Econ. Entomol. 85: 589-593.

Benedict, J. H., K. M. El-Zik, L. R. Oliver, P. A. Roberts, and L. T. Wilson. 1989. Economic injury levels and thresholds for pests of cotton, pp. 121-153. *In* R. E. Frisbie, K. M. El-Zik, and L. T. Wilson (eds.), Integrated Pest Management Systems and Cotton Production. John Wiley and Sons, New York.

Benedict, J. H., A. H. Hyer, T. F. Leigh, and W. M. Tingey. 1982. Evaluations of various cottons for resistance to *Lygus hesperus* Knight. USDA-ARS-ARM-W-33.

Benedict, J. H., J. A. Landivar, B. R. Eddleman, D. R. Ring, A. W. Hartstack, and W. L. Sterling. 1991. ICEMM, an integrated crop ecosystem management model: Insect pest component, pp. 458-459. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Benedict, J. H., T. F. Leigh, J. L. Frazier, and A. H. Hyer. 1981. Ovipositional behavior of *Lygus hesperus* on two cotton genotypes. Ann. Entomol. Soc. Amer. 74: 392-394.

Benedict, J. H., T. F. Leigh, A. H. Hyer, and P. F. Wynholds. 1981. Nectariless cotton: effect of growth, survival, and fecundity of *Lygus* bugs. Crop. Sci. 21: 28-30.

Benedict, J. H., M. F. Treacy, D. W. Altman, and K. M. Schmidt. 1987. Preference of boll weevils and tobacco budworms for five species of *Gossypium*, pp. 92-93. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Benedict, J. H., M. F. Treacy, D. R. Ring, and G. C. Yencho. 1992. Behavior of pyrethroid-susceptible and -resistant *Heliothis virescens* (F.) (Lepidoptera, Noctuidae) larvae on cotton treated with insecticides. J. Econ. Entomol. 85: 2058-2063.

Benedict, J. H., T. C. Urban, D. M. George, J. C. Segars, D. J. Anderson, G. M. McWhorter, and G. R. Zummo. 1985. Pheromone trap thresholds for management of overwintered boll weevils (Coleoptera: Curculionidae). J. Econ. Entomol. 78: 169-171.

Bennett, R. L. 1904. Early cotton. Texas Agric. Exp. Stn. Bull. 75.

Bennett, R. L. 1908. A method of breeding early cotton to escape boll weevil damage. USDA Farmers' Bull. 314.

Bennett, R. S., E. K. Klaas, J. R. Coats, M. A. Mayse, and E. J. Kolbe. 1983. Fenvalerate residues in non-target organisms from Texas cotton fields. Bull. Environ. Toxicol. 31: 61-65.

Benschoter, C. A., and M. P. Leal. 1974. Relation of cotton plant nectar to longevity and reproduction of the cotton leaf perforator in the laboratory. J. Econ. Entomol. 67: 217-218.

Berger, R. S. 1963. Laboratory techniques for rearing *Heliothis* spp. on artificial medium. USDA,ARS 33-84.

Berger, R. S., J. M. McGough, and D. F. Martin. 1965. Sex attractants of *Heliothis zea* and *H. virescens*. J. Econ. Entomol. 58: 1023-1024.

Bergman, D., T. J. Henneberry, and L. A. Bariola. 1981. Overwintering and seasonal development of the pink bollworm in Arizona stub and planted cotton, pp. 66-69. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bergman, D., T. J. Henneberry, and L. A. Bariola. 1982. Distribution of the boll weevil in southwestern Arizona cultivated cotton from 1978-1981, pp. 204-207. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bergman, D., T. J. Henneberry, and L. A. Bariola. 1983. Overwintering boll weevil populations in southwestern Arizona cultivated cotton, pp. 182-185. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bergman, D., T. J. Henneberry, L. A. Bariola, and J. M. Gillespie. 1983. Studies of pest and beneficial insects in Arizona stub and planted cotton. USDA, Agric. Res. Serv., ARS Res. Results, ARR-W-32.

Bergold, G. H. 1963. The nature of nuclear-polyhedrosis viruses, pp. 413-456. *In* E. A. Steinhaus (ed.), Insect pathology, an advanced treatise, Vol. 1. Academic Press, New York.

Berlinger, M. J. 1986. Host plant resistance to *Bemisia tabaci*. Agric. Ecosys. Environ. 17: 69-82.

Berlinger, M. J., Z. Magel, and A. Benzioni. 1983. The importance of pH in food selection by the tobacco whitefly, *Bemisia tabaci*. Phytoparasitica 11: 151-160.

Bernhardt, J. L., J. R. Phillips, and N. P. Tugwell. 1986. Position of the uppermost white bloom defined by node counts as an indicator for termination of insecticide treatments in cotton. J. Econ. Entomol. 79: 1430-1438.

Berry, J. S., W. P. Kemp, and J. A. Onsager. 1991. Integration of simulation models and an expert system for management of rangeland grasshoppers. AI Applications 5: 1-14.

Berry, P. A. 1947. *Anthonomus vestitus* and its natural enemies in Peru, and their importation into the United States. J. Econ. Entomol. 40: 801-804.

Berryman, A. A. 1991. Population theory: an essential ingredient in pest predicion, management and policy making. Am. Entomol. 37: 138-142.

Berstein, C. 1984. Prey and predator emigration responses in the acarine system *Tetranychus urticae-Phytoseiulus persimilis*. Oecologia 61: 134-142.

Bhardwaj, H. L., and J. B. Weaver Jr. 1983. Bollworm resistance in red leaf cotton, pp. 117-119. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bhat, M. G., A. B. Joshi, and M. Singh. 1981a. Possibility of breaking association between hairiness and jassid (*Amrasca devastans* Distant) resistance in cotton (*Gossypium hirsutum* L.). Indian J. Agric. Res. 15: 236-240.

Bhat, M. G., A. B. Joshi, S. L. Mehta, and M. Singh. 1981b. Biochemical basis of resistance to jassid in cotton. Crop. Improv. 8: 1-6.

Bhat, M. G., A. B. Joshi, and M. Singh. 1982. Hairiness in relation to resistance to jassid (*Amrasca devastans* Distant) and other insect pests and quality characters in cotton (*Gossypium* spp.)—a review. Agric. Rev. 3: 1-8.

Bhatkar, A. P. 1988. Confrontation behavior between *Solenopsis invicta*, *S. geminata*, and competitiveness of certain Florida ant species against *S. invicta*, pp. 445-464. *In* J. C. Trager (ed.), Advances in Myrmecology. E. J. Brill, Leiden.

Bhatkar, A. P. 1989. Ecology and population structure of the imported fire ant, pp. 24-29. *In* S. B. Vinson, and J. Teer (eds.), The imported fire ant - assessment and recommendations. SCOT (Sportsmen Conservationist of Texas), Austin, Texas.

Bibby, F. F. 1942. Some parasites of *H. armigera* (Hbn.) in Texas. J. Econ. Entomol. 35: 943-944.

Bickley, W. E., and E. G. MacLeod. 1956. A synopsis of the Nearctic Chrysopidae with a key to the genera. Proc. Entomol. Soc. Wash. 58: 177-202.

Bierl, B. A., M. Beroza, R. T. Staten, P. E. Sonnet, and V. E. Adler. 1974. The pink bollworm sex attractant. J. Econ. Entomol. 67: 211-216.

Bigley, W. S., and F. W. Plapp. 1978. Metabolism of *cis-* and *trans-*(C14) permethrin by the tobacco budworm and the bollworm. J. Agric. Food Chem. 26: 1128-1134.

Bilimoria, S. L. 1986. Ultrastructure of baculoviruses, pp. 37-60. *In* R. R. Granados, and B. A. Federici (eds.), The biology of Baculoviruses, Vol. I. CRC Press, Inc., Boca Raton.

Bindra, O. S. 1985. Relation of cotton cultivars to the cotton-pest problem in the Sudan Gezira. Euphytica 34: 849-856.

Bird, F. T., and M. M. Whalen. 1953. A virus disease of the European pine sawfly, *Neodiprion sertifer* (Geoffr.). Can. Entomol. 85: 433-437.

Bird, L. S. 1975. Tamcot SP21, SP23, SP37 cotton varieties. Texas Agr. Exp. Sta. L. 1351.

Bird, L. S. 1979. Registration of TAMCOT CAMD-E cotton. Crop Sci. 19: 411-412.

Bird, L. S. 1985. Host resistance and its management in cotton, pp. 493-511. *In* R. E. Frisbie and P. L. Adkisson (eds.), Integrated Pest Management on Major Agricultural Systems. Texas Agric. Expt. Sta. MP-1616.

Bird, L. S., K. M. El-Zik, and P. M. Thaxton. 1986. Registration of (Tamcot CAB-CS) upland cotton. Crop. Sci. 26: 384-385.

Bird, L. S., K. M. El-Zik, and P. M. Thaxton. 1988. Registration of 'Tamcot CD3H' cotton. Crop. Sci. 28: 574-575.

Bird, L. S. 1976. Registration of TAMCOT SP21, TAMCOT SP23, and TAMCOT SP37 cottons. Crop. Sci. 16: 884.

Birito, R. M., M. S. Vernon, and F. V. Sances. 1986. Physiological response of cotton plants to feeding of three *Tetranychus* spider mite species (Acari: Tetranychidae). J. Econ. Entomol. 79: 1217-1220.

Bishopp, F. C., and C. R. Jones. 1907. The cotton bollworm. Farmers Bull. 290.

Black, J. H., and T. F. Leigh. 1963. The biology of the boll weevil in relation to cotton type. J. Econ. Entomol. 56: 789-790.

Blair, B. D. 1983. Cotton pest management: the national viewpoint, pp. 228-229. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Blair, B. W. 1986. Strategies to minimize resistance in arthropod pests to acaricides and synthetic pyrethroid insecticide in Zimbabwe, pp. 222-227. *In* Proceedings, IVe Congress Sur la Protection de la Santo Humaine et des Cultures en Milieu Tropical, Marseille.

Bland, C. E., J. N. Couch, and S. Y. Newell. 1981. Identification of Coelomyces, Saprolegniales and Lagenidiales, pp. 129-162. *In* H. D. Burges (ed.), Microbial control of pests and plant diseases 1970-1980. Academic Press, New York.

Bloomquist, J. R., P. M. Adams, and D. M. Soderlund. 1987. Neurotoxic insecticides as antagonists of the GABA receptor function, pp. 97-106. *In* R. M. Hollingworth, and M. B. Green (eds.), Sites of action for neurotoxic pesticides. American Chemical Society, Washington, D.C.

Bloomquist, J. R., and T. A. Miller. 1985. A simple bioassay for detecting and characterizing insecticide resistance. Pestic. Sci. 16: 611-614.

Bloomquist, J. R., and T. A. Miller. 1986. Sodium channel neurotoxins as probes of the knockdown resistance mechanism. Neurotoxicology 7: 217-227.

Boddie, J. W. 1850. Insect physiology. The bollworm. S. Cultiv. 8: 132.

Bode, L. E., B. J. Butler, and C. E. Goering. 1976. Spray drift and recovery as affected by spray thickener, nozzle type and nozzle pressure. Trans. ASAE 19: 213-218.

Bohmann, D. J., T. F. Watson, L. A. Crowder, and M. P. Jensen. 1988. Repression of permethrin resistance by chlordimeform in the tobacco budworm (Lepidopera: Noctuidae). J. Econ. Entomol. 81: 1536-1538.

Bohmfalk, G. T. 1982. Progress with the nuclear polyhedrosis virus of *Heliothis zea* by commercialization of Elcar, pp. 113-117. *In* Proc. Third Interntl. Colloq. Invertebr. Pathol.

Bohmfalk, G. T., R. E. Frisbie, W. L. Sterling, R. B. Metzer, and A. E. Knutson. 1983. Identification, biology, and sampling of cotton insects. Tex. Agric. Extn. Serv. B-933.

Bohmont, B. L. 1981. The new pesticide users guide. B and K Enterprises, Inc., Fort Collins, CO.

Bolton, B., J. B. Penn, F. T. Cooke, and A. M. Heagler. 1968. Days suitable for fieldwork - Mississippi River Delta cotton area. D.A.E. Res. Rept. No. 384, Agric. Exp. Sta. Louisiana State University.

Bondy, F. F., and C. F. Rainwater. 1942. Boll weevil hibernation, survival, and emergence under South Carolina conditions. J. Econ. Entomol. 35: 495-498.

Bonnen, C. A., and L. P. Gabbard. 1947. Cotton statistics for Texas. Texas Agric. Exp. Stn. Circ. 111.

Bonner, C. M. 1988. Effects of herbicides and other soil applied pesticides on earliness: enhancement, retardation and phytotoxicity, pp. 23-25. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Boring III, E. P., T. W. Fuchs, J. F. Leser, and C. T. Allen. 1984. Management of cotton insects in the High Plains, Rolling Plains and Trans-Pecos areas of Texas. Tex. Agric. Ext. Serv. B-1209.

Boring III, E. P., J. F. Leser, T. W. Fuchs, and C. T. Allen. 1989a. Management of cotton insects in the High Plains, Rolling Plains and Trans Pecos areas of Texas. Texas Agric. Ext. Serv. B-1209.

Boring III, E. P., J. F. Leser, T. W. Fuchs, and C. T. Allen. 1989b. Suggested insecticides for management of cotton insects in the High Plains, Rolling Plains and Trans Pecos areas of Texas. Tex. Agric. Ext. Serv. B-1209A.

Borkovec, A. B., C. W. Woods, and P. H. Terry. 1978. Boll weevil: chemosterilization by fumigation and dipping. J. Econ. Entomol. 17: 862-866.

Borlaug, N. E. 1972. Mankind and civilization at another crossroad in balance with nature - a biological myth. BioSci 22: 41-44.

Bottger, G. T., W. H. Cross, W. E. Gundersen, and G. P. Wene. 1964. Recent research on the boll weevil in northern Sonora, Mexico and the thurberia weevil in Arizona. J. Econ. Entomol. 57: 286-290.

Bottrell, D. G. 1976. Biological control agents of the boll weevil, pp. 22-25. *In* Proc. Conf. on Boll Weevil Suppression, Management and Elimination Technology. USDA, ARS-S-71.

Bottrell, D. G. 1979. Integrated pest management. U.S. Govt. Printing Office, Washington, D.C.

Bottrell, D. G., and P. L. Adkisson. 1977. Cotton insect pest management. Annu. Rev. Entomol. 22: 451-481.

Bottrell, D. G., and D. M. Arnold. 1968. Parasitism in fall populations of the bollworm and the tobacco budworm from cotton on the high and rolling plains. Tex. Agr. Exp. Stn. Progr. Rept. 2628.

Bottrell, D. G., L. J. Wade, and D. L. Bruce. 1973. Boll weevils fail to develop resistance to malathion after several years of heavy exposure in Texas High Plains. J. Econ. Entomol. 66: 791-792.

Bottrell, D. G., J. R. White, D. S. Moody, and D. D. Hardee. 1972. Overwintering habitats of the boll weevil in the Rolling Plains of Texas. Environ. Entomol. 65: 633-638.

Bottrell, D. G., J. H. Young, R. G. Price, and R. H. Adams. 1968. Parasites reared from *Heliothis* spp. in Oklahoma in 1965-1966. Ann. Entomol. Soc. Amer. 61: 1053-1055.

Boucias, D. G., and G. L. Nordin. 1978. A scanning electron microscope study of *Hyphantria cunea* CPV-infected midgut tissue. J. Invertebr. Pathol. 32: 229-233.

Bourland, F. M. 1987. Registration of MISCOT 7813 and MISCOT 7841 germplasm lines of cotton. Crop. Sci. 27: 367.

Bourland, F. M. 1988. Registration of MISCOT 7913-51, MISCOT 7913-83, and MISCOT 7913-84 germplasm lines of cotton. Crop. Sci. 28: 200-201.

Bouse, L. F. 1969. Aerial-spray penetration through foliage canopies. Trans. ASAE 12: 86-89.

Bouse, L. F., and J. B. Carlton. 1983. Factors affecting size distribution of vegetable oil spray droplets. ASAE and NAAA Paper No. AA-83-006.

Bouse, L. F., J. B. Carlton, S. L. Jones, R. K. Morrison, and J. R. Ables. 1980. Broadcast aerial release of an egg parasite for lepidopterous insect control. Trans. ASAE 23: 1359-1368.

Bouse, L. F., J. B. Carlton, and R. K. Morrison. 1981. Aerial application of insect egg parasites. Trans. ASAE 24: 1093-1098.

Bouse, L. F., and R. K. Morrison. 1985. Transport, storage, and release of *Trichogramma pretiosum*. Southwest. Entomol. Suppl. 8: 36-48.

Boving, P. A., and R. G. Winterfield. 1980. Testing selected nozzles for deposit efficiency in aerial application of spray. Trans. ASAE 23: 36-38.

Bowden, R. O., R. G. Luttrell, and L. G. Brown. 1990. Cotton insect consultant for expert management (CIC-EM): an expert system for managing cotton insects, pp. 328-333. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bowen, H. D., P. Hebblethwaite, and W. M. Carlton. 1952. Application of electrostatic charging to the deposition of insecticides and fungicides on plant surfaces. Agri. Engin. June: 347-350.

Boyd, F. J. 1976. Boll weevil population levels during the inseason and reproduction-diapause control phases of the pilot boll weevil eradication experiment, pp. 75-89. *In* Proc. Conf. on Boll Weevil Suppression, Management and Elimination Technology. USDA, ARS-S-71.

Boyd, F. J. 1976. Operational plan and execution of the pilot boll weevil eradication experiment, pp. 62-69. *In* Proc. Conf. on Boll Weevil Suppression, Management and Elimination Technology. USDA, ARS-S-71.

Boyd, J. P. 1970. Feeding and searching behavior of *Chrysopa carnea* Stephens. Doctoral, Texas A&M University. College Station, TX.

Boyer, W. P., and R. Bell. 1961. The relationship of spider mite infestations in cotton to early season use of insecticides. J. Kansas Entomol. Soc. 34: 132-134.

Boyer, W. P., L. O. Warren, and C. Lincoln. 1962. Cotton scouting in Arkansas. Univ. of Ark. Agri. Exp. Stn. Bull. 656.

Boykin, L. S., and W. B. Campbell. 1984. Wind dispersal of two-spotted spider mite (Acari: Tetranychidae) in North Carolina peanut fields. Environ. Entomol. 13: 221-227.

Boyle, W. W. 1957. On the mode of dissemination of the two-spotted spider mite, *Tetranychus telarius*. Proc. Hawaii Entomol. Soc. 16: 261-268.

Bozeman, L. L. 1984. Cotton insect management suggestions for 1984. NM State Univ. Coop. Ext. Ser. Guide 400 J-7.

Bradley Jr., J. R. 1988. Influence of habitat on the pest status and management of *Heliothis* species in the southern United States. *In* Evolution of insect pests: the pattern of variations. John Wiley and Sons, New York.

Bradley Jr., J. R., and A. M. Agnello. 1986. Production practices: effects on cotton insect pest populations, pp. 135-138. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bradley Jr., J. R., D. F. Clower, and J. B. Graves. 1968. Field studies of sex attraction in the boll weevil. J. Econ. Entomol. 61: 1457-1458.

Bradley Jr., J. R., J. B. Graves, and D. F. Clower. 1966. Utilization of DDT resistance as a means of investigation of the possible existence of host-specific strains of the bollworm, *Heliothis zea*. J. Econ. Entomol. 59: 460-462.

Bradley Jr., J. R., G. A. Herzog, S. H. Roach, R. E. Stinner, and L. I. Tang. 1986. Cultural control in southern U.S. cropping systems, pp. 22-27. *In* Theory and tactics of *Heliothis* population management: I - Cultural and biological control. S. Coop. Ser. Bull. No. 316.

Bradley Jr., J. R., M. L. Laster, H. N. Pitre, S. H. Roach, and J. W. Smith. 1987. Interactions of insecticides and arthropod natural enemies of *Heliothis* spp., pp. 7-15. *In* J. C. Schneider, A. J. Hammond, D. M. Jackson, E. R. Mitchell, and R. T. Roush (eds.), Theory and Tactics of *Heliothis* Population Management II - Insecticidal and Insect Growth Regulator Control - South. Coop. Ser. Bull. 329.

Bram, R. A., and W. E. Bickley. 1963. The green lacewings of the genus *Chrysopa* in Maryland (Neuroptera: Chrysopidae). Univ. of Maryland Agric. Exp. Stn. Bull. A-124.

Brandenburg, R. L., and G. G. Kennedy. 1982. Intercrop relationships and spider mite dispersal in a corn/peanut agro-ecosystem. Entomol. Exp. Appl. 32: 269-276.

Branner, R., S. D. Wiyatt, J. F. Riggs, R. M. Albert, G. L. Shepler, G. H. Sullivan, and E. S. Dye. 1980. Arizona Agricultural Statistics. U.S. Dept. of Agri. and Univ. of Ariz. Bul. S-16.

Brattsten, L. B. 1987a. Metabolic insecticide defenses in the boll weevil compared to those in a resistance-prone species. Biochem. Physiol. 27: 1-12.

Brattsten, L. B. 1987b. Inducibility of metabolic insecticide defenses in boll weevils and tobacco budworm caterpillars. Pestic. Biochem. Physiol. 27: 13-23.

Brazelton, R. W., N. B. Akesson, K. T. Maddy, and W. E. Yates. 1981. Progress in pesticide worker safety in California. ASAE Paper No. 81-5001.

Brazzel, J. R. 1959. The effect of late-season applications of insecticide on diapausing boll weevils. J. Econ. Entomol. 52: 1042-1045.

Brazzel, J. R. 1961. Boll weevil resistance to insecticides in Texas in 1960. Tex. Agr. Exp. Stn. Prog. Rep. 2171.

Brazzel, J. R. 1963. Resistance to DDT in *Heliothis virescens*. J. Econ. Entomol. 56: 571-574.

Brazzel, J. R. 1964. DDT resistance in *Heliothis zea*. J. Econ. Entomol. 57: 455-457.

Brazzel, J. R. 1989. Boll weevil eradication - an update, pp. 218-220. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Brazzel, J. R., T. B. Davich, and L. D. Harris. 1961. A new approach to boll weevil control. J. Econ. Entomol. 54: 523-530.

Brazzel, J. R., and J. C. Gaines. 1956. The effects of pink bollworm infestations on yield and quality of cotton. J. Econ. Entomol. 49: 852-854.

Brazzel, J. R., and B. G. Hightower. 1960. A seasonal study of diapause, reproductive activity, and seasonal tolerance to insecticides in the boll weevil. J. Econ. Entomol. 53: 41-46.

Brazzel, J. R., C. Lincoln, L. D. Newsom, F. J. Williams, J. S. Roussel, and G. Barnes. 1953. Bollworm and tobacco budworm as cotton pests in Louisiana and Arkansas. La. Tech. Bull. 482.

Brazzel, J. R., and L. D. Newsom. 1959. Diapause in *Anthonomus grandis* Boh. J. Econ. Entomol. 52: 603-611.

Brazzel, J. R., and W. Newton. 1963. Seasonal incidence of tobacco budworms on cotton in Texas. Tex. Agric. Exp. Stn. Prog. Rep. 2272.

Brazzel, J. R., and O. E. Shipp. 1962. The status of boll weevil resistance to chlorinated hydrocarbon insecticides in Texas. J. Chem. Ecol. 55: 941-944.

Brazzel, J. R., W. W. Watson, J. S. Hursh, and M. H. Adair. 1968. Relative efficiency of aerial application of ultra-low-volume and emulsifiable concentrate formulations of insecticides. J. Econ. Entomol. 64: 1537-1541.

Brazzel, J. R., and C. A. Wilson. 1967. Trends in control of cotton pests. Amer. Bee. Journ. 107: 458-459.

Breene, R. G., D. A. Dean, M. Nyffeler, and G. B. Edwards. 1993. Biology, predation ecology, and significance of spiders in Texas cotton ecosystems with a key to the species. Tex. Agric. Exp. Stn. Bull. 1711.

Breene, R. G., A. W. Hartstack, W. L. Sterling, and M. Nyffeler. 1989a. Natural control of the cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter) (Hemiptera: Miridae), in Texas. J. Appl. Entomol. 108: 298-305.

Breene, R. G., W. L. Sterling, and D. A. Dean. 1989b. Predators of the cotton fleahopper on cotton. Southwest. Entomol. 14: 159-166.

Breene, R. G., and W. L. Sterling. 1988. Quantitative phosphorus-32 labeling method for analysis of predators of the cotton fleahopper (Hemiptera: Miridae). J. Econ. Entomol. 81: 1494-1498.

Breene, R. G., W. L. Sterling, and D. A. Dean. 1988. Spider and ant predators of the cotton fleahopper (Hemiptera, Miridae) on woolly croton. Southwest. Entomol. 13: 177-183.

Breene, R. G., W. L. Sterling, and M. Nyffeler. 1990. Efficacy of spider and ant predators on the cotton fleahopper (Hemiptera: Miridae). Entomophaga 35: 393-401.

Breer, H. 1985. Neurochemistry of cholinergic synapses in insects, pp. 89-99. *In* H. C. von Keyserlink, A. Jager, and C. von Szczepanski (eds.), Approaches to new leads for insecticides. Springer-Verlag, New York.

Brett, C. H., R. R. Walton, and E. E. Ivy. 1946. The cotton fleahopper *Psallus seriatus* (Reut.) in Oklahoma. Tech. Bull. No. T-24. Okla. Agr. Exp. Sta.

Brettel, J. H. 1983. Strategies for cotton bollworm control in Zimbabwe. Zimbabwe Agr. J. 80: 105-108.

Brewer, F. D., and W. A. Jones Jr. 1985. Comparison of meridic and natural diets on the biology of *Nezara viridula* (Heteroptera: Pentatomidae) and eight other phytophagous Heteroptera. Ann. Entomol. Soc. Amer. 78: 620-625.

Brewer, M. J., and J. T. Trumble. 1991. Classifying resistance severity in field populations: Sampling inspection plans for an insecticide resistance monitoring program. J. Econ. Entomol. 84: 379-389.

Bridge, R. R. 1980. Registration of three germplasm lines of cotton. Crop. Sci. 20: 417-418.

Bridge, R. R. 1986a. Registration of DES 35 cotton germplasm. Crop. Sci. 26: 650.

Bridge, R. R. 1986b. Registration of 'DES 119' cotton. Crop Sci. 26: 646.

Bridge, R. R. 1987. Registration of DES-237-7 cotton germplasm. Crop. Sci. 27: 1316.

Bridge, R. R. 1990. Improvements in cotton through genetics and breeding since 1975, pp. 16-18. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bridge, R. R., and J. F. Chism. 1978a. Registration of DES 24 cotton. Crop. Sci. 18: 523.

Bridge, R. R., and J. F. Chism. 1978b. Registration of DES 56 cotton. Crop. Sci. 18: 524.

Bridge, R. R., J. F. Chism, and G. R. Tupper. 1975. The influence of row spacing on cotton variety performance. Mississippi Agric. and For. Exp. Sta. Delta Branch Bull. 816.

Bridge, R. R., and L. D. McDonald. 1987. Beltwide efforts and trends in development of varieties for short season production systems, pp. 81-85. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bridge, R. R., and W. R. Meredith Jr. 1983. Comparison performance of obsolete and current cotton cultivars. Crop Sci. 23: 949-9552.

Brito, R. M., V. M. Stern, and F. V. Sances. 1986. Physiological response of cotton plants to feeding of three tetraychus spider mite species (Acari: Tetranychidae). J. Econ. Entomol. 79: 1217-1220.

Brooks, G. T. 1974. Chlorinated insecticides. Vol. 2., Biological and environmental aspects. CRC Press, Boca Raton.

Brooks, W. M. 1974. Protozoan infections, pp. 237-300. *In* G. E. Cantwell (ed.), Insect Diseases. Marcel Dekker, New York.

Brooks, W. M. 1988. Entomogenous protozoa, pp. 1-149. *In* C. M. Ignoffo, and N. B. Mandava (eds.), CRC handbook of natural pesticides vol. V, microbial insecticides, part A, entomogenous protozoa and fungi. CRC Press, Boca Raton.

Brosten, D., and B. Simmonds. 1990. Cotton enters the environmental decade. Agrichem. Age.

Brown Jr., W. L. 1968. An hypothesis concerning the function of the metapleural glands in ants. Am. Nat. 102: 188-191.

Brown Jr., W. L., T. Eisner, and R. H. Whittaker. 1970. Allomones and kairomones: transspecific chemical messengers. BioScience 20: 21-22.

Brown, A. W. A. 1951. Insect control by chemicals. John Wiley and Sons, New York.

Brown, D. W., and D. A. Goyer. 1982. Effects of a predator complex on Lepidopterous defoliators of soybean. Environ. Entomol. 11: 385-389.

Brown, H. B. 1923. Cotton spacing. Mississippi Agr. Exp. Sta. Bull. 212.

Brown, H. B. 1938. Cotton. McGraw-Hill, New York.

Brown, H. B. 1938a. Cultivated varieties of cotton, pp. 41-83. *In* Cotton. McGraw-Hill Book Co., New York and London.

Brown, H. B. 1938b. Cotton breeding, pp. 183-215. *In* Cotton. McGraw-Hill Book Co., New York and London.

Brown, H. B. 1938c. Cotton culture, pp. 281-305. *In* Cotton. McGraw-Hill Book Co., New York and London.

Brown, H. B. 1938d. Fertilizers, manures, and rotations for cotton, pp. 229-253. *In* Cotton. McGraw-Hill Book Co., New York and London.

Brown, H. B., and J. O. Ware. 1958. Cotton. McGraw-Hill Book Co., New York.

Brown, H. B., and J. O. Ware. 1958a. Cotton insects, pp. 199. *In* Cotton. McGraw-Hill Book Co., New York, Toronto and London.

Brown, H. B., and J. O. Ware. 1958b. Cotton culture, pp. 313-316. *In* Cotton. McGraw-Hill Book Co., New York, Toronto and London.

Brown, J. K., and J. Bird. 1992. Whitefly-transmitted geminiviruses and associated disorders in the Americas and the Caribbean Basin. Plant Disease 76: 220-225.

Brown, J. K., H. S. Costa, and J. Bird. 1991. Variation in *Bemisia tabaci* populations based upon geographic origin, silverleaf symptom induction, and esterase banding patterns. Phytopath 81: 1157.

Brown, J. K., and M. R. Nelson. 1984. Geminate particles associated with cotton leaf crumple disease in Arizona. Phytopathology 74: 987-990.

Brown, J. K., and M. R. Nelson. 1986. Host range study of the cotton leaf crumple virus. Arizona Agric. Expt. Sta. Bull., P-63:171-176.

Brown, L. G., A. W. Hartstack, D. W. Parvin Jr., and R. W. Skieth. 1979a. Computer simulation for establishing economic thresholds, pp. 75-84. *In* Economic thresholds and sampling of *Heliothis* species on cotton, corn, soybeans, and other host plants. S. Coop. Ser. Bull. 231.

Brown, L. G., R. W. McClendon, and J. W. Jones. 1979b. Computer simulation of the interaction between the cotton crop and insect pests. Trans. ASAE 22: 771-774.

Brown, L. G., J. W. Jones, J. D. Hesketh, J. D. Hartsog, F. D. Whisler, and F. A. Harris. 1985. COT-CROP: computer simulation of cotton growth and yield. Miss. Agric. For. Exp. Sta. Inf. Bull. 69.

Brown, L. G., and R. W. McClendon. 1982. A new *Heliothis* spp. control strategy for the Mississippi Delta, pp. 191-195. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Brown, L. G., R. W. McClendon, and J. W. Jones. 1983. A cotton insect management simulation model, pp. 437-479. *In* R. L. Ridgway, E. P. Lloyd, and W. H. Cross (eds.), Cotton Insect Management with Special Reference to the Boll Weevil. USDA Agr. Handb. No. 589.

Brown, T. M. 1981. Countermeasurers for insecticide resistance. Bull. Entomol. Soc. Amer. 27: 198-202.

Brown, T. M. 1991. Resistant acetylcholinesterase of the tobacco budworm, *Heliothis virescens*, pp. 185-195. *In* E. Hodgson, R. M. Roe, and N. Motoyama (ed.), Pesticides and the Future: Toxicological Studies of Risks and Benefits. Rev. Pestic. Toxicol. (1). North Carolina State University, Raleigh, North Carolina.

Brown, T. M., and P. K. Bryson. 1992. Selective inhibitors of methyl parathion-resistant acetylcholinesterase from *Heliothis virescens*. Pestic. Biochem. Physiol. 44: 155-164.

Brumley, J. M. 1987. New biopesticides for cotton, pp. 27-28. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bryan, B. B., and E. L. Thomas Jr. 1958. Distribution of fertilizer materials applied through sprinkler irrigation systems. Univ. Ark. Agric. Exp. Stn. Bull. 598.

Bryan, D. C., C. G. Jackson, E. G. Neemann, and R. Patana. 1972. Production of progeny and longevity of *Eucelatoria* sp. parasitic in *Heliothis* species. Environ. Entomol. 1: 23-26.

Bryan, D. E., R. E. Fye, C. G. Jackson, and R. Patana. 1973a. Releases of *Bracon kirkpatricki* (Wilkinson) and *Chelonus blackburni* Cameron for pink bollworm control in Arizona. USDA Prod. Res. Rep. 150.

Bryan, D. E., R. E. Fye, C. G. Jackson, and R. Patana. 1973b. Releases of parasites for suppression of pink bollworms in Arizona. USDA, ARS W-7.

Bryan, D. E., R. E. Fye, C. G. Jackson, and R. Patana. 1976. Nonchemical control of pink bollworms. USDA, ARS W-39.

Bryan, D. E., C. G. Jackson, and R. Patana. 1970. Biological comparison of two species of *Eucelatoria* parasitic in *Heliothis* spp. J. Econ. Entomol. 63: 1469-1472.

Bryan, D. E., C. G. Jackson, and A. Stoner. 1969. Rearing cotton insect parasites in the laboratory. USDA Prod. Res. Rep. 109.

Bryan, D. E., and R. F. Smith. 1956. The *Frankliniella occidentalis* (Pergande) complex in California (Thysanoptera: Thripidae). Univ. Calif. Publ. Entomol. 10: 359-410.

Bryson, C. T., J. C. McCarty Jr., J. N. Jenkins, and W. L. Parrott. 1983. Frequency of pigment glands and capitate and covering trichomes in nascent leaves of selected cottons. Crop. Sci. 23: 369-371.

Buchel, K. H. 1983. Chemistry of pesticides. John Wiley and Sons, New York.

Bucher, G. E. 1963. Nonsporulating bacterial pathogens, pp. 117-147. *In* E. A. Steinhaus (ed.), Insect pathology, an advanced treatise, Vol. II. Academic Press, New York.

Buford, W. T., J. N. Jenkins, and F. G. Maxwell. 1967. A laboratory technique to evaluate boll weevil oviposition preference among cotton lines. Crop Sci. 7: 579-581.

Buford, W. T., J. N. Jenkins, and F. G. Maxwell. 1968. A boll weevil oviposition suppression factor in cotton. Crop Sci. 8: 647-649.

Bull, D. L. 1968. Metabolism of *O,O*-dimethyl phosphorodithioate *S*-ester with 4-(mercaptomethyl)-2-methyoxy- -1,3,4-thiadiazolin-5-one (Geigy GS-13005) in plants and animals. J. Agric. Food Chem. 16: 610-616.

Bull, D. L. 1978. Formulations of microbial insecticides: Microencapsulation and adjuvants. Misc. Publ. Entomol. Soc. Amer. 10: 11-20.

Bull, D. L. 1979. Fate and efficacy of acephate after application to plants and insects. J. Agric. Food Chem. 27: 268-272.

Bull, D. L. 1980. Fate and efficacy of sulprofos against certain insects associated with cotton. J. Econ. Entomol. 73: 262-264.

Bull, D. L. 1986. Toxicity and pharmacodynamics of avermectin in the tobacco budworm, corn earworm and fall armyworm (Noctuidae: Lepidoptera). J. Agric. Food Chem. 34: 74-78.

Bull, D. L., and R. J. Coleman. 1985. Effects of pesticides on *Trichogramma* spp. Southwest. Entomol. Suppl. 8: 156-168.

Bull, D. L., R. L. Harris, and N. W. Prior. 1988. The contribution of metabolism to pyrethroid and DDT resistance in the horn fly (Diptera: Muscidae). J. Econ. Entomol. 81: 449-458.

Bull, D. L., and G. W. Ivie. 1980. Activity and fate of diflubenzuron and certain derivatives in the boll weevil. Pestic. Biochem. Physiol. 13: 41-52.

Bull, D. L., G. W. Ivie, N. W. Pryor, and V. S. House. 1983. Fate and efficacy of *O*-[4-[(4-chlorophenyl)thio]phenyl] *O*-ethyl *S*-propyl phosphorothioate (RH-0994) after application to the tobacco budworm (Lepidoptera: Noctuidae) and the boll weevil (Coleoptera: Curculionidae). J. Econ. Entomol. 76: 227-232.

Bull, D. L., E. G. King, and J. E. Powell. 1989. Effects and fate of selected insecticides after application to *Microplitis croceipes*, pp. 59-70. *In* J. E. Powell, D. L. Bull, and E. G. King (Eds.), Biological control of *Heliothis* spp. by *Microplitis croceipes*. Southwest. Entomol. Suppl. 12.

Bull, D. L., and D. A. Lindquist. 1964. Metabolism of 3-hydroxy-*N,N*-dimethylcrotonamide dimethyl phosphate by cotton plants, insects and rats. J. Agric. Food Chem. 12: 310-317.

Bull, D. L., D. A. Lindquist, and J. R. Coppedge. 1967a. Metabolism of 2-methyl-2-(methylthio)propionaldehyde *O*(methylcarbamoyl)oxime (Temik, UC-21149) in insects. J. Agric. Food Chem. 15: 610-616.

Bull, D. L., D. A. Linquist, and R. R. Grabbe. 1967b. Comparative fate of the geometric isomers of phosphamidon in plants and animals. J. Econ. Entomol. 60: 332-341.

Bull, D. L., D. A. Lindquist, and J. Hacskaylo. 1963. Absorption and metabolism of dimethoate in bollworm and boll weevil. J. Econ. Entomol. 56: 129-134.

Bull, D. L., and D. A. Linquist. 1966. Metabolism of 3-hydroxy-*N*-methyl-*cis*-crotonamide dimethyl phosphate (Azodrin) by insects and rats. J. Agric. Food Chem. 14: 105-109.

Bull, D. L., F. W. Plapp Jr., and T. C. Sparks. 1987. Chemistry and mode of action of insecticides used to control *Heliothis* spp. on field and horticultural crops., pp. 37-54. *In* J. C. Schneider, A. M. Hammond, D. M. Jackson, E. R. Mitchell, and R. T. Roush (eds.), Theory and tactics of *Heliothis* population management II - Insecticidal and insect growth regulator control.

Bull, D. L., N. W. Pryor, and E. G. King Jr. 1987. Pharmacodynamics of different insecticides in *Microplitis croceipes* (Hymenoptera: Braconidae), a parasite of lepidopteran larvae. J. Econ. Entomol. 80: 739-749.

Bull, D. L., and R. L. Ridgway. 1969. Metabolism of trichlorfon in animals and plants. J. Agric. Food Chem. 17: 837-841.

Bull, D. L., R. L. Ridgway, V. S. House, and N. W. Pryor. 1976. Improved formulation of the *Heliothis* nuclear polyhedrosis virus. J. Econ. Entomol. 69: 731-736.

Bull, D. L., and C. J. Whitten. 1972. Factors influencing organophosphorus insecticide resistance in tobacco budworms. J. Agric. Food Chem. 20: 561-564.

Bull, D. L., C. J. Whitten, and G. W. Ivie. 1976. Fate of *O*-ethyl *O*-[4-(methylthio)phenyl] *S*-propyl phosphorodithioate (BAY NTN 9306) in cotton plants and soil. J. Agric. Food Chem. 24: 601-605.

Bullock, H. R. 1967. Persistence of *Heliothis* nuclear polyhedrosis virus on cotton foliage. J. Invertebr. Pathol. 9: 434-436.

Bullock, H. R., and H. T. Dulmage. 1969. *Bacillus thuringiensis* against pink bollworms on cotton in field cages. J. Econ. Entomol. 62: 994-995.

Burch, T. A. 1988. Selection of varieties, row spacing, and plant populations for earliness, pp. 20-23. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Buren, C. S., W. A. Banks, and B. M. Glancey. 1975. Biology and control of imported fire ants. Annu. Rev. Entomol. 20: 1-30.

Burges, H. D. 1981. Strategy for the microbial control of insect pests in 1980 and beyond, pp. 798-836. *In* H. D. Burges (ed.), Microbial control of pests and plant diseases 1970-1980. Academic Press, New York.

Burges, H. D., and N. W. Hussey. 1971. Introduction, pp. 1-11. *In* H. D. Burgess, and N. W. Hussey (eds.), Microbial control of insects and mites. Academic Press, New York.

Burke, H. R., W. E. Clark, J. R. Cate, and P. A. Fryxell. 1986. Origin and dispersal of the boll weevil. Bull. Entomol. Soc. Amer. 32: 228-238.

Burke, H. R., and D. F. Martin. 1956. The biology of three chrysopid predators of the cotton aphid. J. Econ. Entomol. 49: 698-700.

Burks, M. L., and W. C. Nettles Jr. 1978. *Eucelatoria* sp.: effects of cuticular extracts from *Heliothis virescens* and other factors on oviposition. Environ. Entomol. 7: 897-900.

Burleigh, J. G. 1975. Comparison of *Heliothis* spp. larval parasitism and *Spicaria* infection in closed and open canopy cotton varieties. Environ. Entomol. 4: 574-576.

Burris, E., D. F. Clower, and J. E. Jones. 1982. Trap plantings and non-preference for boll weevil control, pp. 130-132. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Burris, E., K. J. Ratchford, H. C. Kinard, D. F. Clower, and J. E. Jones. 1981. Plant bug complex as affected by cotton genotypes, pp. 61. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Burrows, T. M., V. Sevacherian, H. Browning, and J. Baritelle. 1982. Histroy and cost of the pink bollworm (Lepidoptera: Gelechiidae) in the Imperial Valley. Bull. Entomol. Soc. Am. 28: 286-290.

Burt, E. C., E. P. Lloyd, D. B. Smith, W. P. Scott, J. R. McCoy, and F. C. Tingle. 1970. Boll weevil control with insecticide applied in sprays with narrow-spectrum droplet sizes. J. Econ. Entomol. 63: 365-370.

Burt, E. C., and D. B. Smith. 1974. Effects of droplet sizes on deposition of ulv spray. J. Econ. Entomol. 67: 751-754.

Burt, E. C., D. B. Smith, and E. P. Lloyd. 1966. A rotary disc device for applying ulv (undiluted) pesticides with ground equipment. J. Econ. Entomol. 59: 1487-1489.

Burton, R. L. 1970. A low-cost artificial diet for the corn earworm. J. Econ. Entomol. 63: 1969-1970.

Burton, R. L., and H. C. Cox. 1966. Air automated packaging machine for Lepidopterous larvae. J. Econ. Entomol. 59: 907-909.

Burton, V. E. 1981. Insect and nematode recommendations for cotton. Univ. of Calif., Div. of Agric. Sci., Leaflet No. 2083.

Bushell, M. J. 1990. Synthesis of some fluorinated non-ester pyrethroids, pp. 125-141. *In* L. Crombie (ed.), Recent advances in the chemistry of insect control II. Royal Society of Chemistry, Cambridge, U.K.

Bushland, R. C. 1975. Screwworm research and eradication. Bull. Entomol. Soc. Amer. 21: 23-26.

Bushland, R. C., and D. E. Hopkins. 1951. Experiments with screw-worm flies sterilized by X-rays. J. Econ. Entomol. 44: 725-731.

Busk, A. 1917. The pink bollworm, *Pectinophora gossypiella*. J. Agr. Res. 9: 343-370.

Busvine, J. R. 1951. Mechanism of resistance to insecticides in house flies. Nature 168: 193-195.

Butler Jr., G. D. 1958. Braconid wasps reared from lepidopterous larvae in Arizona, 1957. Pan-Pac. Entomol. 34: 221-223.

Butler Jr., G. D. 1966a. Insect predators of bollworm eggs. Progressive Agric. in Arizona 18: 26-27.

Butler Jr., G. D. 1966b. Development of several predaceous Hemiptera in relation to temperature. J. Econ. Entomol. 59: 1306-1307.

Butler Jr., G. D., J. M. Gillespie, T. J. Henneberry, and A. Zvirgzdins. 1983. Seasonal movement of the pink bollworm *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae), pp. 205-208. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Butler Jr., G. D., and A. G. Hamilton. 1976. Temperature-dependent development rates for four strains of *Pectinophora gossypiella*. Ann. Entomol. Soc. Amer. 69: 450-452.

Butler Jr., G. D., A. G. Hamilton, and J. D. Lopez Jr. 1983. *Cardiochiles nigriceps* (Hymenoptera: Braconidae): development time and fecundity in relation to temperature. Ann. Entomol. Soc. Amer. 76: 563-583.

Butler Jr., G. D., and T. J. Henneberry. 1976. Biology, behavior, and effects of larvae of pink bollworm in cotton flowers. Environ. Entomol. 5: 970-972.

Butler Jr., G. D., and T. J. Henneberry. 1984. *Bemisia tabaci*: effect of cotton leaf pubescence on abundance. Southwest. Entomol. 9: 91-94.

Butler Jr., G. D., and T. J. Henneberry. 1986. *Bemisia tabaci* (Gennadius), a pest of cotton in the southwestern United States. USDA Agr. Res. Serv. Tech. Bull. 1707.

Butler Jr., G. D., and T. J. Henneberry. 1988. Laboratory studies of *Chrysoperla carnea* predation on *Bemisia tabaci*. Southwest. Entomol. 13: 165-170.

Butler Jr., G. D., and T. J. Henneberry. 1994. *Bemisia* and *Trialeurodes* (Hemiptera: Aleyrodidae), pp. 325-352. *In* G. A. Matthews, and J. P. Tunstall (eds.), Insect Pests of Cotton. University Press, Cambridge.

Butler Jr., G. D., T. J. Henneberry, and R. J. Barker. 1983. Pink bollworm: comparison of commercial control with gossyplure or insecticides. USDA, Agric. Res. Serv., ARM-W-35.

Butler Jr., G. D., T. J. Henneberry, and A. C. Bartlett. 1985. *Heliothis virescens* (Leptidoptera: Noctuidae): Termination of summer diapause. J. Econ. Entomol. 78: 1287-1292.

Butler Jr., G. D., T. J. Henneberry, and F. D. Wilson. 1986. *Bemisia tabaci* (Homoptera: Aleyrodidae) on cotton: adult activity and cultivar oviposition preference. J. Econ. Entomol. 79: 350-354.

Butler Jr., G. D., T. R. Pfrimmer, and J. W. Davis. 1974. A model to describe the uniform buildup of populations of adult bollworms and cabbage loopers. Environ. Entomol. 3: 978-980.

Butler Jr., G. D., D. Rimon, and T. J. Henneberry. 1988. *Bemisia tabaci* (Homoptera: Aleyrodidae): populations on different cotton varieties and cotton stickiness in Israel. Plant Prot. 7: 43-47.

Butler Jr., G. D., and R. L. Ritchie Jr. 1970. Development of *Chrysopa carnea* at constant and fluctuating temperatures. J. Econ. Entomol. 63: 1028-1030.

Butler Jr., G. D., and A. L. Wardecker. 1971. Temperature and the development of eggs and nymphs of *Lygus hesperus*. Ann. Entomol. Soc. Amer. 64: 144-145.

Butler Jr., G. D., and F. L. Watson. 1980. Simulating the longevity of adult pink bollworms. Ann. Entomol. Soc. Amer. 73: 158-159.

Butler Jr., G. D., and F. D. Wilson. 1984. Activity of adult whiteflies (Homoptera: Aleyrodidae) within plantings of different cotton strains and cultivars as determined by sticky-trap catches. J. Econ. Entomol. 77: 1137-1140.

Butler Jr., G. D., F. D. Wilson, and T. J. Henneberry. 1985. Cotton leaf crumple virus disease in okra-leaf and normal-leaf cotton. J. Econ. Entomol. 78: 1500-1502.

Buxkemper, W. E., H. A. Turney, and J. Cocke Jr. 1983. Management of cotton insects in the Texas Blacklands. Tex. Agric. Ext. Serv. B-1205.

Byerly, K. F., A. P. Gutierrez, R. E. Jones, and R. E. Luck. 1978. A comparison of sampling methods for some arthropod populations in cotton. Hilgardia 46: 257-282.

Byford, R. L., and T. C. Sparks. 1987. Chemical approaches to the management of resistant horn fly, *Haematobia irritans* (L.), populations, pp. 178-189. *In* M. G. Ford, D. W. Holloman, B. P. S. Khambay, and R. M. Sawicki (eds.), Combating Resistance to Xenobiotics. Ellis Horwood Ltd., Chichester, England.

Byrne, D., and T. Bellows. 1991. Whitefly biology. Annu. Rev. Entomol. 36: 31-457.

Byrne, D. N., S. L. Buchmann, and H. G. Spangler. 1988. Relationship between wing loading, wingbeat frequency and body mass in homopterous insects. J. Exp. Biol. 132: 1-15.

Byrne, D. N., and P. K. von Bretzel. 1987. Similarity in flight activity rhythms in coexisting species of Aleyrodidae, *Bemisia tabaci* and *Trialeurodes abutilonea*. Entomol. Exp. Appl. 43: 215-219.

Byrne, D. N., P. K. von Bretzel, and C. J. Hoffman. 1986. Impact of trap design and placement when monitoring for the bandedwinged whitefly and the sweetpotato whitefly (Homoptera: Aleyrodiae). J. Econ. Entomol. 15: 300-304.

Byrne, F. J., I. Denholm, L. C. Birnie, A. L. Devonshire, and M. W. Rowland. 1992. Analysis of insecticide resistance in the whitefly, *Bemisia tabaci*, pp. 165-178. *In* I. Denholm, A. L. Devonshire, and D. W. Hollomon (Eds.), Resistance 91: Achievements and developments in combating pesticide resistance. Elsevier, London.

Byrne, F. J., and A. L. Devonshire. 1991. Insensitive acetylcholinesterase and esterase polymorphism in susceptible and resistant populations of the tobacco whitefly *Bemisia tabaci* (Genn.). Pestic. Biochem. Physiol. 45: 34-42.

Cabanillas, H. E., G. O. Poinar Jr., and J. R. Raulston. 1994. *Steinernema riobravis* n. sp. (Rhabditida: Steinernematidae) from Texas. Fundam. Appl. Nematol. 17: 123-131.

Cadogan, B. L., B. F. Zylstra, C. Nystrom, L. B. Pollock, and P. M. Ebling. 1986. Spray deposits and drop size spectra from a high wing monoplane fitted with rotary atomizers. Trans. ASAE 29: 402-406.

Cai, D., F. Xiang, X. Jaing, Z. Zhu, X. Hau, and Z. Dai. 1993. Fate of aldicarb in the vadose zone beneath a cotton field. J. Contaminant Hydrology 14: 129-142.

Calderon, C. M. 1977. Effect of the nectariless character of cotton on the population dynamics of certain phytophagous and natural enemy insects. Doctoral. Mississippi State University. Mississippi State, MS.

Callahan, P. S. 1962. Techniques for rearing the corn earworm, *Heliothis zea*. J. Econ. Entomol. 55: 453-457.

Callahan, P. S., A. N. Sparks, J. W. Snow, and W. W. Copeland. 1972. Corn earworm moth vertical distribution in nocturnal flight. Environ. Entomol. 1: 497-503.

Cameron, P. J., and E. W. Valentine. 1989. Importation and establishment of predators and parasitoids of *Heliothis* into New Zealand, pp. 397-410. *In* E. G. King and R. D. Jackson (eds.), Proc.

Workshop on Biological Control of *Heliothis*: Increasing the Effectiveness of Natural Enemies. FERRO, USDA.

Campanhola, C., B. F. McCutchen, E. H. Baehrecke, and F. W. Plapp. 1991. Biological constraints associated with resistance to pyrethroids in the tobacco budworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 84: 1404-1411.

Campanhola, C., and F. W. Plapp. 1987. Toxicity of pyrethroids and other insecticides against susceptible and resistant tobacco budworm larvae and synergism by chlordimeform, pp. 326-329. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Campion, D. G. 1994. Pheromones for the control of cotton pests, pp. 505-534. *In* G. A. Matthews, and J. P. Tunstall (eds.), Insect Pests of Cotton. University Press, Cambridge.

Canerday, T. D. 1974. Response of bollworm and tobacco budworm in Georgia to methyl parathion. J. Econ. Entomol. 67: 299.

Cannerday, T. D., and F. S. Arant. 1964. The effect of spider mite populations on yield and quality of cotton. J. Econ. Entomol. 57: 553-556.

Cantelo, W. W., A. H. Baumhover, T. J. Henneberry, and J. W. Smith Jr. 1973. Attempted suppression of tobacco hornworm with sterile males. Environ. Entomol. 2: 48-54.

Cantu, E., and D. A. Wolfenbarger. 1970. Toxicity of three pyrethroids to several insect pests of cotton. J. Econ. Entomol. 63: 1373-1374.

Carey, G. P., T. Lescott, J. S. Robertson, L. K. Spencer, and D. C. Kelley. 1978. Three African isolates of small iridescent viruses: type 21 from *Heliothis armigera* (Lepidoptera: Noctuidae), type 23 from *Heteronychus arator* (Coleoptera: Scarabaeidae), and type 28 from *Lethocerus columbiae* (Hemiptera Heteroptera: Belostomatidae). Virology 85: 307-309.

Carey, J. R. 1982. Demography of the two-spotted spider mite, *Tetranychus urticae* Koch. Oecologia 52: 389-395.

Carey, J. R. 1983. Practical application of the stable age distribution analysis of a *Tetranychid mite* (Acarina: Tetranychidae) population outbreak. Environ. Entomol. 12: 10-18.

Carlson, G. A. 1975. Control of a mobile pest: the imported fire ant. S. J. Agric. Econ. 7: 35-47.

Carlson, G. A., and E. M. Castle. 1972. Economics of pest control, pp. 79-99. *In* Pest control strategies for the future. National Academy of Sciences, Washington, DC.

Carlson, G. A., and D. V. DeBord. 1975. Public mosquito abatement. J. Environ. Econ. Management 3: 142-153.

Carlson, G. A., G. Sappie, and M. Hammig. 1989. Economic returns to boll weevil eradication. Economic Research Service, U.S. Department of Agriculture, Washington, DC. Agricultural Economic Report No. 621.

Carlson, G. A., and L. F. Suguiyama. 1983. Economic evaluation of the boll weevil eradication trial in North Carolina, 1979-1980, pp. 497-517. *In* R. L. Ridgway, E. P. Lloyd, and W. H. Cross (eds.), Cotton Insect Management with Special Reference to the Boll Weevil. USDA Agr. Handb. No. 589.

Carlson, G. A., and L. F. Suguiyama. 1985. Economic evaluation of areawide cotton insect management: boll weevils in the Southeastern United States. NC Agri. Res. Serv., NC State Univ., Raleigh, NC. Bull. No. 473.

Carner, G. R. 1976. A description of the life cycle of *Entomophthora* sp. in the two-spotted spider mite. J. Invertebr. Pathol. 28: 245-254.

Carner, G. R., and T. D. Canerday. 1968. Field and laboratory investigations with *Enthomophthora fresenii*, a pathogen of *Tetranychus* spp. J. Econ. Entomol. 61: 956-959.

Carner, G. R., and T. D. Canerday. 1970. *Entomophthora* spp. as a factor in the regulation of the two-spotted spider mite on cotton. J. Econ. Entomol. 63: 638-640.

Carner, G. R., and J. S. Hudson. 1981. Histopathology of an unidentified virus of *Heliothis zea* and *Heliothis virescens*. Proc. S.E. Electron Microsc. Soc. 4: 27.

Carner, G. R., M. Shepard, and S. G. Turnipseed. 1975. Disease incidence in lepidopterous pests of soybeans. J. Ga. Entomol. Soc. 10: 99-105.

Caron, R. E., and G. L. Lentz. 1988. Cotton insect and mite control. Univ. of Tennessee Ag. Ext. Ser. Pub. 387.

Carpenter, J. E., and A. N. Sparks. 1982. Effects of vision on mating behavior of the male corn earworm. J. Econ. Entomol. 75:(248-250)

Carpenter, J. E., A. N. Sparks, and H. L. Cromroy. 1987a. Corn earworm (Lepidoptera: Noctuidae): influence of irradiation and mating history on the mating propensity of females. J. Econ. Entomol. 80: 1233-1237.

Carpenter, J. E., J. R. Young, H. L. Cromroy, and A. N. Sparks. 1987b. Corn earworm (Lepidoptera: Noctuidae): comparison of field survival of larvae from normal and irradiated parents. J. Econ. Entomol. 80: 883-886.

Carpenter, J. E., J. R. Young, A. N. Sparks, H. L. Cromroy, and M. A. Chowdury. 1987c. Corn earworm (Lepidoptera: Noctuidae): effects of substerilizing doses of radiation and inherited sterility on reproduction. J. Econ. Entomol. 80: 483-489.

Carruth, L. A., and L. Moore. 1973. Cotton scouting and pesticide use in Eastern Arizona. J. Econ. Entomol. 66: 187-190.

Carter, C. C., T. N. Hunt, D. L. Kline, T. E. Reagan, and W. P. Barney. 1982. Insect and related pests of field crops, some important, common and potential pests in North Carolina, pp. 214. *In* T. N. Hunt, and J. R. Baker (eds.), North Carolina Agr. Ext. Ser. Pub. AG-271.

Carter, F. L. 1990. Role of entomologists in producing quality cotton fiber, pp. 171-173. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Carter, F. L., and J. R. Phillips. 1968. Methyl parathion resistance in a laboratory strain of the bollworm. J. Econ. Entomol. 61: 1716-1718.

Carter, F. L., and J. R. Phillips. 1973. Diapause in the boll weevil, *Anthonomus grandis* Boheman, as related to fruiting activity in the cotton plant. Ark. Aca. Sci. Proc. 27: 16-20.

Carter, J. 1966. A complete insect control program. Ariz. Cotton Growers Assoc. Cotton Res. Notes.

Cartwright, B. O., and J. W. Norman. 1987. Management of cotton insects in the Lower Rio Grande Valley of Texas. Tex. Agric. Ext. Serv. B-1210.

Casey, J., and R. D. Lacewell. 1973. Estimated impact of withdrawing specified pesticides from cotton production. So. J. Agr. Econ. 5: 153-159.

Cassidy, T. P., and T. C. Barber. 1939. Hemipterous insects of cotton in Arizona: their economic importance and control. J. Econ. Entomol. 32: 99-104.

Cate, J. R. 1985. Cotton: Status and current limitations to biological control in Texas and Arkansas, pp. 537-556. *In* M. A. Hoy, and D. C. Herzog (eds.), Biological control in Agricultural IPM systems. Academic Press, Inc., New York.

Cate, J. R. 1987. A method of rearing parasitoids of boll weevil without the host plant. Southwestern Entomol. 12: 211-215.

Cate, J. R., G. L. Curry, and R. M. Feldman. 1979. A model for boll weevil ovipositional site selection. Environ. Entomol. 8: 917-921.

Cate, J. R., P. C. Krauter, and K. E. Godfrey. 1990. Pests of cotton, pp. 17-29. *In* D. H. Habeck, F. D. Bennett, and J. H. Frank (eds.), Classical biological control in the southern United States. South. Coop. Ser. Bull. 355.

Certain, G. 1988. Tackling *Heliothis* resistance. Ag. Consultant.

Chakravorty, S. C., A. K. Basu, and V. M. Sahni. 1982. Variability in tannin and protein contents in fruiting parts in relation to the incidence of pink bollworm in cotton. Indian J. Agric. Sci. 52: 767-773.

Chamberlin, F. S., and J. N. Tenhet. 1926. *Cardiochiles nigriceps* Vier., an important parasite of the tobacco budworm, *H. virescens* Fab. J. Agr. Res. 33: 21-27.

Chambers, D. L. 1977. Quality control in mass rearing. Annu. Rev. Entomol. 22: 289-308.

Chambers, D. L., and T. R. Ashley. 1984. Putting the control in quality control in insect rearing, pp. 256-260. *In* E. G. King, and N. C. Leppla (eds.), Advances and challenges in insect rearing. USDA, Agric. Res. Serv., New Orleans.

Champlain, R. A., and C. D. Butler Jr. 1967. Temperature effects on development of the egg and numphal stages of *Lygus hesperus* (Hemiptera: Miridae). Ann. Entomol. Soc. Amer. 60: 519-521.

Champlain, R. A., and L. L. Sholdt. 1966. Rearing *Geocoris punctipes*, a *Lygus* bug predator, in the laboratory. J. Econ. Entomol. 59: 1301.

Champlain, R. A., and L. L. Sholdt. 1967a. Life history of *Geocoris punctipes* (Hemiptera: Lygaeidae) in the laboratory. Ann. Entomol. Soc. Amer. 60: 881-883.

Champlain, R. A., and L. L. Sholdt. 1967b. Temperature range for the development of immature stages of *Geocoris puntipes* (Hemiptera: Lygaeidae). Ann. Entomol. Soc. Amer. 60: 883-885.

Chan, B. G., and A. C. Waiss Jr. 1981. Evidence for acetogenic and shikimic pathways in cotton glands, pp. 49. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Chan, B. G., A. C. Waiss, and M. S. Lukefahr. 1978a. Condensed tannins, an antibiotic chemical from *Gossypium hirsutum*. J. Insect Physiol. 24: 113-118.

Chan, B. G., A. C. Waiss, R. G. Binder, and C. A. Elliger. 1978b. Inhibition of lepidopterous larval growth by cotton constituents. Entomol. Exp. Appl. 24: 94-100.

Chan, B. G., A. C. Waiss, W. L. Stanley, and A. E. Goodban. 1978c. A rapid diet preparation method for antibiotic phytochemical bioassay. J. Econ. Entomol. 71: 366-368.

Chang, C. P., and F. W. Plapp Jr. 1983. DDT and synthetic pyrethroids: mode of action, selectivity, and mechanisms of synergism in the tobacco budworm (Lepidoptera: Noctuidae) and a predator, *Chrysopa carnea* Stephens (Neuroptera: Chrysopidae). J. Econ. Entomol. 76: 1206-1210.

Chang, K. M., and C. O. Knowles. 1977. Formamidine acaricides. Toxicity and metabolism studies with twospotted spider mites, *Tetranychus urticae* Koch. J. Agric. Food Chem. 25: 493-501.

Chang, K. M., and C. O. Knowles. 1978. Aldicarb metabolism in twospotted spider mites. J. Econ. Entomol. 71: 158-160.

Chang, S. C., and J. B. Stokes. 1979. Conjugation: the major metabolic pathway of `14'C-diflubenzuron in the boll weevil. J. Econ. Entomol. 72: 15-19.

Chang, S. C., and C. W. Woods. 1979. Metabolism of `14'C-penfluron in the boll weevil. J. Econ. Entomol. 72: 781-784.

Chant, D. A. 1964. Strategy and tactics of insect control. Can. Entomol. 96: 182-201.

Chapman, A. J., and H. S. Cavitt. 1934. The influence of soil moisture upon survival of the pink bollworm. J. Econ. Entomol. 27: 820-827.

Chapman, A. J., and H. S. Cavitt. 1937. Possibilities of reducing overwintered pink bollworm population in the soil as shown by stripping tests. J. Econ. Entomol. 30: 837-838.

Chauthani, A. R., and P. L. Adkisson. 1965. Comparison of two artificial diets for rearing *Heliothis zea* larvae for insecticide tests. J. Econ. Entomol. 58: 1163-1164.

Cherry, E. T. 1974. Effect of plant bugs on cotton in West Tennessee. Tennessee Farm and Home Sci. Prog. Rep. 90.

Chestnut, T. L., and W. H. Cross. 1971. Arthropod parasites of the boll weevil, *Anthonomus grandis*: comparison of their importance in the United States over a period of thirty-eight years. Ann. Entomol. Soc. Amer. 64: 549-557.

Chiravathanapong, S., and H. N. Pitre. 1980. Effects of *Heliothis virescens* larval size on predation by *Geocoris punctipes*. Fla. Entomol. 63: 146-151.

Chirl, A. A., and E. F. Legner. 1982. Host-searching kairomones alter behavior of *Chelonus* sp. nr. *curvimaculatus*, a hymenopterous parasite of the pink bollworm, *Pectinophora gossypiella* (Saunders). Environ. Entomol. 11: 452-455.

Chow, P. N., C. A. Grant, A. M. Hinshalwood, and E. Simundson. 1988. Adjuvents and agrochemical, Vol. 1. Mode of action and physiological activity, and vol. II recent development, application, and bibliography of agro-adjuvants. CRC Press, Bara Raton.

Clancy, D. W. 1968. Distribution and parasitization of some *Lygus* spp. in western United States and central Mexico. J. Econ. Entomol. 61: 443-445.

Clancy, D. W., and H. D. Pierce. 1966. Natural enemies of some *Lygus* bugs. J. Econ. Entomol. 59: 853-858.

Clark, A. G., and N. A. Shamaan. 1984. Evidence that DDT-dehydrochlorinase from the house fly is a glutathione s-transferase. Pestic. Biochem. Physiol. 22: 249-261.

Clark, E. W., and P. A. Glick. 1961. Some predators and scavengers feeding upon pink bollworm moths. J. Econ. Entomol. 54: 815-816.

Clark, J. M., J. A. Argentine, H. Line, and X. Y. Gao. 1992. Mechanisms of abamectin resistance in the Colorado potato beetle, pp. 247-263. *In* C. A. Mullin, and J. G. Scott (eds.), Molecular mechanisms of insecticide resistance. American Chemical Society, Washington, D.C.

Clark, L. R., P. W. Geier, R. D. Hughes, and R. F. Morris. 1967. The ecology of insect populations in theory and practice. Methuen & Co., London.

Clark, P. S. 1988. Insect control for earliness: a private consultant's viewpoint, pp. 31. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Clarke, G. M., and J. A. McKenzie. 1987. Developmental stability of insecticide resistant phenotypes in blow fly; a result of canalizing natural selection. Nature 325: 345-346.

Clausen, C. P. 1978. Introduced parasites and predators of arthropod pests and weeds: a world review. USDA Agric. Handb. 480.

Clayton, T. E., and T. J. Henneberry. 1982. Pink bollworm: effect of soil moisture and temperature on moth emergence in field and laboratory studies. Environ. Entomol. 11: 147-149.

Cleveland, T. C. 1982. Hibernation and host plant sequence studies of tarnished plant bugs, *Lygus lineolaris*, in the Mississippi Delta. Environ. Entomol. 11: 1049-1052.

Cleveland, T. C. 1987. Predation by tarnished plant bugs (Heteroptera: Miridae) of *Heliothis* (Lepidoptera: Noctuidae) eggs and larvae. Environ. Entomol. 16: 37-40.

Cleveland, T. C., B. W. Hanny, and J. Riley. 1981. Tobacco budworm: effect of larval feeding on presquaring cotton. Environ. Entomol. 10: 372-374.

Cleveland, T. C., and G. L. Smith. 1964. Effects of post season applications of insecticides, defoliants, and desiccants on diapausing boll weevils. J. Econ. Entomol. 57: 527-529.

Clower, D. F. 1980. Changes in *Heliothis* spp. attacking cotton in recent years and how they affected control, pp. 139-141. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Clower, D. F. 1984. Thrips, whitefly, and *Spodoptera* problems in the mid-south, pp. 182-183. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Clower, D. F. 1987. Insecticide resistance-a continuing challenge, pp. 214-215. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Clower, D. F., T. R. Pfrimmer, R. G. Luttrell, G. A. Herzog, J. R. Bradley Jr., J. R. Phillips, A. R. Hopkins, J. A. DuRant, G. L. Lentz, J. A. Harding, J. W. Davis, R. L. McGarr, R. L. Hanna, R. G. Price, and J. H. Young. 1987. Efficacy of chemical insecticides against *Heliothis* species on cotton, pp. 18-24. *In* J. C. Schneider, A. M. Hammond, D. M. Jackson, E. R. Mitchell, and R. T. Roush (eds.), Theory and tactics of *Heliothis* population management, II - Insecticidal and insect growth regulator control.

Clower, D. F., B. Rogers, W. Mullins, D. Marsden, C. Staetz, B. Monke, J. Phelps, and G. Certain. 1992. Status of *Heliothis/Helicoverpa* resistance to pyrethroids in U.S. cotton: PEG-US 1991 update, pp. 739-743. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Clower, J. P., H. R. Mitchell, D. F. Clower, D. C. Rester, and J. B. Graves. 1982. Ultra-low volume application of insecticides in vegetable oil. La. Agric. 25: 22-24.

Coad, B. R. 1918. Recent experimental work on poisoning cotton boll weevils. USDA Bull. No. 731.

Coad, B. R. 1929. Organization and progress of pink bollworm research investigations. J. Econ. Entomol. 22: 743-750.

Coad, B. R. 1931. Insects captured by airplane are found at surprising heights. USDA, Yearbook 1931.

Coad, B. R., and T. P. Cassidy. 1920. Cotton boll weevil control by the use of poison. USDA Bull. No. 875.

Coad, B. R., E. Johnson, and G. L. McNeil. 1924. Dusting cotton from aeroplanes. USDA Bull. No. 1204.

Coakley, J. M., F. G. Maxwell, and J. N. Jenkins. 1969. Influence of feeding, oviposition, and egg and larval development of the boll weevil on abscission of cotton squares. J. Econ. Entomol. 62: 244-245.

Coats, J. R. 1982. Structure activity relationships in DDT analogs, pp. 29-43. *In* J. R. Coats (ed.), Insecticide mode of action. Academic Press, New York.

Cobb, P. P., and M. H. Bass. 1968. Some effects of photoperiod, temperature, and food on the induction of diapause in the boll weevil. J. Econ. Entomol. 61: 624-625.

Cochran, D. C. 1990. Efficacy of abamectin fed to German cockroaches (Dictyptera: Blattellidae) resistant to pyrethroid. J. Econ. Entomol. 83: 1243-1245.

Cochran, M. J., and W. G. Boggess. 1988. Integrated pest management: Risk implications for natural resources use, *In* W. Musser (ed.), Incorporation of risk in analysis of farm management decisions affecting natural resource use. Agric. Exp. Stn. Special Rep. 821. Oregon State University, Corvallis.

Cochran, M. J., W. F. Nicholson, D. W. Parvin, R. Raskin, and J. R. Phillips. 1985. An assessment of the Arkansas experience with bollworm management communities: evaluated from three perspectives, *In* Proc. Beltwide Cotton Prod. Res. Conf.

Cochrane, W. 1986. A new sheet of music: how Kennedy's farm advisor has changed his tune about commodity policy and why. Choices 1: 11-14.

Cohen, A. C. 1982. Water and temperature relations of two hemipteran members of a predator-prey complex. Environ. Entomol. 11: 715-719.

Cohen, A. C., and J. W. Debolt. 1983. Rearing *Geocoris punctipes* on insect eggs. Southwest. Entomol. 8: 61-64.

Cohen, D. B. 1986. Ground water contamination by toxic substances-a California assessment, pp. 499-529. *In* W. Y. Garner, R. C. Honeycutt, and H. N. Nigg (eds.), Evaluation of pesticides in ground water. Symposium Series 315. American Chemical Society, Washington, D.C.

Cohen, E. 1987. Interference with chitin biosynthesis in insects, pp. 43-73. *In* J. E. Wright, and A. Retnakaran (eds.), Chitin and Benzoylphenyl Ureas. Dr. W. Junl Publications, Dordrecht, Netherlands.

Cohen, E. 1993. Chitin synthesis and degradation as targets for pesticide action. Arch. Insect Biochem. 22: 245-261.

Cohen, S., J. Keren, I. Harpaz, and R. Bar-Joseph. 1986. Studies of the epidemiology of a whitefly-borne virus, tomato yellow curl virus, in the Jordan Valley. Phytoparasitica 14: 158.

Cohen, S. Z., C. Eiden, and N. M. Lorber. 1986. Monitoring ground water for pesticides in the U.S.A., pp. 170-196. *In* W. Y. Garner, R. C. Honeycutt, and H. N. Nigg (eds.), Evaluation of pesticides in ground water. Symposium Series 315. American Chemcial Society, Washington, D.C.

Cohn, D. L. 1956. The life and times of king cotton. Oxford University Press, Inc., New York.

Cole, C. L. 1970. Influence of certain seasonal changes on the life history and diapause of the boll weevil, *Anthonomus grandis* Boheman. Ph.D. Thesis, Texas A&M Univ., College Station.

Cole, C. L. 1983. Management of cotton insects in South & East Texas counties. Tex. Agric. Ext. Serv. B-1204.

Cole, C. L. 1988. Management of cotton insects in Blacklands, South & East Texas counties. Tex. Agric. Ext. Serv. B-1204.

Cole, C. L., and P. L. Adkisson. 1981. Life history and fecundity of the boll weevil reared in constant and variable temperature regimens. Southwest. Entomol. 6: 298-302.

Cole, L. M., R. A. Nicholson, and J. E. Casida. 1993. Action of phenylpyrazole insecticides at the GABA-gated chloride channel. Pestic. Biochem. Physiol. 46: 47-54.

Collins, G. S., R. D. Lacewell, and J. Norman. 1979. Economic comparison of alternative cotton production practices: Texas Lower Rio Grande Valley. So. J. of Agric. Econ. 11: 79-82.

Colliot, F., J. A. Kukorowski, D. W. Hawkins, and D. A. Roberts. 1992. Fipronil: A new soil and foliar broad spectrum insecticide, pp. 29-34. *In* Brighton Crop Protection Conference-Pests and Diseases,

Colthern, C. R. 1986. Techniques for the assessment of carcinogenic risk due to drinking water contaminates, pp. 221-245. *In* C. P. Straub (ed.), Critical reviews in environmental control. CRC Press, Boca Raton.

Columbus, E. R. 1987. Chemical residues on ginned lint, pp. 536-538. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Colvin, T. S., and J. H. Turner. 1976. Applying pesticides. Am. Assoc. Voc. Instr. Mat., Athens, GA.

Combe, P. E. 1982. Visual behavior of the greenhouse whitefly, *Trialeurodes vaporariorum*. Physiol. Entomol. 7: 243-251.

Condra, G. P., K. E. Lindsey, and C. W. Neeb. 1975. Proposal for an upland cotton demonstration in Reeves and Pecos counties. Tex. Agric. Ext. Serv. Mimeo.

Cone, W. W., L. M. McDonough, J. C. Maitlen, and S. Burdajewicz. 1971a. Pheromone studies of the twospotted spider mite. 1. Evidence of a sex pheromone. J. Econ. Entomol. 64:355-358.

Cone, W. W., S. Predki, and E. C. Klostermeyer. 1971b. Pheromone studies of the twospotted spider-mite. 2. Behavioral response of males to quiescent deutonymphs. J. Econ. Entomol. 64: 379-382.

Conway, G. R. 1976. The utility of system analyses techniques in pest management and crop protection. Proc. 15th Intern. Cong. Entomol.

Cook, O. F. 1904. Report on the habits of the kelep, or Guatemalan cotton boll weevil ant. USDA Bur. Entomol. Bull. 49.

Cook, O. F. 1905. The social organization and breeding habits of the cotton protecting kelep of Guatemala. USDA Bur. Entomol. Tech. Ser. Bull. 10.

Cook, O. F. 1913. A new system of cotton culture. USDA Bur. Plt. Ind. Circ. 115.

Cooke Jr., F. T., and D. W. Parvin. 1983. The cost of insecticides used on cotton in the United States, pp. 29-52. *In* R. L. Ridgway, E. P. Lloyd, and W. H. Cross (eds.), Cotton Insect Management with Special Reference to the Boll Weevil. USDA Agr. Handb. No. 589.

Cooke, F. T., D. W. Parkvin, and S. R. Spurlock. 1991. The costs of cotton harvesting systems in the Mississippi Delta, pp. 409-412. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Cool, M., and C. K. Jankowski. 1985. A survey of the metabolism of carbamate insecticides, pp. 87-142. *In* D. H. Huston, and T. R. Roberts (eds.), Insecticides. John Wiley and Sons, New York.

Coppedge, J. R., D. A. Linquist, R. L. Ridgway, C. R. Cowan, and L. A. Bariola. 1969. Sidedress applications of Union Carbide-21149 for control of the overwintering boll weevil. J. Econ. Entomol. 62: 558-565.

Coppedge, J. R., and R. L. Ridgway. 1973. The integration of selected boll weevil suppression techniques in an eradication experiment. USDA Prod. Res. Rep. No. 152.

Coppock, S. 1962. Control cotton insects in New Mexico. NM State Univ. Coop. Ext. Ser. Circular 327.

Corbett, J. R., K. Wright, and A. C. Baillie. 1984. The biochemical mode of action of pesticides. Academic Press, New York.

Cosper, R. D., M. J. Gaylor, and J. C. Williams. 1983. Intraplant distribution of three insect predators on cotton, and seasonal effects of their distribution on vacuum sampler efficiency. Environ. Entomol. 12: 1568-1571.

Costa, H. S., and J. K. Brown. 1991. Variation in biological characteristics and esterase patterns among populations of *Bemisia tabaci*, and the association of one population with silverleaf symptom induction. Entomol. Exp. Appl. 61: 211-219.

Cotton, L. R., and H. B. Brown. 1934. Cotton spacing in Southern Louisiana in relation to certain plant characters. Louisiana Agric. Exp. Sta. Bull. 246.

Coudriet, D. L., D. E. Meyerdirk, N. Prabhaker, and A. N. Kishaba. 1986. Bionomics of the sweetpotato whitefly (Homoptera: Aleyrodidae) on weed hosts in the Imperial Valley, California. Environ. Entomol. 15: 1179-1183.

Coudriet, D. L., N. Prabhaker, A. N. Kishaba, and D. E. Meyerdirk. 1985. Variation in developmental rate on different hosts and overwintering of the sweetpotato whitefly, *Bemisia tabaci* (Homoptera: Aleyrodidae). Environ. Entomol. 14: 516-519.

Coulson, J. R. 1987. Studies on the biological control of plant bugs (Heteroptera: Miridae): an introduction and history, 1961-83, pp. 1-12. *In* R. C. Hedlund, and H. M. Graham (eds.), Economic importance and biological control of *Lygus* and *Adelphocoris* in North America. USDA-ARS, ARS-64.

Coulson, R. N., R. M. Feldman, P. J. H. Sharpe, P. E. Pulley, T. L. Wagner, and T. L. Payne. 1989a. An overview of the TAMBEETLE model of population dynamics of the southern pine beetle. Holarctic Ecol. 12: 445-450.

Coulson, R. N., M. C. Saunders, D. K. Loh, F. L. Oliveria, D. Drummond, P. J. Barry, and K. M. Swain. 1989b. Knowledge system environment for integrated pest management in forest landscapes: the southern pine beetle (Coleoptera: Scolytidae). Bull. Entomol. Soc. Amer. 35: 26-32.

Coulson, R. N., R. O. Flamm, F. L. Oliveria, D. Drummond, and C. N. Lovelady. 1990a. Implementation of emerging technologies: forestry. Entomol. Soc. Amer. Cent. Symp., Entomol. Soc. Amer. Natl. Meeting, San Antonio, Texas, December 11-14.

Coulson, R. N., C. N. Lovelady, R. O. Flamm, S. L. Spradling, and M. C. Saunders. 1990b. Intelligent geographic information system for natural resource management, *In* M. G. Turner, and R. G. Gardner (eds.), Quantitative methods in landscape ecology. Springer-Verlag, New York.

Cousins, S. E. 1991. Progress in the United States boll weevil eradication programs, pp. 609-610. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Cowan Jr., C. B., and J. W. Davis. 1967. Systemic insecticides for control of the boll weevil and the cotton fleahopper. J. Econ. Entomol. 60: 1038-1041.

Cowan Jr., C. B., and M. J. Lukefahr. 1970. Characters of cotton plants that affect infestations of cotton fleahoppers, pp. 79-80. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Cowan, C. B., R. L. Ridgway, J. W. Davis, J. K. Walker, W. C. Watkins Jr., and R. F. Dudley. 1966. Systemic insecticides for control of cotton insects. J. Econ. Entomol. 59: 958-961.

Cox, P. G., and N. W. Forrester. 1992. Economics of insecticide resistance management in *Heliothis armigera* (Lepidoptera: Noctuidae) in Australia. J. Econ. Entomol. 85: 1539-1550.

Creech, R. G. 1987. How the COMAX-GOSSYM model works and what it can do, pp. 56-61. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Creeger, S. M. 1986. Considering pesticide potential for reaching ground water in the registration of pesticides, pp. 548-557. *In* W. Y. Garner, R. C. Honeycutt, and H. N. Nigg (eds.), Evaluation of pesticides in ground water. Symp. Ser. 315. American Chemical Society, Washington, D.C.

Crocker, R. L., and W. H. Whitcomb. 1980. Feeding niches of the big-eyed bugs *Geocoris bullatus*, *G. punctipes*, and *G. uliginosus* (Hemiptera: Lygaeidae: Geocorinae). Environ. Entomol. 9: 508-513.

Crocker, R. L., W. H. Whitcomb, and R. M. Ray. 1975. Effects of sex, developmental stage, and temperature on predation by *Geocoris punctipes*. Environ. Entomol. 4: 531-534.

Croft, B. A. 1990. Developing a philosophy and program of pesticide resistance management, pp. 277-296. *In* R. T. Roush, and B. E. Tabashnik (eds.), Pesticide resistance in arthropods. Chapman & Hall, New York.

Crombie (ed.), L. 1990. Recent advances in the chemistry of insect controll II. Royal Society of Chemistry, Cambridge, U.K.

Crosby, B. L., R. L. Byford, and T. C. Sparks. 1991. Bioassay for detecting active site insensitivity in horn fly (Diptera: Muscidae) larvae. J. Econ. Entomol. 84: 367-370.

Crosby, C. R., and M. D. Leonard. 1914. The tarnished plant bug *Lygus pratensis* Linnaeus. N. Y. Agr. Exp. Sta. Bull. 346: 463-525.

Cross, W. H. 1976. History of the boll weevil problem, pp. 1-2. *In* Proc. Conf. on Boll Weevil Suppression, Management and Elimination Technology. USDA, ARS-S-71.

Cross, W. H. 1976. Relative populations and suggested long-range movements of boll weevils throughout the area of the pilot boll weevil eradication experiment as indicated by traps in 1973, pp. 103-107. *In* Proc. Conf. on Boll Weevil Suppression, Management and Elimination Technology. USDA, ARS-S-71.

Cross, W. H. 1983. Ecology of cotton insects with special reference to the boll weevil, pp. 53-70. *In* R. L. Ridgway, E. P. Lloyd, and W. H. Cross (eds.), Cotton Insect Management with Special Reference to the Boll Weevil. USDA Agr. Handb. No. 589.

Cross, W. H., and T. H. Chesnut. 1971. Arthropod parasites of the boll weevil, *Anthonomus grandis*: 1. An annotated list. Ann. Entomol. Soc. Amer. 64: 516-527.

Cross, W. H., D. D. Hardee, F. Nichols, H. C. Mitchell, E. B. Mitchell, P. M. Huddleston, and J. H. Tumlinson. 1969. Attraction of female boll weevils to trap baited with males or extract of males. J. Econ. Entomol. 62: 154-161.

Cross, W. H., M. J. Lukefahr, P. A. Fryxell, and H. R. Burke. 1975. Host plants of the boll weevil. Environ. Entomol. 4: 19-26.

Cross, W. H., W. L. McGovern, and H. C. Mitchell. 1969. Biology of *Bracon kirkpatricki* and field releases of the parasite for control of the boll weevil. J. Econ. Entomol. 62: 448-454.

Cross, W. H., and H. C. Mitchell. 1966. Mating behavior of the female boll weevil. J. Econ. Entomol. 59: 1503-1506.

Crowder, L. A., M. P. Jensen, and T. F. Watson. 1984. Pyrethroid resistance in the tobacco budworm, *Heliothis virescens*, pp. 229-231. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Crowder, L. A., M. S. Tollefson, and T. F. Watson. 1979. Dosage-mortality studies of synthetic pyrethroids and methyl parathion on the tobacco budworm in Central Arizona. J. Econ. Entomol. 72: 1-3.

Culin, J., S. Brown, J. Rogers, D. Scarborough, A. Swift, B. Cotterill, and J. Kovach. 1990. A simulation model examining boll weevil dispersal: historical and current situations. Environ. Entomol. 19: 195-208.

Culp, T. W. 1979. Registration of PEE DEE 695 and PEE DEE 875 germplasm lines of cotton. Crop Sci. 19: 751.

Culp, T. W., A. R. Hopkins, and R. F. Moore. 1979. Resistance of cotton cultivars to insects, pp. 84. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Culp, T. W., A. R. Hopkins, and R. F. Moore. 1981. Response of six cultivars and breeding lines to *Heliothis* spp. under three insecticide regimes, pp. 83. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Culp, T. W., R. F. Moore, and J. B. Pitner. 1985. Registration of PD-2 cotton. Crop Sci. 25: 198-199.

Cunningham, J. C., and J. F. Longworth. 1968. The identification of some cytoplasmic-polyhedrosis viruses. J. Invertebr. Pathol. 11: 196-202.

Curl, L. F. 1949. The pink bollworm situation in the United States and Mexico in April 1949. Acco Press.

Curry, G. L., and J. R. Cate. 1984. Strategies for cotton-boll weevil management in Texas, pp. 169-183. *In* G. R. Conway (ed.), Pest and pathogen control: strategic, tactical, and policy models. John Wiley & Sons, New York.

Curry, G. L., J. R. Cate, and P. J. H. Sharpe. 1982. Cotton bud drying: contributions to boll weevil mortality. Environ. Entomol. 11: 345-350.

Curry, G. L., and R. M. Feldman. 1987. Mathematical foundations of population dynamics. Texas Engin. Exp. Stn. Monograph Ser. 3, Texas A&M Univ. Press, College Station.

Curry, G. L., R. M. Feldman, and K. C. Smith. 1978a. A stochastic model of a temperature-dependent population. Theor. Popul. Biol. 13: 197-213.

Curry, G. L., R. M. Feldman, and P. J. H. Sharpe. 1978b. Foundations of stochastic development. J. Theor. Biol. 74: 397-410.

Curry, G. L., P. J. H. Sharpe, D. W. DeMichele, and J. R. Cate. 1980. Towards a management model of the cotton-boll weevil ecosystem. J. Environ. Mgt. 11: 187-223.

Curtis, C. F. 1968. Possible use of translocations to fix desirable genes in insect pest populations. Nature (London) 218: 368-369.

Curtis, C. F. 1985. Theoretical models of the use of insecticide mixtures for the management of resistance. Bull. Entomol. Res. 75: 259-265.

Cushman, R. A. 1911. Studies in the biology of the boll weevil in the Mississippi delta region of Louisiana. J. Econ. Entomol. 4: 432-448.

Daly, J. C. 1988. Insecticide resistance in *Heliothis armigera* in Australia. Pestic. Sci. 23: 165-176.

Danks, H. V., R. L. Rabb, and P. S. Southern. 1979. Biology of insect parasites of *Heliothis* larvae in North Carolina. J. Ga. Entomol. Soc. 14: 36-64.

Daum, R. J., R. E. McLaughlin, and D. D. Hardee. 1967. Development of the bait principle for boll weevil control: cotton seed oil, a source of attractants and feeding stimulants for the boll weevil. J. Econ. Entomol. 60: 321-325.

Dauterman, W. C. 1976. Extramicrosomal metabolism of insecticides. *In* C. F. Wilkinson (ed.), Insecticide biochemistry and physiology. Plenum Press, New York.

Dauterman, W. C. 1985. Insect metabolism: extramicrosomal, pp. 713-730. *In* G. A. Kerkut, and L. I. Gilbert (eds.), Comprehensive insect physiology biochemistry and pharmacology. Vol. 12., Insect control. Pergamon Press, New York.

Davich, T. B. 1976. Foreword, pp. I-II. *In* Proc. Conf. on Boll Weevil Suppression, Management and Elimination Technology. USDA, ARS-S-71.

Davich, T. B., D. D. Hardee, and J. Alcala M. 1970. Long-range dispersal of boll weevils determined with wing traps baited with males. J. Econ. Entomol. 63: 1706-1708.

Davich, T. B., J. C. Keller, E. B. Mitchell, P. A. Huddleston, R. Hill, D. A. Lindquist, G. H. McKibben, and W. H. Cross. 1965. Preliminary field experiments with sterile males for eradication of the boll weevil. J. Econ. Entomol. 58: 127-131.

Davich, T. B., and D. A. Lindquist. 1962. Exploratory studies on gamma radiation for the sterilization of the boll weevil. J. Econ. Entomol. 55: 164-167.

David, W. A. L. 1975. The status of viruses pathogenic for insects and mites. Ann. Rev. Entomol. 20: 97-117.

Davidson, R. H., and W. F. Lyon. 1979. Insect pests of farm, garden, and orchard. 7th edition. John Wiley & Sons, New York.

Davies, R. A. H. 1984. Insecticide resistance-an industry viewpoint, pp. 593-600. *In* British Crop Protection Conf. Pest and Disease,

Davies, W. P. 1992. Prospects for pest resistance to pesticides, pp. 95-110. *In* A. A. Kadir, and H. S. Barlow (eds.), Pest management and the environment in 2000. CAB International,.

Davis Jr., L. D. 1981. Population dynamics of four species of *Geocoris* in peanut agroecosystem. Doctoral, Texas A&M University. College Station, TX.

Davis, D. D., N. R. Malm, C. E. Barnes, and C. L. Roberts. 1978. Double-row cotton trials in New Mexico. New Mexico Agric. Exp. Stn. Res. Rep. 352.

Davis, F. M., S. Malone, T. G. Oswalt, and W. C. Jordan. 1990. Medium-sized lepidopterous rearing system using multicellular rearing trays. J. Econ. Entomol. 83: 1535-1540.

Davis, F. W., C. B. Cowan Jr., and C. R. Parencia. 1976. Boll weevil: survival in hibernation cages and in surface woods trash in central Texas. J. Econ. Entomol. 69: 797-799.

Davis, J. W., C. B. Cowen Jr., and C. R. Parencia Jr. 1967. Emergence of overwintered boll weevils from hibernation sites near Waco, Texas. J. Econ. Entomol. 60: 1102-1104.

Davis, J. W., D. A. Wolfenbarger, and J. A. Harding. 1977. Activity of several synthetic pyrethroids against the boll weevil and *Heliothis* spp. Southwest. Entomol. 2: 164-169.

de Neufville, R., and J. H. Stafford. 1971. Systems Analysis for Engineers and Managers. McGraw Hill, New York.

Dean, D. A., and W. L. Sterling. 1987. Distribution and abundance patterns of spiders inhabiting cotton in Texas. Texas Agric. Exp. Stn. Bull. 1566.

Dean, D. A., and W. L. Sterling. 1992. Comparison of sampling methods to predict phenology of predaceous arthropods in a cotton agroecosystem. Tex. Agric. Exp. Stn. Misc. Publ. 1731.

Dean, D. A., W. L. Sterling, and N. V. Horner. 1982. Spiders in eastern Texas cotton fields. J. Arachnol 10: 251-60.

Dean, D. A., W. L. Sterling, M. Nyffeler, and R. G. Breene. 1987. Foraging by selected spider predators on the cotton fleahopper and other prey. Southwest. Entomol. 12: 263-270.

Deaton, W. R. 1991. Field performance of cotton genetically-modified to express insecticidal protein from *Bacillus thuringiensis*. I. Introduction, pp. 576. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Debolt, J. W. 1982. Meridic diet for rearing successive generations of *Lygus hesperus*. Ann. Entomol. Soc. Amer. 75: 119-122.

Debolt, J. W. 1987. Augmentation: rearing, release, and evaulation of plant bug parasites, pp. 82-87.

In R. C. Hedlund, and H. M. Graham (eds.), Economic importance and biological control of *Lygus* and *Adelphocoris* in North America. USDA-ARS. ARS-64.

Debolt, J. W., and R. Patana. 1985. *Lygus hesperus*, pp. 329-338. *In* P. Singh, and R. F. Moore (eds.), Handbook of Insect Rearing, Vol. 1 Elsevier, New York.

DeBord, D. V. 1977. Cotton insect and weed loss analysis. The Cotton Foundation. National Cotton Council. Memphis, Tennessee.

Decoursey, R. M., and C. O. Esselbaugh. 1962. Descriptions of the nymphal stages of some North American Pentatomidae (Hemiptera-Heteroptera). Ann. Entomol. Soc. Amer. 55: 323-342.

Deitz, L. L., J. W. Van Duyn, J. R. Bradley Jr., R. L. Rabb, W. M. Brooks, and R. E. Stinner. 1976. A guide to the identification and biology of soybean arthropods in North Carolina. N. C. Agric. Exp. Stn. Tech. Bull. 238.

DeLima, J. O. G., and T. F. Leigh. 1984. Effect of cotton genotypes on the western big-eyed bug (Heteroptera: Miridae). J. Econ. Entomol. 77: 898-902.

DeLoach, C. J., and D. G. Peters. 1972. Effect of strip-planting vs solid-planting on predators of cotton insects in southeastern Missouri, 1969. Environ. Entomol. 1: 94-102.

DeLucca, A. J., J. G. Simonson, and A. D. Larson. 1981. *Bacillus thuringiensis* distribution in soils of the United States. Can. Jour. Microbiol. 27: 865-870.

DeMichele, D. W., and D. G. Bottrell. 1976. Systems approach to cotton insect pest management, pp. 200. *In* J. L. Apple, and R. F. Smith (eds.), Integrated pest management. Plenum Press, New York.

DeMichele, D. W., G. L. Curry, P. J. H. Sharpe, and C. S. Barfield. 1976. Cotton bud drying: a theoretical model. Environ. Entomol. 5: 1011-1016.

Denholm, I., A. Farnham, K. O'Dell, and R. M. Sawicki. 1983. Factors affecting resistance to insecticides in house flies, *Musca domestica* L. (Diptera: Muscidae). I. Long-term control with bioresmethrin of flies with strong pyrethroid-resistance potential. Bull. Entomol. Res. 73: 481-489.

Denholm, I., and M. W. Rowland. 1992. Tactics for managing pesticide resistance in arthropods: Theory and practice. Annu. Rev. Entomol. 37: 91-112.

Dennehy, T. J., and J. Granett. 1984. Spider mite resistance to dicofol in San Joaquin Valley cotton: inter- and intraspecific variability in susceptibility of three species of *Tetranychus* (Acari: Tetranychidae). J. Econ. Entomol. 77: 1381-1385.

Dennehy, T. J., J. Granett, and T. F. Leigh. 1983. Relevance of slide-dip and residual bioassay comparisons to detection of resistance in spider mites. J. Econ. Entomol. 76: 1225-1230.

Dennehy, T. J., J. Granett, T. F. Leigh, and A. Colvin. 1987. Laboratory and field investigations of spider mite (Acari: Tetranychidae) resistance to the selective acaricide propargite. J. Econ. Entomol. 80: 565-574.

Desaiah, D., L. K. Cutkomp, and R. B. Koch. 1973. Inhibition of spider mite ATPases by plictran and three organochlorine acaricides. Life Sci. 13: 1693-1703.

Devonshire, A. L., and L. M. Field. 1991. Gene amplification and insecticide resistance. Annu. Rev. Entomol. 36: 1-23.

Devonshire, A. L., and G. D. Moores. 1982. A carboxylesterase with broad substrate specificity causes organophosphorus, carbamate and pyrethoid resistance in peach-potato aphids (*Myzus persicae*). Pestic. Biochem. Physiol. 18: 235-246.

Devonshire, A. L., G. D. Moores, and R. H. ffrench-Constant. 1986. Detection of insecticide resistance by immunological estimation of carboxylesterase activity in *Myzus persicae* (Sulzer) and cross reaction of the antiserum with *Phorodon humuli* (Schrank) (Hemiptera: Aphididae). Bull. Entomol. Soc. Amer. 76: 97-107.

Devonshire, A. L., and R. M. Sawicki. 1979. Insecticide-resistant (*Myzus persicae*) as an example of evolution by gene duplication. Nature 270: 140-141.

Dickens, J. C. 1989. Green leaf volatiles enhance aggregation pheromone of boll weevil *Anthonomus grandis*. Entomol. Exp. Appl. 52: 191-203.

Dickens, J. C., and G. D. Prestwich. 1989. Differential recognition of geometric isomers by the boll weevil, *Anthonomus grandis* Boh. (Coleoptera: Curculionidae): evidence for only three essential components in aggregation pheromone. J. Chem. Ecol. 15: 529-540.

Dickens, J. C., and H. R. Agee. 1987. Photosensitivity and spectral response of boll weevils reared on natural host and artificial larval diets supplemented with carotenoids. J. Appl. Entomol. 103: 185-192.

Dickerson, W. A. 1986. Grandlure: use in boll weevil control and eradication programs in the United States. Florida Entomol. 69: 147-153.

Dickerson, W. A., R. L. Ridgway, and F. R. Planer. 1987a. Southeastern Boll Weevil Eradication Program: improved pheromone traps and program status, pp. 335-337. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Dickerson, W. A., B. A. Leonhardt, and R. L. Ridgway. 1987b. Field bioassay and laboratory chemical analysis of controlled-release dispensers for the pheromone of the boll weevil, *Anthonomus grandis*, pp. 249-250. *In* Proceedings, Intern. Symp. on Controlled Release of Bioactive Materials, August 2-5, 1987, Toronto, Canada.

Dickerson, W. A., R. L. Ridgway, F. R. Planer, J. R. Brazzel, and T. J. Bradway. 1986. Pheromone trap captures and insecticide use in the Southeastern boll weevil eradication program, pp. 231-232. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Dilday, R. H. 1986. Development of a cotton plant with glandless seed and glanded foliage and fruiting forms. Crop Sci. 26: 639-641.

Dilday, R. H., H. Muramoto, and H. E. Brown. 1982. Potential development of a glanded cotton genotype which produces glandless seed, pp. 136. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Dilday, R. H., and T. N. Shaver. 1976a. Survey of the regional *Gossypium hirsutum* L. primitive race collection for flower bud gossypol. USDA Report ARS-S-80.

Dilday, R. H., and T. N. Shaver. 1976b. Survey of the regional *Gossypium hirsutum* L. primitive race collection for flower bud gossypol and seasonal variation between years in gossypol percentage. USDA Report ARS-S-146.

Dilday, R. H., and T. N. Shaver. 1980. Variability in flower-bud gossypol content and agronomic and fiber properties within the primitive race collection of cotton. Crop Sci. 20: 91-95.

Dinkins, R. L., J. R. Brazzel, and C. A. Wilson. 1970a. Species and relative abundance of *Chrysopa*, *Geocoris*, and *Nabis* in Mississippi cotton fields. J. Econ. Entomol. 63: 660-661.

Dinkins, R. L., J. R. Brazzel, and C. A. Wilson. 1970b. Seasonal incidence of major predaceous arthropods in Mississippi cotton fields. J. Econ. Entomol. 63: 814-817.

Dittrich, V. 1967. A formamidine acaricide as an ovicide for three insect species. J. Econ. Entomol. 60: 13-156.

Dittrich, V. 1969. Chlorophenamidine negatively correlated with OP resistance in a strain of two-spotted spider mite. J. Econ. Entomol. 65: 44-47.

Dittrich, V., S. C. Hassan, and G. E. Ernst. 1985. Sudanese cotton and the whitefly: a case study of the emergence of a new primary pest. Crop Prot. 4: 161-176.

Dittrich, W., S. O. Hassen, and G. H. Ernst. 1986. Development of a new primary pest of cotton in the Sudan: *Bemisia tabaci*, the whitefly. Agric. Ecos. Environ. 17: 1337-1342.

Doane, C. C., and T. W. Brooks. 1981. Research and development of pheromones for insect control with emphasis on the pink bollworm, pp. 285-303. *In* E. Mitchell (ed.), Management of Insect Pests - Concepts and Practice. Plenum Press, New York.

Doutt, R. L. 1964. Biological characteristics of entomophagous adults, pp. 145-167. *In* P. DeBach (ed.), Biological control of insect pests and weeds. Reinhold, New York.

Doutt, R. L., and R. F. Smith. 1971. The pesticide syndrome, pp. 3-15. *In* C. B. Huffaker (ed.), Biological control. Plenum, New York.

Doutt, R. L., and R. L. Smith. 1971. The pesticide syndrome-diagnosis and suggested prophylaxis, pp. 3-15. *In* C. B. Huffaker (ed.) Biological Control. Plenum, New York.

Dover, B. D., D. H. Davies, and S. B. Vinson. 1988. Dose-dependent influence of *Campoletis* *sonorensis* polydnavirus on the development and ecdysteroid titers of last-instar *Heliothis virescens* larvae. Archiv. of Insect Biochem. and Physiol. 8: 113-126.

Dowd, P. F. 1989. In situ production of hydrolytic detoxifying enzymes by symbiont yeast in the cigarette beetle (Coleoptera: Anobiidae). J. Econ. Entomol. 82: 396-400.

Dowd, P. F., C. C. Gagne, and T. C. Sparks. 1977. The involvement of hydrolysis in pyrethroid resistance in the tobacco budworm, *Heliothis virescens* (F.). Pestic. Biochem. Physiol. 28: 9-16.

Dowd, P. F., and T. C. Sparks. 1987a. Comparisons of midgut, fat body, and cuticular enzymes from Pseudoplusia includens (Walker) and Heliothis *virescens* (F.) responsible for the hydrolysis of permethrin and fenvalerate. Pestic. Biochem. Physiol. 27: 309-317.

Dowd, P. F., and T. C. Sparks. 1987b. Comparative hydrolysis of permethrin and fenvalerate in *Pseudoplusia includens* (Walker) and *Heliothis virescens* (F.). Pestic. Biochem. Physiol 27: 123-131.

Dowd, P. F., and T. C. Sparks. 1987c. Inhibition of *trans*-permethrin hydrolysis in *Pseudoplusia includens* (Walker) and the use of inhibitor as pyrethroid synergists. Pestic. Biochem. Physiol. 27: 237-245.

Dowd, P. F., and T. C. Sparks. 1988. Relative toxicity and ester hydrolysis of pyrethroids in *Pseudoplusia includens* (Walker) and *Heliothis virescens* (L.). J. Econ. Entomol. 81: 1014-1018.

Drabek, J., and R. Neuman. 1985. Proinsecticides, pp. 35-86. *In* D. H. Hutson, and T. R. Roberts (eds.), Insecticides. John Wiley and Sons, New York.

Drake, V. A. 1985. Radar observations of moths migrating in a nocturnal low-level jet. Ecol. Entomol. 10: 259-265.

Drake, V. A., and R. A. Farrow. 1988. The influence of atmospheric structure and motions on insect migration. Ann. Rev. Entomol. 33: 183-210.

Drake, W. A. 1984. The vertical distribution of macro-insects migrating in the nocturnal boundary layer: a radar study. Boundary-Layer Meteorol 28: 353-374.

Drost, Y. C., W. J. Lewis, and J. H. Tumlinson. 1987. Beneficial arthropod behavior mediated by airborne semiochemicals V. Influence of rearing method, host plant, and adult experience on host-searching behavior of *Microplitis croceipes* (Cresson), a larval parasitoid of "Heliothis". J. Chem. Ecol. 14: 1607-1616.

Drost, Y. C., W. J. Lewis, P. O. Zannen, and M. A. Keller. 1986. Beneficial arthropod behavior mediated by airborne semiochemicals I. Flight behavior and preflight handling of *Microplitis croceipes* (Cresson). J. Chem. Ecol. 12: 1247-1262.

Duce (ed.), I. R. 1992. Neurotox '91: Molecular basis of drug and pesticide action. Elsevier, New York.

Ducoff, H. S., A. P. Vaughn, and J. L. Crossland. 1969. Dose-fractionation studies on adult flower beetles. Radiat. Res. 39: 472.

Ducoff, H. S., A. P. Vaughn, and J. L. Crossland. 1971. Dose-fractionation and the sterilization of radiosensitiive male confused flour beetles. J. Econ. Entomol. 64: 541-543.

Duelli, P. 1980a. Preovispository migration flights in the green lacewing *Chrysopa carnea* (Planipennia: Chrysopidae). Behav. Ecol. Sociobiol. 7: 239-246.

Duelli, P. 1980b. Adaptive dispersal and appetitive flight in the green lacewing *Chrysopa carnea*. Ecol. Entomol. 5: 213-220.

Duffus, J. E., and R. A. Flock. 1982. Whitefly-transmitted disease complex of the Desert Southwest. Calif. Agric. 36: 4-6.

Duffy, P. A., D. L. Cain, G. J. Young, and M. E. Wetzstein. 1994. Effects of the boll weevil eradication program on Alabama cotton farms. Dept. Agric. Econ., Auburn University, Alabama.

Duggar, J. F. 1897. Experiments with cotton. Ala. Agr. Exp. Sta. Bull. 76.

Duggar, J. F. 1898. Experiments with cotton. Ala. Agr. Exp. Sta. Bull. 89.

Duggar, J. F. 1899. Results of experiments on cotton in Alabama. Ala. Agr. Exp. Sta. Bull. 107.

Duggar, J. F. 1899. The manuring of cotton. Ala. Agr. Exp. Sta. Bull. 107.

Duke, S. O., J. J. Menn, and J. R. Plimmer (eds.). 1993. Pest control with enhanced environmental safety. American Chemical Society, Washington, D.C.

Dulmage, H. T. 1981. Insecticidal activity of isolates of *Bacillus thuringiensis* and their potential for pest control, pp. 193-222. *In* H. D. Burgess (ed.), Microbial control of pests and plant diseases 1970-1980. Academic Press, New York.

Dulmage, H. T., H. M. Graham, and E. Martinez. 1978. Interactions between the tobacco budworm, *Heliothis virescens*, and the delta-endotoxin produced by the HD-1 isolate of Bt. var. Kurstaki: relationship between length of exposure to the toxin and survival. J. Invertebr. Pathol. 32: 40-50.

Dunbar, D. M., and O. G. Bacon. 1972a. Influence of temperature on development and reproduction of *Geocoris atricolor*, *G. pallens*, and *G. punctipes* (Heteroptera: Lygaeidae) from California. Environ. Entomol. 1: 596-599.

Dunbar, D. M., and O. G. Bacon. 1972b. Feeding, development, and reproduction of *Geocoris punctipes* (Heteroptera: Lygaeidae) on eight diets. Ann. Entomol. Soc. Amer. 65: 892-895.

Duncombe, W. G. 1973. The acaricide spray rotation for cotton. Rhodesia Agr. J. 70: 115-118.

Dunkelblum, E., and M. Kehat. 1989. Female sex pheromone components of *Heliothis peltigera* (Lepidoptera: Noctuidae). Chemical identification from gland extracts and male response. J. Chem. Ecol. 15: 2233-2245.

Dunn, P. H., and B. J. Mechalis. 1963. The potential of *Beauveria bassiana* (Balsamo) Vuillemin as a microbial insecticide. J. Insect Pathol. 5: 451-459.

Durkin, J. J. 1961. Control cotton insects in New Mexico. NM Coop. Ext. Serv. Circ. 321.

Durkin, J. J. 1959. Use of *Trichograma* wasps in cotton insect control. NM Coop. Ext. Serv. Insect Letter for May 4, 1959.

Durkin, J. J. 1964. Control cotton insects in New Mexico. NM Coop. Ext. Serv. 400 J-10.

Durkin, J. J. 1966a. Control cotton insects. NM Coop. Ext. Serv. Circ. 390.

Durkin, J. J. 1966b. Control pink bollworms. NM Coop. Ext. Serv. 400-A-201.

Durkin, J. J. 1967. Cotton stalks outlawed. NM Coop. Ext. Serv. Insect Letter. Dec. 5, 1967.

Durkin, J. J. 1968. Control pink bollworms. NM Coop. Ext. Serv. 400 J-20.

Durkin, J. J. 1973. Cotton insect management suggestions. NM Coop. Ext. Serv. Circ. 454.

Durkin, J. J. 1978. Cotton insect management suggesions for 1978. NM Coop. Ext. Serv. Circ. 400 J-7.

Durkin, J. J., and L. Gholson. 1980. Cotton insect management suggestions. NM Coop. Ext. Serv. Circ.

Earle, M. W., S. S. Nilakhe, and L. A. Simmons. 1979. Mating ability of irradiated male boll weevils treated with diflubenzuron or penfluron. J. Econ. Entomol. 72: 334-336.

Earle, N. W., and R. A. Leopold. 1975. Sterilization of the boll weevil: vacuum fumigation with hempa combined with feeding busulfan-treated diet. J. Econ. Entomol. 68: 283-286.

Earle, N. W., and L. D. Newsom. 1964. Initiation of diapause in the boll weevil. J. Insect Physiol. 10: 131-139.

Earle, N. W., and L. A. Simmons. 1979. Boll weevil: ability to fly affected by irradiated male boll weevils treated with diflubenzuron or penfluron. J. Econ. Entomol. 72: 334-336.

Earle, N. W., L. A. Simmons, S. S. Nilakhe, E. J. Villavaso, G. H. McKibben, and P. P. Sikorowski. 1978. Pheromone production and sterility in boll weevils: effect of acute and fractionated gamma irradiation. J. Econ. Entomol. 71: 591-595.

Eaton, F. M. 1931. Early defloration as a method of increasing cotton yields and the relation of fruitfulness to fiber and boll characteristics. J. Agr. Res. 42: 447-462.

Eden, W. G. 1978. Eradication of plant pests. Bull. Entomol. Soc. Amer. 24: 52-54.

Edson, K. M., S. B. Vinson, D. B. Stoltz, and M. D. Summers. 1981. Virus in a parasitoid wasp: suppression of the cellular immune response in the parasitoid's host. Science 211: 582-583.

Edwards, D. R., N. C. Leppla, and W. A. Dickerson. 1987. Arthropod species in culture. Entomological Society of America.

Eger Jr., J. E., W. L. Sterling, and A. W. Hartstack Jr. 1982. Population dynamics of *Heliothis* spp. on *Castilleja indivisa*, an unreported host plant, and *Lupinus texensis* in Texas. Environ. Entomol. 11: 327-333.

Ehart, O. R., C. Chesters, and K. J. Sherman. 1986. Ground water regulations: impact, public acceptance, and enforcement, pp. 488-498. *In* W. Y. Garner, R. C. Honeycutt, and H. N. Nig (eds.), Evaluation of pesticides in ground water. Symposium Series 315. American Chemical Society, Washington, D.C.

Ehler, L. E., K. G. Eveleens, and R. van den Bosch. 1973. An evaluation of some natural enemies of cabbage looper on cotton in California. Environ. Entomol. 2: 1009-1015.

Ehler, L. E., and J. C. Miller. 1978. Biological control in temporary agroecosystems. Entomophaga 23: 207-212.

Ehling, C. F., T. J. Henneberry, and L. A. Bariola. 1983. Chemical termination experiments at Brawley, pp. 56-58. *In* Proc. Beltwide Cotton Prod. Res. Conf.

El-Sayed, G., and C. H. Knowles. 1984a. Formamidine synergism of pyrethroid toxicity to twospotted spider mites (Acari: Tetranychidae). J. Econ. Entomol. 77: 23-30.

El-Sayed, G., and C. H. Knowles. 1984b. Synergism of insecticide activity to *Heliothis zea* (Boddie) (Lepidoptera: Noctuidae) by formanilides and formamidines. J. Econ. Entomol. 77: 872-875.

El-Zik, K. M., and R. E. Frisbie. 1985. Integrated crop management systems for pest control and plant protection, pp. 21-122. *In* N. B. Mandava (ed.) CRC Handbook of Natural Pesticides: Methods, Vol. I, Theory, Practice and Detection. CRC Press, Inc., Boca Raton.

Elbert, A., H. Overbeck, K. Iwaya, and S. Tsuboi. 1992. Imidacloprid, a novel systemic nitromethylene analogue insecticide for crop protection, pp. 21-28. *In* Brighton Crop Protection Conference-Pests and Diseases.

Eldefrawi, M. E. 1985. Nicotine, pp. 263-272. *In* G. A. Kerkut, and L. I. Gilbert (eds.), Comprehensive Insect Physiology Biochemistry and Pharmacology, vol. 12. Pergamon Press, New York.

Eldefrawi, M. E., and A. T. Eldefrawi. 1990. Nervous-system-based insecticides, pp. 155-207. *In* E. Hodgson, and R. J. Kuhr (eds.), Safer Insecticides: Development and Use. Marcel Dekker, New York.

Elkarmi, L. A., M. K. Harris, and R. K. Morrison. 1987. Laboratory rearing of *Chrysoperla rufilabris* (Burmeister), a predator of insect pests of pecans. Southwest. Entomol. 12: 73-78.

Eller, F. J., J. H. Tumlinson, and W. J. Lewis. 1987. Beneficial arthropod behavior mediated by airborne semiochemicals. II. Olfactometric studies of host-location by the parasitoid *Microplitis croceipes* (Cresson) (Hymenoptera: Braconidae). J. Chem. Ecol. 14: 425-434.

Elliger, C. A., B. G. Chan, and A. C. Waiss Jr. 1978. Relative toxicity of minor cotton terpenoids compared to gossypol. J. Econ. Entomol. 71: 161-164.

Elliot, F., and A. C. Gunter. 1952. Texas Agr. Ext. Ser. L. 173.

Elliott, M. 1971. The relationship between the structure and the activity of pyrethroids. Bull. W. H. O. 44: 315-317.

Elliott, M. 1976. Properties and applications of pyrethroids. Environ. Health Perspect. 14: 3-13.

Elliott, M. 1977. Synthetic pyrethroids, pp. 1-28. *In* M. Elliott (ed.), Synthetic Pyrethroids. American Chemical Society, Washington, D.C.

Elliott, M. 1985. Lipophilic insect control agents, pp. 73-102. *In* N. F. Janes (ed.), Recent Advances in the Chemistry of Insect Control. Royal Society of Chemistry, London.

Elliott, M. 1990. Pyrethroid insecticides and human welfare, pp. 345-355. *In* J. E. Casida (ed.), Pesticide and Alternatives: Innovative Chemical and Biological Approaches to Pest Control. Elsevier, New York.

Elliott, M., A. W. Farnham, N. F. Janes, P. H. Needham, D. A. Pulman, and J. H. Stevenson. 1973. A photostable pyrethroid. Nature 246: 169-170.

Elliott, M., N. F. Janes, and C. Potter. 1978. The future of pyrethroids in insect control. Annu. Rev. Entomol. 23: 443-469.

Ellsworth, P., L. Moore, and T. F. Watson. 1993. Insect pest management for cotton. Ariz. Coop. Ext. Publ. 193003.

Elsey, K. D. 1974. Influence of plant host on searching speed of two predators. Entomophaga 19: 3-6.

Elzen, G. W., S. H. Martin, and J. B. Graves. 1993. Characterization of tobacco budworm resistnce: seasonal aspects and synergism, pp. 1024-1028. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Elzen, G. W., P. J. O'Brien, and J. E. Powell. 1989. Toxic and behavioral effects of selected insecticides on the *Heliothis* parasitoid *Microplitis croceipes*. Entomophaga 34: 87-94.

Elzen, G. W., P. J. O'Brien, and G. L. Snodgrass. 1990. Toxicity various classes of insecticide to pyrethroid resistant *Heliothis virescens* larvae. Southwest. Entomol. 15: 33-37.

Elzen, G. W., P. J. O'Brien, G. L. Snodgrass, and J. E. Powell. 1987. Susceptibility of the parasitoid *Microplitis croceipes* (Hymenoptera: Braconidae) to field rates of selected cotton insecticides. Entomophaga 32: 545-550.

Elzen, G. W., and J. E. Powell. 1988. Mating behavior and sex pheromone response of the *Heliothis* parasitoid *Microplitis croceipes*, pp. 257-260. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Elzen, G. W., and J. E. Powell. 1989. Mate finding and mating behavior of Microplitis croceipes, pp. 49-52. *In* J. E. Powell, D. L. Bull, and E. G. King (eds.), Biological control of *Heliothis* spp. by *Microplitis croceipes*. Southwest. Entomol. Suppl. 12.

Elzen, G. W., H. J. Williams, and S. B. Vinson. 1983. Response by the parasitoid *Campoletis sonorensis* (Hymenoptera: Ichneumonidae) to chemicals (synomones) in plants: implications for host habitat location. Environ. Entomol. 12: 1873-1877.

Elzen, G. W., H. J. Williams, and S. B. Vinson. 1984a. Isolation and identification of cotton synomones mediating searching behavior by parasitoid *Campoletis sonorensis*. J. Chem. Ecol. 10: 1251-1264.

Elzen, G. W., H. J. Williams, and S. B. Vinson. 1984b. Role of diet in host selection of *Heliothis virscens* by parasitoid *Campoletis sonorensis* (Hymenoptera: Ichneumonidae). J. Chem. Ecol. 10: 1535-1541.

Elzen, G. W., H. J. Williams, S. B. Vinson, and J. E. Powell. 1987. Comparative flight behavior of parasitoids *Campoletis sonorensis* and *Microplitis croceipes*. Entomol. Exp. Appl. 445: 175-180.

Enfield, F. D., D. T. North, R. Erickson, and L. Rotering. 1983. A selection plateau for radiation resistance in the cotton boll weevil. Theor. Appl. Genet. 65: 277-281.

Enfield, F. D., D. T. North, and R. Erickson. 1981. Response to selection for resistance to gamma radiation in the cotton boll weevil. Ann. Entomol. Soc. Am. 74: 422-424.

Entomological Society of America. 1989. Common names of insects and related organisms. Entomological Society of America, Lanham, Maryland.

Esselbaugh, C. O. 1946. A study of the eggs of the Pentatomidae (Hemiptera). Ann. Entomol. Soc. Amer. 39: 667-691.

Essig, E. O. 1926. Insects of Western North America. The MacMillan Co., New York.

Essig, E. O., R. C. Dickson, R. F. Smith, and J. E. Swift. 1955. Common species of aphids found on alfalfa and clovers in California. Univ. Calif. Mimeo. No. 2.

Eto, M. 1974. Organophosphorus Insecticides: Organic and Biological Chemistry. CRC Press, Cleveland.

Eto, M. 1992. Rational approaches to finding agrochemical leads, pp. 147-161. *In* W. Draber, and T. Fujita (eds.), Rational approaches to structure, activity, and ecotoxicity of agrochemicals. CRC Press, Boca Raton, FL.

Eto, M., S. Okabe, Y. Ozoe, and K. Maekawa. 1977. Oxidative activation of *O,S*-dimethyl phosphoramidothiolate. Pestic. Biochem. Physiol. 7: 367-377.

Evans, P. D. 1985. Biogenic amines and second messenger systems, pp. 117-131. *In* H. C. von Keyserlingk, A. Jager, and S. C. von (eds.). Approaches to new leads for insecticides. Springer-Verlag, New York.

Eveleens, K. G., R. van den Bosch, and L. E. Ehler. 1973. Secondary outbreak induction of beet armyworm by experimental insecticide applications in cotton in California. Environ. Entomol. 2: 497-503.

Ewing, H. E. 1914. The common red spider or spider mite. Oreg. Agric. Exp. Stn. Bull. 121: 1-95.

Ewing, K. P. 1929. Effects on the cotton plant of the feeding of certain Hemiptera of the family Miridae. J. Econ. Entomol. 22: 761-765.

Ewing, K. P., and E. E. Ivy. 1943. Some factors influencing bollworm populations and damage. J. Econ. Entomol. 36: 602-606.

Ewing, K. P., and C. R. Parencia Jr. 1950. Early-season applications of insecticides on a community-wide basis for cotton insect control in 1950. USDA, Bureau of Entomol. and Plant Quarantine E 810: 8.

Eyer, J. R., and J. T. Medler. 1941. Control of thrips on seedling cotton. J. Econ. Entomol. 34: 726-727.

Eyer, J. R., and J. T. Medler. 1942a. Control of hemipterous cotton insects by the use of dusts. J. Econ. Entomol. 35: 630-634.

Eyer, J. R., and J. T. Medler. 1942b. Control of hemipterous cotton insects by insecticidal dusts. NM Agric. Exp. Sta. Press Bull. 949.

Fadare, T. A. 1967. Susceptibility of the bollworm, *Heliothis zea* (Boddie), to DDT in Arizona. Masters Thesis, Univ. of Ariz.

Falcon, L. A. 1971. Microbial control as a tool in integrated control programs, pp. 346-364. *In* C. B. Huffaker (ed.), Biological control. Plenum Press, New York.

Falcon, L. A. 1978. Application technology: improving coverage with microdroplet applicator. *In* G. E. Allen, C. M. Ignoffo, and R. E. Jacques (eds.), Proceeding, NSF-USDA-Univ. Fl. Workshop on Microbial Control of Insect Pests: Future Strategies in Pest Management Systems.

Falcon, L. A., R. van den Bosch, J. Gallagher, and A. Davidson. 1971. Investigations on the pest status of *Lygus hesperus* in cotton in central California. J. Econ. Entomol. 64: 56-61.

Farlow, R. A., G. Giddard, R. Kepner, K. Umeda, and J. R. Whitehead. 1992. Efficacy of pirate insecticide-miticide against insect and mite pests of U. S. cotton, pp. 877-880. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Farr, C. R., and M. L. Lame. 1987. Late season agronomic evaluation of boll weevil control programs, pp. 341. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Farrar Jr., R. R., and J. R. Bradley Jr. 1985. Effect of within-plant distribution of *Heliothis zea* (Boddie) (Lepidoptera: Noctuidae) eggs and larvae on larva development and survival on cotton. J. Econ. Entomol. 78: 1233-1237.

Farrow, R. A., and J. C. Daly. 1987. Long-range movement as an adaptive strategy in the genus *Heliothis* (Lepidoptera: Noctuidae): a review of its occurrence and detection in four pest species. Aust. J. Zool. 35: 1-24.

Faulkner, L. R. 1950a. Thrips of economic importance in the Mesilla Valley of New Mexico. NM Agric. Exp. Sta. Press Bull. 11037.

Faulkner, L. R. 1950b. New Mexico cotton insects of economic importance. NM Agric. Exp. Press Bull. 1039.

Faust, R. M., and L. A. Bulla Jr. 1982. Bacteria and their toxins as insecticides, pp. 75-208. *In* E. Kurstak (ed.), Microbial and viral pesticides. Marcel Dekker, New York.

Federici, B. A. 1983. Enveloped double-stranded DNA insect virus with novel structure and cytopathology. Proc. Natl. Acad. Sci. USA 80: 7664-7668.

Federici, B. A. 1986. Ultrastructure of baculoviruses, pp. 61-68. *In* R. R. Granados, and B. A. Federici (eds.), The biology of baculoviruses, vol. I biological properties and molecular biology. CRC Press, Inc., Boca Raton.

Feldman, R. M., and G. L. Curry. 1983. A PDE formulation and numerical solution for a boll weevil-cotton crop model. Comp. & Maths. with Appls. 9: 393-402.

Feldman, R. M., and G. L. Curry. 1984. Mathematical foundations for modeling poikilotherm mortality. Math. Biosci. 71: 81-104.

Feldman, R. M., G. L. Curry, and T. E. Wehrly. 1984. Statistical procedure for validating a simple population model. Environ. Entomol. 13: 1446-1451.

Fenton, F. A. 1929. Biological notes on the pink bollworm (*Pectinophora gossypiella* Saunders) in Texas. Inter. Congress Entomol. 2: 439-447.

Fenton, F. A., and E. W. Dunnam. 1928. Dispersal of the cotton-boll weevil, *Anthonomus grandis* Boh. J. Agric. Res. 36: 135-149.

Fenton, F. A., and E. W. Dunnam. 1929. Biology of the cotton boll weevil at Florence, South Carolina. USDA Tech. Bull. No. 112.

Fenton, F. A., and W. L. Owen Jr. 1931. Hibernation of *Pectinophora gossypiella* in Texas. J. Econ. Entomol. 24: 1197-1207.

Fenton, F. A., and W. L. Owen Jr. 1953. The pink bollworm of cotton in Texas. Misc. Publ., Texas Agric. Exp. Stn., Texas A&M College System, College Station, Texas.

Ferguson, J. 1988. Breaking biotech barriers. Ag. Consultant 44: 5-6.

Fergusson-Kolmes, L. A., J. G. Scott, and T. J. Dennehy. 1991. Dicofol resistance in *Tetranychus urticae* (Acari: Tetranychidae): Cross-resistance and pharmacokinetics. J. Econ. Entomol. 84: 41-48.

Ferris, E. B. 1904. Report of work at McNeill Branch Station for 1903. Mississippi Agr. Exp. Sta. Bull. 83.

Ferro, D. N. 1993. Potential for resistance to *Bacillus thuringiensis*: Colorado potato beetle (Coleoptera: Chrysomelidae)-A model system. Am. Entomol. 39: 38-44.

Ferron, P. 1978. Biological control of insect pests by entomogenous fungi. Ann. Rev. Entomol. 23: 409-442.

Ferron, P. 1981. Pest control by the fungi *Beauveria* and *Metarhizium*, pp. 465-482. *In* H. D. Burges (ed.), Microbial control of pests and plant diseases. Academic Press, New York.

ffrench-Constant, R. H., S. J. Clark, and A. L. Devonshire. 1988a. Effect of decline of insecticide residues on selection for insecticide resistance in *Myzus persicae* (Sulzer) (Hemiptera: Aphididae). Bull. Entomol. Soc. Amer. 78: 19-29.

ffrench-Constant, R. H., A. L. Devonshire, and R. D. White. 1988b. Spontaneous loss and reselection of resistance in extremely resistant *Myzus persicae* (Sulzer). Pestic. Biochem. Phyiol. 30: 1-10.

Field, L. M., A. L. Devonshire, and B. G. Forde. 1988. Molecular evidence that insecticide resistance in peach-potato aphids (*Myzus persicae* Sulz.) results from amplification of an esterase gene. Biochem. J. 251: 309-312.

Fife, L. D., I. Shiller, and A. J. Chapman. 1947. Pink bollworm carryover from one cotton crop to the next in the lower Rio Grande Valley. J. Econ. Entomol. 40: 540-545.

Fillman, D. A., and W. L. Sterling. 1983. Killing power of the red imported fire ant (Hym.: Formicidae): a key predator of the boll weevil (Col.: Curculionidae). Entomophaga 28: 339-344.

Fillman, D. A., and W. L. Sterling. 1985. Inaction levels for the red imported fire ant, *Solenopsis invicta* (Hym.: Formicidae): a predator of the boll weevil, *Anthonomus grandis* (Col.: Curculionidae). Agric. Ecosys. Environ. 13: 93-102.

Fincher, G. T., and H. O. Lund. 1967. Notes on the biology of the imported fire ant, *Solenopsis saevissima richteri* Forel in Georgia. J. Ga. Entomol. Soc. 2: 91-94.

Finney, J. R. 1991. Where do we stand - where do we go?, pp. 555-576. *In* H. Frehse (ed.), Pesticide chemistry. Advnces in international research, development and legislation. VCH, Weinheim.

Firko, M. J. 1991. Insecticide resistance: the myth of single gene inheritance, pp. 651-653. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Firko, M. J., and E. G. King. 1990. Genetic improvement of tobacco budworm sterile hybrid: Pyrethroid resistance, pp. 312-314. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Firko, M. J., and D. A. Wolfenbarger. 1991. Tolerance to cypermethrin in Texas and Mississippi of tobacco budworm: genetic analysis and relationship between LD50 estimates and observation time, pp. 657-659. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Fischhoff, D. A., K. S. Bowdish, F. J. Perlak, P. G. Marrone, S. J. G. Niedermeyer, D. A. Dean, K. Kusano-Kretsmer, E. J. Mayer, D. E. Rochester, S. G. Rogers, and R. T. Fraley. 1987. Insect tolerant transgenic tomato plants. Biotechnology 5: 807-813.

Fischoff, D. A. 1992. Management of lepidopteran pests with insect resistant cotton: recommended approaches, pp. 751-753. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Fisher, M. H. 1985. The avermectins, pp. 53-72. *In* N. F. Janes (ed.), Recent advances in the chemistry of insect control. Royal Society of Chemistry, London.

Fisher, M. H. 1990. Novel avermectin insecticides and miticides, pp. 52-68. *In* L. Crombie (ed.), Recent advances in the chemistry of insect control II. Royal Society of Chemistry, Cambridge, U.K.

Fisher, M. H. 1993. Recent progress in avermectin research, pp. 169-182. *In* S. O. Duke, J. J. Menn, and J. R. Plimmer (eds.), Pest control with enhanced environmental safety. American Chemical Society, Washington, D.C.

Fisher, R. W., and D. R. Menzies. 1976. Effect of spray droplet density and exposure time on the immobility of newly-hatched oriental fruit moth larvae. J. Econ. Entomol. 69: 438-440.

Fisher, R. W., D. R. Menzies, D. C. Herne, and M. Chida. 1974. Parameters of dicofol spray deposit in relation to mortality of European red mite. J. Econ. Entomol. 67: 124-126.

Fisher, S. W., and D. L. Wrensch. 1986. Quantification of biological effectiveness for pesticides against *Tetranychus urticae* (Acarina: Tetranychidae). J. Econ. Entomol. 79: 1472-1476.

Fisher, W. R., and N. C. Leppla. 1985. Insectary design and operation, pp. 167-183. *In* P. Singh, and R. F. Moore (eds.), Handbook of Insect Rearing, Vol. 1 Elsevier, New York.

Fitt, G. P. 1984. Comparisons of the biology of pyrethroid resistant and susceptible *Heliothis armigera*, pp. 103-122. *In* Proc. Australian Cotton Growers Res. Conf., Toowoomba, Australia.

Fitt, G. P. 1989. The ecology of *Heliothis* species in relation to agroecosystems. Annu. Rev. Entomol. 34: 17-52.

Flamm, R. O., R. N. Coulson, J. A. Jordan, M. E. Sterle, H. N. Brodale, R. J. Mayer, F. L. Oliveria, D. Drummond, P. J. Barry, and K. M. Swain. 1991. The integrated southern pine beetle expert system: ISPBEX. Expert Sys. with Applications 2: 97-105.

Flanders, S. E. 1962. The parasitic Hymenoptera: specialists in population regulation. Can. Entomol. 94: 1133-1147.

Fleischer, S. J., and M. J. Gaylor. 1987. Seasonal abundance of *Lygus lineolaris* (Hemiptera: Miridae) and selected predators in early season uncultivated hosts: implications for managing movement into cotton. Environ. Entomol. 16: 379-389.

Fleischer, S. J., and M. J. Gaylor. 1988. *Lygus lineolaris* (Heteroptera: Miridae) population dynamics: Nymphal development, life tables, and Leslie matrices on selected weeds and cotton. Environ. Entomol. 17: 246-253.

Fleischer, S. J., M. J. Gaylor, and N. V. Hue. 1988. Dispersal of *Lygus lineolaris* (Heteroptera: Miridae) adults through cotton following nursery host destruction. Environ. Entomol. 17: 533-541.

Fletcher, R. K., and F. L. Thomas. 1943. Natural control of eggs and first instar larvae of *Heliothis armigera*. J. Econ. Entomol. 36: 557-560.

Flint, H. M., W. R. Bibow, and C. K. Lahren. 1966. Radiation studies with the boll weevil: lethal effects on larvae, pupae and adults; male sterility and dose fractionation. J. Econ. Entomol. 59: 1249-1255.

Flint, H. M., N. F. Curtice, and Q. H. Siddiqui. 1987. Early to mid-season distribution of male pink bollworms as determined with pheromone traps in host and non-host crops. Southwest. Entomol. 12: 139-145.

Flint, H. M., and E. L. Kressin. 1967. Gamma irradiation of pupae of the tobacco budworm. J. Econ. Entomol. 60: 1655-1659.

Flint, H. M., and E. L. Kressin. 1968. Gamma irradiation of the tobacco budworm: sterilization, competitiveness, and observations on reproductive biology. J. Econ. Entomol. 61: 477-483.

Flint, H. M., and F. R. Merkle. 1981. Early-season movements of pink bollworm male moths between selected habitats. J. Econ. Entomol. 74: 366-371.

Flint, H. M., S. S. Salter, and S. Walters. 1979. Caryophyllene: an attractant for the green lacewing. Environ. Entomol. 8: 1123-1125.

Flint, H. M., F. D. Wilson, and N. J. Parks. 1989. Causes of square shed on cotton in Central Arizona. Southwest. Entomol. 14: 271-278.

Flint, H. M., B. Wright, H. Sallam, and B. Horn. 1975a. A comparison of irradiated or chemosterilized pink bollworm moths for suppressing native populations in field cages. Canadian Entomol. 107: 1069-1072.

Flint, H. M., B. S. Wright, A. A. Sallam, and B. Horn. 1975b. Dispersal and mating in the field by male pink bollworm, *Pectinophora gossypiella*, labeled with 32P. Entomol. Exp. Appl. 18: 451-456.

Folsom, J. W. 1928. Calcium arsenate as a cause of aphid infestation. J. Econ. Entomol. 21: 174.

Folsom, J. W. 1932. Insect enemies of the cotton plant. USDA Farmers' Bull. 1688.

Folsom, J. W. 1936. Notes on little-known cotton insects. J. Econ. Entomol. 29: 282-285.

Folsom, J. W. 1936. Observations of *Microbracon mellitor* in relation to the boll weevil. J. Econ. Entomol. 29: 111-116.

Foote, L. 1988. Pink bollworm program in the San Joaquin Valley, California, pp. 8-9. *In* Proc.International Cotton Pest Work Committee, Puerto Vallarta, Mexico.

Forbes, A. R., B. D. Frazer, and C. K. Chan. 1985. Aphids, pp. 353-359. *In* P. Singh, and R. F. Moore (eds.), Handbook of Insect Rearing. Elsevier, New York.

Forgash, A. J. 1984. History, evolution and consequences of insecticide resistance. Pestic. Biochem. Physiol. 22: 178-186.

Fox, J. L. 1992. Insect resistant to Bt delta-endotoxin: What it means for farming practices and the environment. National Audubon Society, Washington, D.C.

Fox, J. W. 1907. Report of work at the Delta Station for 1906. Mississippi Agr. Exp. Sta. Bull. 106.

Frank, A. W. 1985. The cotton gazetteer. Arlen W. Frank. Slidell, LA.

Franklin, E. J., and C. O. Knowles. 1981. Metabolism of diflubenzuron by spider mites and bean plants. Pestic. Sci. 12: 133-141.

Franklin, E. J., and C. O. Knowles. 1984. Degradation of xylyformamidines by the twospotted spider mite (Acari: Tetranychidae). J. Econ. Entomol. 77: 1405-1408.

Franklin, E. J., and C. O. Knowles. 1984. Influence of formamidines on two-spotted spider mite (Acarina: Tetranychidae) dispersal behavior. J. Econ. Entomol. 77: 318-323.

Frazer, B. D., and N. Gilbert. 1976. Coccinellids and aphids: a quantitative study of the impact of adult ladybirds (Coleoptera: Coccinellidae) preying on field populations of pea aphid (Homoptera: Aphididae). J. Entomol. Soc. Brit. Columb. 73: 33-56.

Freed, A. N. 1984. Foraging behavior in the jumping spider *Phidippus audax*: bases for selectivity. J. Zool. 203: 49-61.

French, R. A., and G. W. Hurst. 1969. Moth immigration in the British Isles in July 1968. Entomologist's Gazette 20: 37-44.

Fried, M. 1971. Determination of sterile insect competitiveness. J. Econ. Entomol. 64: 869-872.

Frisbie, R. E. 1981. A statewide pest management plan for Texas. Texas Agric. Exp. Stn. 8-81.

Frisbie, R. E. 1985. Regional implementation of cotton IPM, pp. 638-651. *In* R. E. Frisbie and P. L. Adkisson (eds.), CIPM: Integrated Pest Management on Major Agricultural Systems. Texas Agric. Exp. Stn. MP-1616.

Frisbie, R. E. 1987. Should growers be concerned about development of resistance to insecticides?, pp. 28-29. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Frisbie, R. E. and P. L. Adkisson. 1985. IPM: Definitions and current status in U.S. agriculture, pp. 41-51. *In* M. A. Hoy, and D. C. Herzog (eds.), Biological control in agricultural IPM systems. Academic Press, New York.

Frisbie, R. E., and P. L. Adkisson (eds.). 1985. CIPM: Integrated Pest Management on Major Agricultural Systems. Texas Agric. Exp. Stn. MP-1616.

Frisbie, R. E., J. L. Crawford, C. M. Bonner, and F. G. Zalom. 1989. Implementing IPM in cotton, pp. 389-412. *In* R. E. Frisbie, K. M. El-Zik, and L. T. Wilson (eds.), Integrated Pest Management Systems and Cotton Production. John Wiley and Sons, New York.

Frisbie, R. E., and G. M. McWhorter. 1986. Implementing a statewide pest management program for Texas, U.S.A., pp. 234-262. *In* J. Palti and R. Ausher (eds.), Advisory Work in Crop Pest and Disease Management. Springer-Verlag, Berling Heidelberg, Germany.

Frisbie, R. E., J. R. Phillips, W. A. Lambert, and H. B. Jackson. 1983. Opportunities for improving cotton insect management programs and some constraints on beltwide implementation, pp. 521-557. *In* R. L. Ridgway, E. P. Lloyd, and W. H. Cross (eds.), Cotton Insect Management with Special Reference to the Boll Weevil. USDA Agr. Handb. No. 589.

Frisbie, R. E., J. M. Sprott, R. D. Lacewell, R. D. Parker, W. E. Buxkemper, W. E. Baghley, and J. W. Norman. 1976. A practical method of economically evaluating an operational cotton pest management program in Texas. J. Econ. Entomol. 69: 211-214.

Frisbie, R. E., J. K. Walker Jr., K. M. El-Zik, and L. T. Wilson. 1989. Perspective on cotton production and integrated pest management, pp. 1-36. *In* R. E. Frisbie, K. M. El-Zik, and L. T. Wilson (eds.), Integrated Pest Management Systems and Cotton Production. John Wiley and Sons, New York.

Frisbie, R. E., and J. K. Walker. 1981. Pest management system for cotton insects, pp. 656. *In* D. Pimentel (ed.), CRC Handbook of pest management in agriculture, Vol. III.. CRC Press, Inc., Boca Raton.

Fristrom, J. W., and M. T. Clegg. 1988. Principles of genetics 2nd ed. Chiron Press, New York.

Fry, K. E., and T. J. Henneberry. 1977. Measuring leaf damage by the cotton leafperforator. J. Econ. Entomol. 70: 141-142.

Fry, K. E., and T. J. Henneberry. 1983. Yield reduction in upland cotton due to pink bollworm infestations and boll rot, pp. 77-80. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Fuchs, T. W., and J. A. Harding. 1976. Seasonal abundance of arthropod predators in various habitats in the Lower Rio Grande Valley of Texas. Environ. Entomol. 5: 288-290.

Fuchs, T. W., J. F. Leser, C. T. Allen, and E. P. Boring III. 1987. Management of cotton insects in the High Plains, Rolling Plains and Trans Pecos areas of Texas. Tex. Agric. Ext. Serv. B-1209.

Fuchs, T. W., J. F. Leser, E. P. Boring III, and C. W. Neeb. 1982. Management of cotton insects in the High Plains, Rolling Plains, and Trans-Pecos areas of Texas. Tex. Agric. Ext. Serv. B-1209.

Fukami, J. I. 1985. Insecticides as inhibitors of respiration, pp. 47-69. *In* H. C., Jager, A. von Keyserlingk, and C. von Szczepanski (eds.), Approaches to new leads for insecticides. Springer-Verlag, New York.

Fukuto, T. R. 1976. Physiochemical aspects of insecticidal action, pp. 397-428. *In* C. F. Wilkinson (ed.), Insecticide biochemistry and physiology. Plenum Press, New York.

Fukuto, T. R. 1979. Effect of structure on the interaction of organophosphorus and carbamate esters with acetylcholinesterase, pp. 277-295. *In* T. Narahashi (ed.). Neurotoxicology of insecticides and pheromones. Plenum Press, New York.

Fukuto, T. R. 1984. Propesticides, pp. 87-101. *In* P. S. Magee, G. K. Kohn, and J. J. Menn (eds.), Pesticide synthesis through rational approaches. American Chemical Society, Washington, D.C.

Fukuto, T. R., and S. Keadtisuke. 1992. Physical-organic concepts in structure-activity relationships in the development of insecticides, pp. 163-183. *In* W. Draber, and T. Fujita (eds.), Rational approaches to structure, activity, and ecotoxicity of agrochemicals. CRC Press, Boca Raton, FL.

Fullerton, D. 1982. Effects of plant coverage on whitefly control. Ariz. Agr. Exp. Sta. P-56.

Fullerton, D. G., L. P. Crowder, and T. F. Watson. 1975. Overwinter survival of pink bollworm larvae in buried cotton bolls. Environ. Entomol. 4: 514-516.

Furr, R. E. 1978. Toxicity of methomyl to tobacco budworm as determined by topical application. Southwest. Entomol. 3: 34-36.

Furr, R. E., and T. R. Pfrimmer. 1968. Effects of early-, mid-, and late season infestations of two-spotted spider mites on the yield of cotton. J. Econ. Entomol. 61: 1446-1447.

Furth, D. G. 1974. The stink bugs of Ohio. Bull. Ohio Biol. Survey N.S. 5: 1-60.

Fye, R. E. 1968. Spread of the boll weevil by drainage water and air currents. J. Econ. Entomol. 61: 1418-1424.

Fye, R. E. 1969. Longevity and fecundity of the boll weevil complex in Arizona. J. Econ. Entomol. 62: 1408-1412.

Fye, R. E. 1971. Grain sorghum—a source of insect predators for insects on cotton. Prog. Agr. in Ariz. 23: 12-13.

Fye, R. E. 1971. Mortality of mature larvae of the pink bollworm caused by high soil temperatures. J. Econ. Entomol. 64: 1568-1569.

Fye, R. E. 1980. Weed sources of *Lygus* bugs in the Yakima Valley and Columbia River Basin in Washington. J. Econ. Entomol. 73: 469-473.

Fye, R. E. 1982. Weed hosts of the *Lygus* (Heteroptera: Miridae) complex in central Washington. J. Econ. Entomol. 75: 724-727.

Fye, R. E., and C. D. Bonham. 1970. Analysis of populations of the boll weevil in one acre of cotton at Florence, South Carolina, in 1957-59. J. Econ. Entomol. 63: 1505-1510.

Fye, R. E., and C. D. Bonham. 1970. Summer temperatures of the soil surface and their effect on the survival of boll weevils in fallen cotton squares. J. Econ. Entomol. 63: 1599-1602.

Fye, R. E., and C. D. Bonham. 1972. Relationship of temperatures to boll weevil complex populations in Arizona. U.S. Dept. Agric., Agric. Res. Serv., Prod. Res. Rep. No. 136.

Fye, R. E., and R. L. Carranza. 1972. Movement of insect predators from grain sorghum in cotton. Environ. Entomol. 1: 790-791.

Fye, R. E., W. W. McMillian, A. R. Hopkins, and R. L. Walker. 1959. Longevity of overwintered and first generation boll weevils at Florence, South Carolina. J. Econ. Entomol. 52: 453-454.

Fye, R. E., W. W. McMillian, R. L. Walker, and A. R. Hopkins. 1959. The distance into woods along a cotton field at which the boll weevil hibernates. J. Econ. Entomol. 52: 310-313.

Fye, R. E., and C. R. Parencia Jr. 1972. The boll weevil complex in Arizona. USDA Prod. Res. Rept. No. 139.

Fye, R. E., R. Patana, and W. C. McAda. 1969. Developmental periods for boll weevils reared at several constant and fluctuating temperatures. J. Econ. Entomol. 62: 1402-1405.

Gaines, J. C. 1942. Effect of boll weevil and cotton aphid on yield as shown in a factorial experiment in 1941. J. Econ. Entomol. 35: 493-495.

Gaines, J. C., and H. G. Johnston. 1949. Destruction of stalks. Acco Press, June, Williamson County.

Gaines, R. C. 1935. Cotton boll weevil survival and emergence in hibernation cages in Louisiana. USDA Tech. Bull. No. 486.

Gaines, R. C. 1944. Federal reseach on cotton insects in 1943. Proc. South. War. Conf. Entomol.

Gaines, R. C. 1952. The boll weevil, pp. 501-504. *In* A. Stefferud (ed.), Insects: the yearbook of agriculture 1952. USDA, Washington, DC.

Gaines, R. C. 1954. Effect on beneficial insects of several insecticides applied for cotton insect control. J. Econ. Entomol. 47: 543-544.

Gaines, R. C. 1955. Effect on beneficial insects of three insecticide mixtures applied for cotton insect control in 1954. J. Econ. Entomol. 48: 477-478.

Gaines, R. C. 1957. Cotton insects and their control in the United States. Annu. Rev. Entomol. 2: 319-38.

Gaines, R. C. 1959. Ecological investigations of the boll weevil, Tallulah, Louisiana, 1915-1958. USDA Tech. Bull. No. 1208.

Gaines, R. C., M. T. Young, and G. L. Smith. 1940. Effect of insecticides used in boll weevil control upon aphids and mirids. J. Econ. Entomol. 33: 792-796.

Gameel, O. I. 1969. Studies on whitefly parasites *Encarsia lutea* Masi and *Eretmocerus mundus* Mercet. (Hymenoptera: Aphelinidae). Rev. Zool. Bot. Afr. 79: 65-77.

Gameel, O. I. 1977. *Bemisia tabaci*, pp. 320-322. *In* J. Kranz, H. Schmutterer, and W. Koch (eds.), Diseases, pests and weeds in tropical crops. Verlag, Berlin.

Gameel, O. I. 1978. The cotton whitefly, *Bemisia tabaci* (Genn.), in the Sudan Gezira, pp. 111-131. *In* Third seminar on the strategy for cotton pest control, May 8-10, 1978 Basel.

Gammon, D. W., M. A. Brown, and C. A. Casida. 1981. Two classes of pyrethroid action in the cockroach. Pestic. Biochem. Physiol. 15: 181-191.

Gannaway, J. R. 1994. Breeding for insect resistance, pp. 431-453. *In* G. A. Matthews, and J. P. Tunstall (eds.), Insect Pests of Cotton. University Press, Cambridge.

Gannaway, J. R., and D. R. Rummel. 1991. Field performance of cotton genetically-modified to express insecticidal protein from *Bacillus thuringiensis*. V. Halfway, TX., pp. 578. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Ganyard, M. C., J. R. Brazzel, J. H. Dillier, and A. E. Miller. 1981. Boll weevil eradication trial, pp. 38-40. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Ganyard, M. C., J. Dillier, and J. R. Brazzel. 1981. Operational report of the boll weevil eradication trial. Attachment C of Appendix A, biological evaluation of Beltwide boll weevil/cotton insect management programs. USDA, Science and Education Administration.

Gardner, S. M., and J. C. van Lenteren. 1986. Characterization of the arrestment responses of *Trichogramma evanescens*. Oecologia 68: 265-270.

Gardner, W. A., and J. R. Fuxa. 1980. Pathogens for the suppression of the fall armyworm. Fla. Entomol. 63: 439-447.

Garman, H., and G. G. Jewett. 1914. The life history and habits of the corn earworm (*Chloridea obsoleta*). Kentucky Agric. Exp. Stn. Bull. No. 187.

Gassner, G. D., D. Childress, G. Pomonis, and J. Eaton. 1974. Boll weevil chemosterilization by hypobarometric distillation. J. Econ. Entomol. 67: 278-280.

Gast, R. T. 1961. Factors involved in differential susceptibility of corn earworm larvae to DDT. J. Econ. Entomol. 54: 1203-1206.

Gast, R. T. 1961. Some shortcuts in laboratory rearing of boll weevils. J. Econ. Entomol. 54: 395-396.

Gast, R. T. 1966. Oviposition and fecundity of boll weevils in mass-rearing laboratory cultures. J. Econ. Entomol. 59: 173-176.

Gast, R. T., and T. B. Davich. 1966. Boll weevils, pp. 405-418. *In* C. N. Smith (ed.), Insect colonization and mass production. Academic Press, New York.

Gaston, L. D., R. S. Kaae, H. H. Shorey, and D. Sellers. 1977. Controlling the pink bollworm by disrupting sex pheromone communication between adult moths. Science 196: 904-905.

Gayen, A. K., and C. O. Knowles. 1981. Penetration and fate of methomyl and its oxime metabolite in insects and twospotted spider mites. Arch. Environ. Contam. Toxicol. 10: 55-67.

Gaylor, M. J., and F. R. Gilliland Jr. 1976. The relative and seasonal abundance of selected predaceous arthropods in Alabama cotton fields. Alabama Agric. Exp. Stn. Circ. 227.

Gaylor, M. J., and W. L. Sterling. 1975. Effects of temperature on the development, egg production, and survival of the cotton fleahopper, *Pseudatomoscelis seriatus*. Environ. Entomol. 4: 487-490.

Geier, P. W. 1966. Management of insect pests. Annu. Rev. Entomol. 11: 471-490.

Geier, P. W., and L. R. Clark. 1961. An ecological approach to pest control, pp. 10-18. *In* Proc. 8th Tech. Mtg. Intern. Union Consv. of Nature and Natural Res., Warsaw.

Geiser, M. 1986. The impact of molecular biology on the biotechnological development of *B. thuringiensis* delta-endotoxin as bioinsecticide, pp. 599-603. *In* Proc. Fourth Intern. Colloq. of Invert. Pathol. , Koningshof, Veldhoven, Netherlands.

Gelernter, W. D. 1990. Targeting insecticice-resistant markets: new developments in microbial-based products, pp. 1105-1117. *In* M. B. Green, H. M. LeBaron, and W. K. Moberg (eds.), Managing resistance to agrochemicals: from fundamental research to practical strategies. American Chemical Society, Washington, D.C.

Gentry, C. R., F. R. Lawson, and J. D. Hoffman. 1964. A sex attractant in the tobacco budworm. J. Econ. Entomol. 57: 819-821.

Georghiou, G. P. 1986. Overview of insecticide resistance, pp. 18-41. *In* M. B. Green, H. M. LeBaron, and W. K. Moberg (eds.), Managing Resistance to Agrochemicals: From Fundamental Research to Practical Strategies. American Chemical Society, Washington, D.C.

Georghiou, G. P. 1986. The magnitude of the resistance problem, pp. 14-43. *In* National Research Council, Pesticide resistance: strategies and tactics for management. National Academy Press, Washington, D.C.

Gerling, D. 1967. Bionomics of the whitefly - parasite complex associated with cotton in southern California (Homoptera: Aleyrodidae; Hymenoptera: Aphelinidae). Ann. Entomol. Soc. Amer. 60: 1306-1321.

Gerling, D. 1984. The overwintering mode of *Bemisia tabaci* and its parasitoids in Israel. Phytoparasitica 12: 109-118.

Gerling, D., and A. R. Horowitz. 1984. Yellow traps for evaluating the population levels and dispersal patterns of *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae). Ann. Entomol. Soc. Amer. 77: 753-759.

Gerson, U., and A. Aronowitz. 1981. Spider mite webbing. Part IV: the effect of acaricides on spinning by the carmine spider mite *Tetranychus cinnabarinus* (Boisduval). Pestic. Sci. 12: 211-214.

Getz, W. M., and A. P. Gutierrez. 1982. A perspective on systems analysis in crop production and insect pest management. Ann. Entomol. Soc. Amer. 27: 447-466.

Getzin, L. W. 1961. *Spicaria rileyi* (Farlow) Charles, an entomogenous fungus of *Trichoplusia ni* (Hubner). J. Insect Pathol. 3: 2-10.

Gibbs, A. J. 1957. *Leptomonas serpens* n. sp. parasitic in the digestive tract and salivary glands of *Nezara viridula* (Pentatomidae) and in the sap of *Solanum lycopersicum* (tomato) and other plants. Parasitology 47: 297-303.

Gill, R. J. undated. Color-photo and host keys to California whiteflies. Scale and Whitefly Key #2. Calif. Dept. Food and Agric.

Gill, S. J., E. A. Cowles, and P. V. Pietrantonio. 1992. The mode of action of *Bacillus thuringiensis* endotoxins. Annu. Rev. Entomol. 37: 615-636.

Gilliland Jr., F. R. 1974. Traps and trap crops for boll weevil suppression, pp. 128-130. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Gilliland Jr., F. R. 1981. The *Lygus* problem - decreasing or increasing, pp. 147-148. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Gilliland Jr., F. R., W. R. Lambert, J. R. Weeks, and R. L. Davis. 1976. Trap crops for boll weevil control, pp. 41-44. *In* Proc. Conf. on Boll Weevil Suppression, Management and Elimination Technology. USDA, ARS-S-71.

Gilliland Jr., F. R., and C. E. McCoy. 1969. The behavior of newly emerged boll weevils. Ann. Entomol. Soc. Amer. 62: 602-605.

Glass, E. H., W. P. Murdock, and J. S. Packer. 1975. Integrated pest management: rationale, needs, and improvements, pp. 75-82. *In* Entomological Society of America Special Publication.

Glick, P. A. 1939. The distribution of insects, spiders, and mites in the air. USDA Tech. Bull. 673.

Glick, P. A. 1957. Collecting insects by airplane in Southern Texas. USDA Tech. Bull. 1158.

Glick, P. A. 1967. Aerial dispersal of the pink bollworm in the United States and Mexico. USDA, ARS, Prod. Res. Report 96.

Glick, P. A., and L. W. Noble. 1961. Airborne movement of the pink bollworm and other arthropods. USDA Tech. Bull. 1255.

Glover, T. 1855. Cited in A.W. Morrill, Plant bugs injurious to cotton bolls. U.S. Bur. Entomol. Bull. No. 86:78.

Goldblum, A., M. Yoshimoto, and C. Hansch. 1981. Quantitative structure-activity relationship of phenyl *N*-methylcarbamate inhibition of acetylcholinesterase. J. Agric. Food Chem. 29: 277-288.

Gonzalez, D., D. A. Ramsey, T. F. Leigh, B. S. Ekbom, and R. van den Bosch. 1977. A comparison of vacuum and whole - plant methods for sampling predaceous arthropods on cotton. Environ. Entomol. 6: 750-760.

Gonzalez, D., and L. T. Wilson. 1982. A food-web approach to economic thresholds: A sequence of pests/predaceous arthropods on California cotton. Entomophaga 27: 31-43.

Goodenough, J. L., M. J. Gaylor, V. E. Harris, T. F. Mueller, J. Heiss, J. R. Phillips, G. Burris, K. J. Ratchford, D. F. Clower, A. M. Pavloff, R. L. Rogers, H. N. Pitre, J. W. Smith, A. H. Baumhover, J. J. Lam Jr., J. D. Lopez Jr., G. J. Puterka, J. E. Slosser, and W. L. Sterling. 1986. Efficacy of entomophaous arthropods. #2, pp. 75-91. *In* S. J. Johnson, E. G. King, and J. R. Bradley Jr. (Eds.). Theory and tactics of *Heliothis* population management: 1 - cultural and biological control. S. Coop. Ser. Bull. 316.

Goodenough, J. L., and J. A. Witz. 1985. Modeling augmentative releases of *Trichogramma pretiosum*. Southwest. Entomol. Suppl. 8: 169-189.

Gordh, G., and H. E. Evans. 1976. A new species of *Goniozus* imported into California from Ethiopia for the biological control of pink bollworm and some notes on the taxonomic status of *Parasierola* and *Goniozus* (Hymenoptera: Bethylidae). Proc. Entomol. Soc. Wash. 78: 479-489.

Gordh, G., and R. E. Medved. 1986. Biological notes on *Goniozus pakmanus* Gordh (Hymenoptera:

Bethylidae), a parasite of pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae). J. Kans. Entomol. Soc. 59: 723-734.

Gould, F. 1984. Role of behavior in the evolution of insect adaptation to insecticides and resistant host plants. Bull. Entomol. Soc. Amer. 30: 34-41.

Gould, F. 1988. Evolutionary biology and genetically engineered crops. BioSci 38: 26-29.

Gould, F. 1991. The evolutionary potential of crop pests. American Scientist 79: 496-507.

Gould, F., and R. E. Stinner. 1984. Insects in heterogeneous habitats, pp. 427-447. *In* C. B. Huffaker, and R. L. Rabb (eds.), Ecological Entomology. Wiley, New York.

Gould, T. 1991. Arthropod behavior and the efficacy of plant protection. Annu. Rev. Entomol. 36: 305-330.

Gourd, T. R., and R. J. Gouger. 1983. Observations in the biology of the European corn borer in North Carolina, pp. 186-187. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Grafton-Cardwell, E. E. 1991. Geographical and temporal variation in response to insecticides in various life stages oof *Aphis gossypii* (Homoptera: Aphididae) infesting cotton in California. J. Econ. Entomol. 84: 741-749.

Grafton-Cardwell, E. E., J. Granett, and T. F. Leigh. 1987. Spider mite species (Acarina: Tetranychidae) response to propargite: basis for an acaricide resistance management program. J. Econ. Entomol. 80: 579-580.

Grafton-Cardwell, E. E., and M. A. Hoy. 1985. Intraspecific variability in response to pesticides in the common green lacewing *Chrysoperla carnea* (Stephens). Hilgardia 53: 1-32.

Grafton-Cardwell, E. E., and M. A. Hoy. 1986. Genetic improvement of the common green lacewing, *Chrysoperla carnea*: selection for carbaryl resistance. Environ. Entomol. 15: 1130-1136.

Graham, H. M. 1987. Attraction of *Lygus* spp. males by conspecific and congeneric females. Southwest. Entomol. 12: 147-155.

Graham, H. M. 1978. Sterile pink bollworm: field releases for population suppression. J. Econ. Entomol. 71: 232-235.

Graham, H. M. 1980. Pink bollworm control in the Western United States. USDA, ARM-W-16.

Graham, H. M., L. C. Fife, O. T. Roberston, and P. L. Adkisson. 1962. Pink bollworm population dynamics, pp. 5-10. *In* D. F. Martin, and R. D. Lewis (eds.), A summary of recent research basic to the cultural control of the pink bollworm. Tex. Agr. Exp. Sta. MP. 579.

Graham, H. M., N. S. Hernandez Jr., and J. R. Llanes. 1972. The role of host plants in the dynamics of populations of *Heliothis* spp. Environ. Entomol. 1: 424-431.

Graham, H. M., C. G. Jackson, and J. W. Debolt. 1986. *Lygus* spp. (Hemiptera: Miridae) and their parasites in agricultural areas of southern Arizona. Environ. Entomol. 15: 132-142.

Graham, H. M., P. D. Lingren, C. Lincoln, and P. L. Adkisson. 1972. The economic threshold of infestations for *Heliothis* spp. on cotton, pp. 7-15. *In* Distribution abundance and control of *Heliothis* species in cotton and other host plants. S. Coop. Ser. 169.

Graham, O. H. 1985. Introduction, pp. 1-3. *In* O. H. Graham (ed.), Symposium on eradication of the screwworm from the United States and Mexico. Misc. Publ. Entomol. Soc. Amer. 62,.

Granados, R. R., and K. A. Williams. 1986. In vivo infection and replication of baculoviruses, pp. 89-108. *In* R. R. Granados, and B. A. Federici (eds.), The biology of baculoviruses, vol. I biological properties and molecular biology. CRC Press, Inc., Boca Raton.

Gravena, S., and W. L. Sterling. 1983. Natural predation on the cotton leafworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 76: 799-784.

Graves, J. B. 1987. An illustrated look at insecticide resistance and how it develops, pp. 29-31. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Graves, J. B. 1994. Insecticide resistance management strategies, pp. 43-45. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Graves, J. B., and D. F. Clower. 1971. Is insecticide resistance increasing? La. Agric. 15: 12-13.

Graves, J. B., D. F. Clower, J. L. Bagent, and J. R. Bradley. 1964. Bollworms increasing in resistance to insecticides. La. Agric. 7: 3-16.

Graves, J. B., D. F. Clower, D. R. Melville, and L. W. Sloane. 1973. Tobacco budworm in Louisiana now resistant to methyl parathion. La. Agric. 16: 10-11.

Graves, J. B., B. Leonard, S. Micinski, S. Martin, D. Long, E. Burris, and J. Baldwin. 1992. Situation on tobacco budworm resistance to pyrethroids in Louisiana during 1991, pp. 743-747. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Graves, J. B., B. R. Leonard, G. Burris, and S. Micinski. 1991a. Insecticide resistance management: An integral part of IPM, pp. 23-25. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Graves, J. B., B. R. Leonard, S. Micinski, and G. Burris. 1991b. A three year study of pyrethroid resistance in tobacco budworm in Louisiana: Resistance management implications. Southwest. Entomol. Suppl. 15: 33-41.

Graves, J. B., B. R. Leonard, S. Micinski, E. Burris, S. H. Martin, C. A. White, and J. L. Baldwin. 1993. Monitoring insecticide resistance in tobacco budworm and bollworm in Louisiana, pp. 788-790. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Graves, J. B., B. R. Leonard, and J. A. Ottea. 1995. Chemical approaches to managing arthropods, pp. (In press). *In* J. R. Ruberson (ed.), Handbook of Pest Management. Marcel Dekker, New York.

Graves, J. B., B. R. Leonard, A. M. Pavloff, S. Micinski, G. Burris, and K. Ratchford. 1988a. Status of pyrethroid resistance in tobacco budworm in Louisiana, pp. 353-356. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Graves, J. B., B. R. Leonard, A. M. Pavloff, G. Burris, K. Ratchford, and S. Micinski. 1988b. Monitoring pyrethroid resistance in tobacco budworm in Louisiana during 1987: resistance management implications. J. Agric. Entomol. 5: 109-15.

Graves, J. B., and J. S. Roussel. 1962. Status of boll weevil resistance to insecticides during 1961. J. Econ. Entomol. 55:

Graves, J. B., J. S. Roussel, and J. R. Phillips. 1963. Resistance to some chlorinated hydrocarbon insecticides in the bollworm, *Heliothis zea*. J. Econ. Entomol. 56: 442-444.

Graves, J. B., D. F. Clower, and J. R. Bradley. 1967. Resistance to the tobacco budworm to several insecticides in Louisiana. J. Econ. Entomol. 60: 887-888.

Grayson, J. M. 1944. Two important parasites of the tobacco budworm. J. Econ. Entomol. 37: 712-713.

Greany, P. D., S. M. Ferkovich, and W. R. Clark. 1989. Progress towards development of an artificial diet and an *in vitro* rearing system for *Microplitis croceipes*, pp. 89-94. *In* J. E. Powell, D. L. Bull, and E. G. King (Eds.), Biological control of *Heliothis* spp. by *Microplitis croceipes*. Southwest. Entomol. Suppl. 12.

Griffin, J. G. 1984. Equipment for field-releasing nonchilled or anesthetized sterile boll weevils. J. Agric. Entomol. 1: 120-125.

Griffin, J. G. 1984. Facility and production equipment, pp. 11-52. *In* P. P. Sikorowski, J. G. Griffin, J. Roberson, and O. H. Lindig (eds.), Boll weevil mass rearing technology. Univ. Press of Mississippi, Jackson.

Grimes, D. W. 1985. Cultural techniques for management of pests in cotton, pp. 365-382. *In* R. E. Frisbie and P. L. Adkisson (eds.), CIPM: Integrated Pest Management on Major Agricultural Systems. Texas Agric. Exp. Stn. MP-1616.

Grissom Jr., R. E., T. Konno, N. Motoyama, and W. C. Dauterman. 1989. Comparisons between in vivo and in vitro cutaneous penetration of fenvalerate in tobacco budworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 82: 41-44.

Grondin, B. 1985. Working through the confusion of adjuvants. Agrichemical Age., April 1985.

Gross Jr., H. R., and R. Johnson. 1985. *Archytas marmoratus* (Diptera: Tachinidae): Advances in large-scale rearing and associated biological studies. J. Econ. Entomol. 78: 1350-1353.

Gross Jr., H. R., W. J. Lewis, R. L. Jones, and D. A. Nordlund. 1975. Kairomones and their use for management of entomophagous insects: III. Stimulation of *Trichogramma achaeae*, *T. pretiosum*, and *Microplitis croceipes* with host-seeking stimuli at time of release to improve their efficiency. J. Chem. Ecol. 1: 431-438.

Gross Jr., H. R., S. D. Pair, and R. D. Jackson. 1985. Behavioral responses of primary entomophagous predators to larval homogenates of *Heliothis zea* and *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in whorl-stage corn. Environ. Entomol. 14: 360-364.

Gross Jr., H. R., B. R. Wiseman, and W. W. McMillian. 1976. Comparative suitability of whorl stages of sweet corn for establishment by larvae of the corn earworm. Environ. Entomol. 5: 955-958.

Grosscurt, A. C., and B. Jongsma. 1987. Mode of action and insecticidal properties of diflubenzuron, pp. 75-99. *In* J. E. Wright, and A. Retnakaran (eds.), Chitin and benzoylphenyl ureas. Dr. W. Junl. Publ., Dordrecht, Netherlands.

Guerra, A. A. 1986. Boll weevil movement: dispersal during and after the cotton season in the Lower Rio Grande Valley of Texas. Southwest. Entomol. 11: 10-16.

Guerra, A. A., K. M. Robacker, and S. Martinez. 1993. *In vitro* rearing of *Bracon mellitor* and *Catolaccus grandis* with artificial diets devoid of insect components. Entomol. Exp. Appl. 68: 303-307.

Guerra, A. A., D. A. Wolfenbarger, and R. D. Garcia. 1973. Activity of juvenile hormone analogues against the tobacco budworm. J. Econ. Entomol. 66: 833-835.

Guillot, F. S., R. L. Joiner, and S. B. Vinson. 1974. Host discrimination and isolation of hydrocarbons from Dufour's gland of a braconid parasitoid. Ann. Entomol. Soc. Amer. 67: 720-721.

Guillot, F. S., and S. B. Vinson. 1972. Sources of substances which elicit a behavioural response from the insect parasitoid, *Campoletis perdistinctus*. Nature 235: 169-172.

Guillot, F. S., and S. B. Vinson. 1972. The role of the calyx and poison gland of *Cardiochiles nigriceps* in the host-parasitoid relationship. J. Insect Physiol. 18: 1315-1321.

Gunning, R. V., C. S. Easton, L. R. Greenup, and V. E. Edge. 1984. Pyrethroid resistance in *Heliothis armigera* (Hubner) (Lepidoptera: Noctuidae) in Australia. J. Econ. Entomol. 77: 1283-1287.

Gupta, R. K., G. Tamaki, and C. A. Johansen. 1980. *Lygus* bug damage, predator-prey interaction, and pest management implications on alfalfa grown for seed. Wash. State Univ. Tech. Bul. 92.

Guthrie, D. S. 1988. Using plant growth regulators for earliness, pp. 27-28. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Gutierrez, A. P., and J. U. Baumgaertner. 1984. Multitrophic level models of predator-prey energetics. I. Age specific energetics models - pea aphid *Acrythosiphon pisum* (Harris) (Homoptera: Aphididae) as an example. Can. Entomol. 116: 924-932.

Gutierrez, A. P., G. D. Butler Jr., and C. K. Ellis. 1981. Pink bollworm: diapause induction and termination in relation to fluctuating temperatures and decreasing photoperiod. Environ. Entomol. 10: 936-942.

Gutierrez, A. P., G. D. Butler Jr., Y. Wang, and D. Westphal. 1977a. The interaction of pink bollworm (Lepidoptera: Gelechiidae), cotton, and weather: a detailed model. Can. Entomol. 109: 1457-1468.

Gutierrez, A. P., T. F. Leigh, Y. Wang, and R. D. Cave. 1977b. An analysis of cotton production in California: *Lygus hesperus* (Heteroptera: Miridae) injury — an evaluation. Can. Entomol. 109: 1375-1386.

Gutierrez, A. P., G. L. Curry, and L. Brown. 1985. Conceptual framework for studying crop-pest system, pp. 131-156. *In* R. E. Frisbie and P. L. Adkisson (eds.), CIPM: Integrated Pest Management on Major Agricultural Systems. Texas Agric. Exp. Stn. MP-1616.

Gutierrez, A. P., D. W. DeMichele, Y. Wang, G. L. Curry, R. Skeith, and L. G. Brown. 1980. The systems approach to research and decision making for cotton pest control, pp. 155-186. *In* C. B. Huffaker (ed.), New technology of pest control. John Wiley & Sons, New York.

Gutierrez, A. P., W. J. Dos Santos, M. A. Pizzamiglio, A. M. Villacorta, C. K. Ellis, C. A. P. Fernandes, and I. Tutida. 1991a. Modelling the interaction of cotton and the cotton boll weevil. II. Boll weevil (*Anthonomus grandis* Boh.) in Brazil. J. Applied Ecol. 28: 398-418.

Gutierrez, A. P., W. J. Dos Santos, A. M. Villacorta, M. A. Pizzamiglio, C. K. Ellis, L. H. Carvalho, and N. D. Stone. 1991b. Modelling the interaction of cotton and the cotton boll weevil. I. A comparison of growth and development of cotton varieties. J. Applied Ecol. 28: 371-397.

Gutierrez, A. P., L. A. Falcon, W. Loew, P. A. Leipzig, and R. van den Bosch. 1975. An analysis of cotton production in California: a model for acala cotton and the effect of defoliators on its yields. Environ. Entomol. 4: 125-136.

Gutierrez, A. P., M. A. Pizzamiglio, W. J. Dos Santos, R. Tennyson, and A. M. Villacorta. 1984. A distributed delay time varying life table plant population model: cotton (*Gossypium hirsutum* L.) as an example. Ecol. Modelling 26: 231-249.

Gutierrez, A. P., Y. Wang, and R. Daxl. 1979a. The interaction of cotton and the pink bollworm (Lepidoptera: Gelechiidae) - a study of co-adaptation. Can. Entomol. 111: 357-366.

Gutierrez, A. P., Y. Wang, and U. Regev. 1979b. An optimization model for *Lygus hesperus* (Heteroptera: Miridae) damage in cotton: the economic threshold revisited. Can. Entomol. 111: 41-54.

Gutierrez, A. P., and Y. H. Wang. 1984. Models for managing the economic impact of pest populations in agricultural crops, pp. 729-761. *In* C. B. Huffaker, and R. L. Rabb (eds.), Ecological Entomology. John Wiley and Sons, New York.

Gutierrez, A. P., and L. T. Wilson. 1989. Development and use of pest models, pp. 65-83. *In* R. E.R. E. Frisbie, K. M. El-Zik, and L. T. Wilson (eds.), Integrated Pest Management Systems and Cotton Production. John Wiley and Sons, New York.

Hackett, D. S., and A. G. Gatehouse. 1982. Studies on the biology of *Heliothis* spp. in Sudan, pp. 29-38. *In* W. Reed and V. Kumble (eds.), Proc. Interml. Workshop on *Heliothis* Management. ICRISAT, Patancheru, A.P., India.

Hagen, D. S., P. Greany, E. F. Sawall Jr., and R. L. Tassan. 1976. Tryptophan in artificial honeydews as a source of an attractant for adult *Chrysopa carnea*. Environ. Entomol. 5: 458-468.

Hagen, K. S., and R. Hale. 1974. Increasing natural enemies through use of supplementary feeding and non-target prey, pp. 170-181. *In* F. G. Maxwell and F. A. Harris (eds.), Proc. Summer Instit. Biol. Contrl. Plant Insects and Diseases. Univ. Press Miss., Jackson, Mississippi.

Hagen, K. S., E. F. Sawall Jr., and R. L. Tassan. 1971. The use of food sprays to increase effectiveness of entomophagous insects. Proc. Tall Timbers Conf. Ecol. Anim. Contr. Habitat Mgmt. 2: 59-81.

Hagen, K. S., and R. L. Tassan. 1970. The influence of the food Wheast and related *Saccharomyces fragilis* yeast products on the fecundity of *Chrysopa carnea* (Neuroptera: Chrysopidae). Can. Entomol. 102: 806-811.

Hagen, K. S., R. van den Bosch, and D. L. Dahlsten. 1971. The importance of naturally-occurring biological control in the Western United States, pp. 253-293. *In* C. B. Huffaker (ed.), Biological Control. Plenum Press, New York.

Haggis, M. J. 1982. Distribution of *Heliothis armigera* eggs on cotton in the Sudan Gezira: spatial and temporal changes and their possible relation to weather, pp. 87-89. *In* W. Reed and V. Kumble (eds.), Proc. Interml. Workshop on *Heliothis* Management. ICRISAT, Patancheru, A.P., India.

Haile, D. G., J. W. Snow, and J. R. Young. 1975. Movement of adult *Heliothis* released on St. Croix to other islands. Environ. Entomol. 4: 225-226.

Haine, E. 1955. Aphid take-off in controlled wind speeds. Nature 175: 474.

Hajjar, N. P. 1985. Chitin synthesis inhibitors as insecticides, pp. 275-310. *In* D. H. Hutson, and T. R. Roberts (eds.), Insecticides. John Wiley and Sons, New York.

Haldane, J. B. S. 1922. Sex ratio and unisexual sterility in hybrid animals. J. Genet. 12: 101-109.

Hall, D. C., and G. M. Duncan. 1984. Econometric evaluation of new technology with an application to integrated pest management. Ager. J. Agr. Econ. 66: 626-633.

Hall, D. C., and R. B. Norgaard. 1973. On the timing of application of pesticides. Amer. J. Agr. Econ. 55:

Hall, D. W. 1985. Pathobiology of invertebrate icosahedral cytoplasmic deoxyriboviruses (Iridoviridae), pp. 163-196. *In* K. Maramarosch, and K. E. Sherman (eds.), Viral insecticides for biological control. Academic Press, New York.

Hall, F. R. 1991. Pesticide targeting: Improving the dose transfer process, pp. 305-315. *In* E. Hogdson, Roe R.M., and N. Motoyama (eds.), Pesticides and the Future: Toxicological Studies of Risks and Benefits. North Carolina State University, Raleigh.

Hall, I. M. 1963. Microbial control, pp. 477-517. *In* E. A. Steinhaus (ed.), Insect pathology, an advanced treatise, Vol. II. Academic Press, New York.

Hall, P. K., W. L. Parrott, J. N. Jenkins, and J. C. McCarty Jr. 1980. Use of tobacco budworm eggs and larvae for establishing field infestations on cotton. J. Econ. Entomol. 73: 393-395.

Hamer, J. L., G. L. Andrews, R. W. Seward, D. F. Young Jr., and R. B. Head. 1983. Optimum pest management trial in Mississippi, pp. 385-407. *In* R. L. Ridgway, E. P. Lloyd, and W. H. Cross (eds.), Cotton Insect Management with Special Reference to the Boll Weevil. USDA Agr. Handb. No. 589.

Hamm, J. J. 1980. Epizootics of *Entomophthora aulicae* in lepidopterous pests of sorghum. J. Invertebr. Pathol. 36: 60-63.

Hamm, J. J., D. A. Nordlund, and O. G. Marti. 1985. Effects of a nonoccluded virus of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on the development of a parasitoid, *Cotesia marginiventris* (Hymenoptera: Braconidae). Environ. Entomol. 14: 258-261.

Hamm, J. J., S. D. Pair, and O. D. Marti Jr. 1986. Incidence and host range of a new ascovirus isolated from fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Fla. Entomol. 69: 524-531.

Hamm, J. J., and J. P. Young. 1974. Mode of transmission of nuclear polyhedrosis virus to progeny of adult *Heliothis zea*. J. Invertebr. Pathol. 24: 70-80.

Hammock, B. D. 1985. Regulation of juvenile hormone titer: degradation, pp. 431-472. *In* G. A. Kerkut, and L. I. Gilbert (eds.), Comprehensive insect physiology, biochemistry and pharmacology. Vol. 7., Insect control. Pergamon Press, New York.

Hammock, B. D., B. F. McCutchen, J. Beetham, P. V. Choudary, E. Fowler, R. Ichinose, V. K. Ward, J. M. Vickers, B. C. Bonning, L. G. Harshman, D. Grant, T. Uematsu, and S. Maeda. 1993. Development of recombinant viral insecticides by expression of an insect-specific toxin and insect-specific enzyme in nuclear polyhedrosis viruses. Arch. Insect. Biochem. Physiol. 22: 315-344.

Hammock, B. D., S. M. Mumby, and P. W. Lee. 1977. Mechanisms of resistance to the juvenoid methoprene in the house fly *Musca domestica* L. Pestic. Biochem. Physiol. 7: 261-272.

Hammock, B. D., and G. B. Quistad. 1981. Metabolism and mode of action of juvenile hormone, juvenoids and other insect growth regulators, pp. 1-83. *In* D. G. Hutson, and T. R. Roberts (eds.), Progress in pesticide biochemistry. John Wiley and Sons, New York.

Hammock, B. D., and D. M. Soderlund. 1986. Chemical strategies for resistance management, pp. 111-129. *In* National Research Council, Pesticide resistance: strategies and tactics for management. National Academy Press, Washington, D.C.

Hanny, B. W., J. C. Bailey, and W. R. Meredith Jr. 1979. Yellow cotton pollen suppresses growth of tobacco budworm larvae, pp. 84. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Hanny, B. W., T. C. Cleveland, and W. R. Meredith Jr. 1977. Effects of tarnished plant bug (*Lygus lineolaris* Palisot de Beauvois) infestation on presquaring cotton (*Gossypium hirsutum*). Environ. Entomol. 6: 460-462.

Hardee, D. D. 1975. Boll weevil population management, detection, or elimination with in-field traps, pp. 132. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Hardee, D. D., and F. J. Boyd. 1976. Trapping during the pilot boll weevil eradication experiment, 1971-1973, pp. 82-89. *In* Proc. Conf. on Boll Weevil Suppression, Management and Elimination Technology. USDA, ARS-S-71.

Hardee, D. D., W. H. Cross, and E. B. Mitchell. 1969. Male boll weevils are more attractive than cotton plants to boll weevils. J. Econ. Entomol. 62: 165-169.

Hardee, D. D., W. H. Cross, E. B. Mitchell, P. M. Huddleston, H. C. Mitchell, M. E. Merkle, and T. B. Davich. 1969. Biological factors influencing responses of the female boll weevil to the male sex pheromone in field and large-cage tests. J. Econ. Entomol. 62: 161-165.

Hardee, D. D., and G. A. Herzog. 1994. 47th annual conference report on cotton insect research and control, pp. 717-740. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Hardee, D. D., O. H. Lindig, and T. B. Davich. 1971. Suppression of population of boll weevil over a large area in West Texas with pheromone traps in 1969. J. Econ. Entomol. 64: 928-933.

Hardee, D. D., G. H. McKibben, D. R. Rummel, P. M. Huddleston, and J. R. Coppedge. 1974. Response of boll weevils to component ratios and doses of the pheromone, grandlure. Environ. Entomol. 3: 135-138.

Hardee, D. D., E. B. Mitchell, and P. M. Huddleston. 1967. Procedure for bioassaying the sex attractant of the boll weevil. J. Econ. Entomol. 60: 1221-1224.

Harding, J. A. 1976. *Heliothis* spp.: seasonal occurrence, hosts, and host importance in the Lower Rio Grande Valley. Environ. Entomol. 5: 66-68.

Harding, J. A., and C. B. Cowan Jr. 1971. Infestations of seven cotton insects on pilose, glanded, frego bract, and colored cottons in 1969. Texas Agric. Exp. Stn. Progr. Rpt. 2862.

Harding, J. A., F. R. Huffman, D. A. Wolfenbarger, and J. W. Davis. 1977. Insecticidal activity of *alpha*-cyano-3-phenoxybenzyl pyrethroids against the boll weevil and tobacco budworm. Southwest. Entomol. 2: 42-45.

Hardwick, D. F. 1965. The corn earworm complex. Mem. Entomol. Soc. Canada, No. 40.

Hargett, J. 1988. Insect control for earliness - a producer's viewpoint, pp. 30-31. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Harper, J. D., and G. R. Carner. 1973. Incidence of *Entomophthora* sp. and other natural control agents in populations of *Pseudoplusia includens* and *Trichoplusia ni*. J. Invertebr. Pathol. 22: 80-85.

Harris, F. A. 1970. Monitoring of insecticide resistance. Miss. Farm. Res. 33: 3.

Harris, F. A. 1972. Resistance to methyl parathion and toxaphene-DDT in bollworm and tobacco budworm from cotton in Mississippi. J. Econ. Entomol. 65: 1193-1194.

Harris, F. A. 1988. A practical alternative to IPM. Progressive Farmer. February Issue.

Harris, F. A., L. G. Brown, J. W. Jones, G. L. Andrews, and M. W. Parker. 1976. Use of cotton plant-insect interaction in insecticide, plant resistance and economic thresholds studies, pp. 144-149. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Harris, F. A., J. B. Graves, S. J. Nemec, S. B. Vinson, and D. A. Wolfenbarger. 1972. Insecticide resistance, pp. 17-27. *In* Distribution, abundance, and control of *Heliothis* species in cotton and other host plants. Southern Coop. Ser. Bull. No. 169.

Harris, F. A., K. K. Shaunak, C. A. Wilson, C. A. Hurst, and C. L. Simmons. 1976. Effects of the pilot boll weevil eradication experiment on non-target species, pp. 113-118. *In* Proc. Conf. on Boll Weevil Suppression, Management and Elimination Technology. USDA, ARS-S-71.

Harris, V. E., and J. R. Phillips. 1986. Mowing spring host plants as a population management technique for *Heliothis* spp. J. Agric. Entomol. 3: 125-134.

Harris, V. E., and J. W. Todd. 1980. Male-mediated aggregation of male, female and 5th-instar southern green stink bugs and conocomitant attraction of a tachinid parasite, *Trichopoda pennipes*. Entomol. Exp. Appl. 27: 117-126.

Hartley, G. G. 1990. Multicellular rearing methods for the beet armyworm, soybean looper, and velvetbean caterpillar (Lepidoptera: Noctuidae). J. Entomol. Sci. 25: 326-340.

Hartley, G. G., E. G. King, F. D. Brewer, and C. W. Gantt. 1982. Rearing of the *Heliothis* sterile hybrid with a multicellular larval rearing container and pupal harvesting. J. Econ. Entomol. 75: 7-10.

Hartstack, A. W., D. E. Hendricks, J. D. Lopez, E. A. Stadelbacher, J. R. Phillips, and J. A. Witz. 1979. Adult sampling. Southern Coop. Series Bull. 231: 105-131.

Hartstack, A. W., J. L. Henson, J. A. Witz, J. A. Jackman, J. P. Hollingsworth, and R. E. Frisbie. 1977. The Texas program for forecasting *Heliothis* spp. infestations on cotton, pp. 151-154. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Hartstack, A. W., and J. P. Hollingsworth. 1974. A computer model for predicting *Heliothis* populations. Trans. ASAE 17: 112-115.

Hartstack, A. W., J. P. Hollingsworth, J. A. Witz, D. R. Buck, J. D. Lopez, and D. E. Hendricks. 1978. Relation of tobacco budworm catches in pheromone baited traps to field populations. Southwest. Entomol. 3: 43-51.

Hartstack, A. W., E. G. King, and J. R. Phillips. 1983. Monitoring and predicting *Heliothis* populations in southeast Arkansas, pp. 187-190. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Hartstack, A. W., J. D. Lopez, R. A. Muller, W. L. Sterling, E. G. King, J. A. Witz, and A. C. Eversull. 1982. Evidence of long range migration of *Heliothis zea* (Boddie) into Texas and Arkansas. Southwest. Entomol. 7: 188-201.

Hartstack, A. W., and W. L. Sterling. 1986. Texas cotton fleahopper model users guide, version 2: Basic. Tex. Agr. Exp. Sta. Misc. Publ. 1595.

Hartstack, A. W., and W. L. Sterling. 1988a. Estimating fruit value with TEXCIM, pp. 370-374. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Hartstack, A. W., and W. L. Sterling. 1988b. TEXCIM23: the Texas cotton-insect model. Texas Argic. Exp. Stn. Misc. Publ. 1646.

Hartstack, A. W., and W. L. Sterling. 1989. TEXCIM30: the Texas cotton-insect model. Texas Agric. Exp. Stn. Misc. Publ. 1646 (Rev.).

Hartstack, A. W., W. L. Sterling, and D. A. Dean. 1990. TEXCIM40: the Texas cotton-insect model. Texas Agric. Exp. Stn. Misc. Publ. MP-1646 (Rev.).

Hartstack, A. W., W. L. Sterling, and D. A. Dean. 1991. TEXCIM41: The Texas cotton insect model. Tex. Agric. Exp. Stn. Misc. Publ. MP-1646.

Hartstack, A. W., and J. A. Witz. 1981a. Insect modeling. Agric. Engin. 62: 19-20.

Hartstack, A. W., and J. A. Witz. 1981b. Estimating field populations of tobacco budworm moths from pheromone trap catches. Environ. Entomol. 10: 908-914.

Hartstack, A. W., and J. A. Witz. 1981. Simplified method of modeling cotton insect damage. ASAE Tech. Paper 81-4091.

Hartstack, A. W., and J. A. Witz. 1983. Models for cotton insect pest management, pp. 359-381. *In* R. L. Ridgway, E. P. Lloyd, and W. H. Cross (eds.), Cotton Insect Management with Special Reference to the Boll Weevil. USDA Agr. Handb. No. 589.

Hartstack, A. W., J. A. Witz, and D. R. Buck. 1979. Moth traps for the tobacco budworm. J. Econ. Entomol. 72: 519-522.

Hartstack, A. W., J. A. Witz, J. P. Hollingsworth, R. L. Ridgway, and J. D. Lopez. 1976a. MOTHZV-2: a computer simulation of *Heliothis zea* and *Heliothis virescens* population dynamics users manual. USDA, ARS, Publ. ARS-S-127.

Hartstack, A. W., J. A. Witz, J. P. Hollingsworth, and D. L. Bull. 1976b. SPERM — A sex pheromone emission and response model. Trans. ASAE 19: 1170-1180.

Hassan, S. A. 1982. Mass-production and utilization of *Trichogramma*: 3. Results of some research projects related to the practical use in the Federal Republic of Germany. Les Trichogrammes, Colloq. INRA (France) 9.

Hatfield, L. D., and S. G. McDaniel. 1984. Impact of emulsified oil on delivery, droplet spectra and efficacy in cotton insect control, pp. 207-209. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Hatfield, L. D., S. A. Ryerson, and S. G. McDaniel. 1984. Aerial application of Ammo 2.5 EC vegetable oils for cotton and corn insect control, *In* Proc. Ag-Chem. Uses of Soybean Oil, Am. Soybean Assoc., St. Louis.

Hauter, L. H. 1928. Economics of crop production on the Elephant Butte Irrigation Project. NM Col. of Agric. and Mechan. Arts, Agric. Ext. Ser. Circ. 97.

Hayden, M. R. 1981. Huntington's chorea. Springer-Verlag, New York.

Hayes, J. L., and R. J. Coleman. 1989. Relating *Heliothis* spp. pheromone trap captures to egg counts in cotton: II. Second year data from the Mississippi Delta, pp. 313-316. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Haynes, J. W. 1963. Chemical sterility agents as they affect the boll weevil, *Anthonomus grandis* Boheman. M.S. Thesis, Mississippi State University, Mississippi State.

Haynes, J. W. 1981. Effects of soil temperatures and chillingon flight and mortality of sterile boll weevils. J. Ga. Entomol. Soc. 16: 254-257.

Haynes, J. W. 1990. Recovery from genetic damage in progeny of irradiated male boll weevils. Miss. Agric. Forest. Exp. Stn. Res. Rept. No. 15.

Haynes, J. W., W. L. McGovern, and J. E. Wright. 1981. Diflubenzuron (solvent-water suspension) dip for boll weevils: effects measured by flight, sterility and sperm transfer. Environ. Entomol. 10: 492-495.

Haynes, J. W., N. Mitlin, T. B. Davich, J. R. Dawson, W. L. McGovern, and G. H. McKibben. 1977. Sterilization of boll weevil pupae with fractionated doses of gamma irradiation. Entomol. Exp. Appl. 21: 57-62.

Haynes, J. W., N. Mitlin, T. B. Davich, B. J. Nail, and J. R. Dawson. 1975. Mating and sterility of male boll weevils treated with busulfan plus hempa. Environ. Entomol. 4: 315-318.

Haynes, J. W., and J. W. Smith. 1989. Cumulative genetic sterility in progeny of boll weevils (Coleoptera: Curculionidae) treated with apholate. J. Agric. Entomol. 6: 147-152.

Haynes, K. W., T. A. Miller, R. T. Staten, W. G. Li, and T. C. Baker. 1986. Monitoring insecticide resistance with insect pheromones. Experientia 42: 1293-1295.

Haynes, K. W., T. A. Miller, R. T. Staten, W. G. Li, and T. C. Baker. 1987. Pheromone trap for monitoring insecticide resistance in the pink bollworm moth (Lepidoptera: Gelechiidae); New tool for resistance management. Environ. Entomol. 16: 84-89.

Head, R. B. 1981. An areawide *Heliothis* suppression program in Leflore and Monroe counties of Mississippi.

Head, R. B. 1982. Report of the Cotton Insect Loss Committee of the Thirty-Fifth Annual Conference on Cotton Insect Research and Control, pp. 182. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Head, R. B. 1983. Cooperative areawide cotton insect management program: Carroll-Leflore, Tallahatchie-Quitman counties, Mississippi. Annual Report.

Head, R. B. 1983. The impact of cotton insect pest management programs on the private sector, pp. 234-236. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Head, R. B. 1984. Report of the Cotton Insect Loss Committee of the Thirty-Seventh Annual Conference on Cotton Insect Research and Control, pp. 180. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Head, R. B. 1985. Report of the Cotton Insect Loss Committee of the Thirty-Eighth Annual Conference on Cotton Insect Research and Control, pp. 120. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Head, R. B. 1989. Cotton insect losses-1988, pp. 193-197. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Head, R. B. 1990. Cotton insect losses 1989, pp. 603-608. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Head, R. B. 1991. Cotton insect losses 1990, pp. 602-607. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Head, R. B. 1992. Cotton insect losses 1991, pp. 621-625. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Head, R. B. 1993. Cotton insect control guide. Mississippi St. Univ. Coop. Ext. Serv. Pub. 343.

Head, R. B. 1993. Cotton insect losses 1992, pp. 655-660. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Headley, J. C. 1971. Defining the economic threshold. Presented at Symp. Pest Control Strategies for the Future. Nat. Acad. Sci.-Nat. Res. Counc. Washington, DC.

Headley, J. C. 1972. Economics of agricultural pest control. Annu. Rev. Entomol. 17: 273-286.

Hedin, P. A., J. N. Jenkins, and F. G. Maxwell. 1977. Behavioral and developmental factors affecting host plant resistance to insects, pp. 231-275. *In* Host plant resistance to pests. American Chem. Soc. Symposium Series 62.

Hedin, P. A., F. G. Maxwell, and J. N. Jenkins. 1974. Insect plant attractants, feeding stimulants, repellents, deterrents, and other related factors affecting insect behavior, pp. 494-527. *In* F. G. Maxwell and F. A. Harris (eds.), Proc. Summer Instit. Biol. Contrl. Plant Insects and Diseases. Univ. Press Miss., Jackson, Mississippi.

Heilman, M. D., M. J. Lukefahr, L. N. Namken, and J. W. Norman. 1977. Field evaluation of a short-season production system in the Lower Rio Grande Valley of Texas, pp. 80-83. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Heilman, M. D., and L. N. Namken. 1978. Short-season cotton production system for increased efficiency., pp. 95-99. *In* Proc. 37th Planning Meeting of the International Cotton Advisory Committee, San Salvador.

Heitz, J. R. 1987. Development of photo activated pesticides, pp. 1-21. *In* J. R. Heitz, and K. R. Downing (eds.), Proc. American Chem. Soc. Symp. 339.

Heller, J. J., H. Mattioda, E. Klein, and A. Sagenmuller. 1992. Field evaluation of RH 5992 on lepidopterous pests in Europe, pp. 59-65. *In* Brighton Crop Protection Conference-Pests and Diseases.

Helms, D. 1980. Revision and reversion: changing cultural control practices for the cotton boll weevil. Agric. His. 54: 108-125.

Helms, J. D. 1977. Just lookin' for a home: the cotton boll weevil and the South. Ph.D. dissertation, Florida State University.

Hemingway, J. R., and K. E. Bobrwosicz. 1986. The use of ELISA demonstrates the absence of *Culex* organophosphorus-resistance-associated esterase in *Anopheles* species. Pestic. Biochem. Physiol. 25: 327-337.

Hendricks, D. E., H. M. Graham, and J. R. Raulston. 1973. Dispersal of sterile tobacco budworms from release points in northeastern Mexico and southern Texas. Environ. Entomol. 2: 1085-1088.

Hendricks, D. E., B. A. Leonhardt, and T. N. Shaver. 1989. Development of optimized blends of two sex pheromone components impregnated in PVC dispensers for tobacco budworm bait. Southwest. Entomol. 14: 17-25.

Hendrix III, W. W., T. J. Mueller, F. R. Phillips, and O. K. Davis. 1987. Pollen as an indicator of long-distance movement of *Heliothis zea* (Lepidoptera: Noctuidae). Environ. Entomol. 16: 1148-1151.

Henneberry, T. J. 1980. Potential of sterile moth releases for pink bollworm management, pp. 52-66. *In* H. M. Graham (ed.), Pink bollworm control in the United States. U.S. Dept. Agric. Sci. and Educ. Admin. ARM-W-16.

Henneberry, T. J. 1987. The effects of short season cotton systems on pest insect populations, pp. 87-90. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Henneberry, T. J. 1993. Sweetpotato whitefly - current status and national research and action plan, pp. 663-667. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Henneberry, T. J., L. A. Bariola, and D. L. Kittock. 1977. Nectariless cotton: effect on cotton leaf perforator and other cotton insects in Arizona. J. Econ. Entomol. 70: 797-799.

Henneberry, T. J., and G. D. Butler. 1986. Effects of high temperature on tobacco budworm (Lepidoptera: Noctuidae) reproduction, diapause, and spermatocyst development. J. Econ. Entomol. 79: 410-413.

Henneberry, T. J., and T. E. Clayton. 1982. Pink bollworm: seasonal oviposition, egg predation, and square and boll infestations in relation to cotton plant development. Environ. Entomol. 11: 663-666.

Henneberry, T. J., and T. E. Clayton. 1985. Consumption of pink bollworm (Lepidoptera: Gelechiidae) and tobacco budworm (Lepidoptera: Noctuidae) eggs by some predators commonly found in cotton fields. Environ. Entomol. 14: 416-419.

Henneberry, T. J., E. H. Glass, R. G. Gilbert, E. G. King Jr., and R. W. Miller. 1991. Integrated pest management, a sustainable technology. *In* Agriculture and the Environment: The 1991 Yearbook of Agriculture. U.S. Government Printing Office, Washington, D.C.

Henneberry, T. J., and D. F. Keaveny. 1985. Suppression of pink bollworm by sterile moth releases. USDA, Agric. Res. Serv. ARS-32.

Henneberry, T. J., D. L. Kittock, and L. A. Bariola. 1982. Pink bollworm: effect of cotton types and planting date on early season infestations. Southwest. Entomol. 7: 65-69.

Henneberry, T. J., N. C. Toscano, R. M. Faust, and J. R. Coppedge. 1993. Proc. First Annual Rev. Sweetpotato Whitefly National Res. and Action Plan. USDA-ARS, ARS-112.

Henrick, C. A. 1982. Juvenile hormone analogs: structure activities relationships, pp. 315-402. *In* J. R. Coats (ed.), Insecticide mode of action. Academic Press, New York.

Henrick, C. A., B. A. Garcia, G. B. Staal, D. C. Cerf, R. J. Anderson, K. Gill, H. R. Chinn, J. N. Labovitz, M. M. Leippe, S. L. Woo, R. L. Carney, D. C. Gordon, and G. K. Kohn. 1980. 2-Anilino-3-methylbutyrates and 2-(isoindolin-2-yl)-3-methylbutyrates, two novel groups of synthetic pyrethroid esters not containing a cyclopropane ring. Pestic. Sci. 1: 224-241.

Herard, F., M. A. Keller, W. J. Lewis, and J. H. Tumlinson. 1987. Beneficial arthropod behavior mediated by airborne semiochemicals III. Influence of age and experience on flight chamber responses of *Microplitis demolitor* Wilkinson. J. Chem. Ecol. 14: 1583-1596.

Herard, F., M. A. Keller, W. J. Lewis, and J. H. Tumlinson. 1987. Beneficial arthropod behavior mediated by airborne semiochemials. IV. Influence of host diet on host-oriented flight chamber responses to *Microplitis demolitor* Wilkinson. J. Chem. Ecol. 14: 1597-1606.

Hererra, J. M., and F. Alvarez. 1979. El control biologico de *Bucculatrix thurberiella* Busck (Lepidoptera: Lyonettidae) en Piura y Chira. Rev. Peru Entomol. 22: 37-41.

Herman, H. R., and G. Morrison. 1980. Ovipositor and associated glands of *Microplitis croceipes* (Braconidae). J. Ga. Entomol. Soc. 15: 479-485.

Herrera, J. M., and F. Alvarez. 1979. El control biologico de *Bucculatrix thurberiella* Busck (Lepidoptera: Lyonettidae) en Piura y Chira. Rev. Peru Entomol. 22: 37-41.

Herring, J. L. 1966. The genus *Orius* of the Western hemisphere (Hemiptera: Anthocoridae). Ann. Entomol. Soc. Amer. 59: 1093-1109.

Herzog, G. A. 1980. The potential for short-season cotton in the southeast, pp. 157-158. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Herzog, G. A. 1988. Performance of pyrethroids in the Southeast, pp. 231-232. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Herzog, G. A., J. A. Joyce, and R. J. Ottens. 1987. Insecticide resistance monitoring in *Heliothis* spp. and *Spodoptera* spp. Univ. of Georgia, Coop. Ext. Serv. Misc. Publ. No. 181.

Herzog, G. A., W. R. Lambert III, S. E. Law, W. E. Seigler, and D. K. Giles. 1983. Evaluation of an electrostatic spray application system for control of insect pests in cotton. J. Econ. Entomol. 76: 637-640.

Higgins, A. H. 1970. A machine for free aerial release of sterile pink bollworm moths. USDA/ARS 81-40.

Higley, L. G., and W. K. Wintersteen. 1992. A novel approach to environmental risk assessment of pesticides as a basis for incorporating environmental costs into economic injury levels. Am. Entomol. 38: 34-39.

Hill, J. R. 1985. Effects on non-target organisms, pp. 151-262. *In* J. P. Leahey (ed.), The pyrethroid insecticides. Taylor and Francis, London.

Himel, C. M. 1969. The optimum size for insecticide spray droplets. J. Econ. Entomol. 62: 912-916.

Hinds, W. E. 1906. Proliferation as a factor in the natural control of the Mexican cotton boll weevil. USDA Bur. Entomol. Bull. 59.

Hinds, W. E. 1907. An ant enemy of the cotton boll weevil. USDA Bur. Entomol. Bull. 63.

Hinds, W. E. 1925. Airplane dusting of cotton for boll weevil control. J. Econ. Entomol. 19: 607.

Hinds, W. E., and W. W. Yothers. 1909. Hibernation of the Mexican cotton boll weevil. USDA Bur. Entomol. Bull. 77.

Hodgson, E., and P. E. Levi. 1987. A textbook of modern toxicology. Elsevier, New York.

Hogg, D. B., and M. Calderon. 1981. Field developmental times of *Heliothis zea* and *H. virescens* (Lepidoptera: Noctuidae) larvae and pupae in cotton. Environ. Entomol. 10: 177-179.

Hogg, D. B., and A. P. Gutierrez. 1980. A model of the flight phenology of the beet armyworm (Lepidoptera: Noctuidae) in Central California. Hilgardia 48: 1-36.

Hogg, D. B., and E. V. Nordheim. 1983. Age-specific survivorship analysis of *Heliothis* spp. populations on cotton. Res. Popul. Ecol. 25: 280-297.

Holan, G., W. M. P. Johnson, D. F. O'Keefe, G. L. Quint, K. Rihs, T. H. Spurling, R. Walser, C. T. Virgona, C. Frelin, M. Lazdunski, G. A. R. Johnston, and S. Chen Chow. 1985. Multidisciplinary studies in the design of new insecticides, pp. 114-132. *In* N. F. Janes (ed.), Recent advances in the chemistry of insect control. Royal Society of Chemistry, London.

Hollingworth, R. M. 1976. The biochemical and physiological basis of selective toxicity, pp. 431-506. *In* C. F. Wilkinson (ed.), Insecticide biochemistry and physiology. Plenum Press, New York.

Hollingworth, R. M., K. I. Ahammad-Sahib, G. G. Gadelhak, and J. L. McLaughlin. 1994. New inhibitors of Complex I of the mitochondrial electron transport chain with activity as pesticides. Biochem. Soc. trans. 22: 230-233.

Hollingworth, R. M., and A. E. Lund. 1982. Biological and neurotoxic effects of amidine pesticides, pp. 189-227. *In* J. R. Coats (ed.), Insecticide mode of action. Academic Press, New York.

Hope, J. H. 1993. IRAC-Cotton-U.S. overview and its role in insecticide resistance management, pp. 4. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Hopkins, A. R., and R. F. Moore. 1980. Thidiazuron: effects of applications on boll weevil and bollworm population densities, leaf abscission, and regrowth of the cotton plant. J. Econ. Entomol. 73: 768-770.

Hopkins, A. R., R. F. Moore, and W. James. 1982. Economic injury level for *Heliothis* spp. larvae on cotton plants in the four-true-leaf to pinhead-square stage. J. Econ. Entomol. 75: 328-332.

Hopkins, A. R., and H. M. Taft. 1965. Control of certain cotton pests with a new insecticide UC-21149. J. Econ. Entomol. 58: 746-749.

Hopkins, A. R., H. M. Taft, and A. R. Agee. 1971. Movement of the boll weevil into and out of a cotton field as determined by flight screens. Ann. Entomol. Soc. Amer. 64: 254-257.

Hopkins, A. R., H. M. Taft, and W. James. 1969. Life history of the boll weevil in field cages. J. Econ. Entomol. 62: 964-965.

Hopkins, A. R., H. M. Taft, and W. James. 1975. Reference LD50 values for some insecticides against the boll weevil. J. Econ. Entomol. 68: 189-192.

Hopkins, A. R., H. M. Taft, and W. James. 1979. Comparison of spray nozzles for ground applications for control of cotton insects and spider mites. J. Econ. Entomol. 72: 180-183.

Hopkins, A. R., H. M. Taft, S. H. Roach, and W. James. 1972. Movement and survival of boll weevils in several hibernation environments. J. Econ. Entomol. 65: 82-85.

Hopper, K. R. 1989. Conservation and augmentation of *Microplitis croceipes* for controlling *Heliothis* spp., pp. 95-115. *In* J. E. Powell, D. L. Bull, and E. G. King (Eds.), Biological control of *Heliothis* spp. by *Microplitis croceipes*. Southwest. Entomol. Suppl. 12.

Hopper, K. R., and E. G. King. 1984a. Preference of *Microplitis croceipes* (Hymenoptera: Braconidae) for instars and species of *Heliothis* (Lepidoptera: Noctuidae). Environ. Entomol. 13: 1145-1150.

Hopper, K. R., and E. G. King. 1984b. Feeding and movement on cotton of *Heliothis* species (Lepidoptera: Noctuidae) parasitized by *Microplitis croceipes* (Hymenoptera: Braconidae). Environ. Entomol. 13: 1654-1660.

Hopper, K. R., and E. G. King. 1986. Linear functional response of *Microplitis croceipes* (Hymenoptera: Braconidae) to variation in *Heliothis* spp. (Lepidoptera: Noctuidae) density in the field. Environ. Entomol. 15: 476-480.

Hopper, K. R., J. E. Powell, and E. G. King. 1991. Spatial density dependence in parasitism *Heliothis virescens* (Lepidoptera: Noctuidae) by *Microplitis croceipes* (Hymenoptera: Braconidae) in the field. Environ. Entomol. 20: 292-302.

Hopper, K. R., and S. B. Stark. 1987. A simulation model for making decisions about *Heliothis* control, pp. 286-290. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Hornchan, P. 1977. Biology of three exotic species, and role of native species of the genus *Peristenus*-parasites of tarnished plant bug, *Lygus lineolaris*, in Mississippi. Ph.D. dissertation. Miss. State Univ.

Horner, N. V. 1972. *Metaphidippus galathea* as a possible biological control agent. J. Kans. Entomol. 45: 324-327.

Horowitz, A. R. 1986. Population dynamics of *Bemisia tabaci* (Gennadius): with special emphasis on cotton fields. Agric. Ecos. Environ. 17: 37-47.

Horowitz, J. K., and E. Lichtenberg. 1993. Insurance, moral hazard, and chemical use in agriculture. Am. J. Agric. Econ. 75: 926-935.

Horowitz, R., H. Podoler, and D. Gerling. 1982. Population dynamics (life tables) of *Bemisia tabaci* under field conditions. Phytoparasitica 10: 4.

Hoskinson, P. E., C. R. Graves, and T. McCutchen. 1974. Effects of four harvest dates on agronomic and fiber properties of cotton. Tennessee Farm and Home Sci. 89: 17-19.

Howard, L. O. 1895. The Mexican cotton-boll weevil. USDA Div. Entomol. Circ. 6. (2nd Ser.).

Howard, L. O. 1896. Insects affecting the cotton plant. USDA Office of Exp. Sta. Bull. 33.

Howard, L. O. 1896. The Mexican cotton boll weevil. USDA Bur. Entomol. Circ. 14 (2nd Ser.).

Howe, R. W. 1916. Studies of the Mexican cotton boll weevil in the Mississippi Valley. USDA Bull 358.

Hoy, M. A. 1982. Aerial dispersal and field efficacy of a genetically improved strain of the spider mite predator *Metaseiulus occidentalis*. Entomol. Exp. Appl. 32: 205-212.

Hoy, M. A., and J. Conley. 1987. Selection for abamectin resistance in *Teranychus urticae* and *T. pacificus* (Acari: Teranychidae). J. Econ. Entomol. 80: 221-225.

Hoy, M. A., J. J. R. Groot, and H. E. van de Baan. 1985. Influence of aerial dispersal on persistence and spread of pesticide-resistant *Metaseiulus occidentalis* in California almond orchards. Entomol. Exp. Appl. 37: 17-31.

Hoy, M. A., and J. J. Mckelvey Jr. (eds). 1979. Genetics in relation to insect management, March 31-April 5, 1978, Bellagio, Italy. The Rockefeller Foundation, New York.

Hoyt, A. S. 1953. The pink bollworm situation-a beltwide menace, pp. 57-59. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Hsieh, C., J. N. Jenkins, J. C. McCarty Jr., R. L. Shepherd, and W. L. Parrott. 1987. Breeding potential of cotton germplasm tolerant to tobacco budworm *Heliothis virescens* (Fab.). Miss. Agric. For. Exp. Stn. Tech. Bull. 144.

Hsu, A. C. T. 1991. 1,2-Diacyl-1-alkylhydrazines: a new class of insect growth regulator, pp. 478-490. *In* D. R. Baker, J. G. Fenyes, and W. K. Moberg (eds.), Synthesis and chemistry of agrochemicals II. American Chemical Society, Washington, D.C.

Huddleston, P. M., E. B. Mitchell, and N. M. Wilson. 1977. Disruption of boll weevil communication. J. Econ. Entomol. 70: 83-85.

Huffaker, C. B., C. A. Shoemaker, and A. P. Gutierrez. 1978. Current status, urgent needs and future prospects of integrated pest management, pp. 237-259. *In* E. H. Smith, and D. Pimentel (eds.), Pest Control Strategies. Academic Press, New York.

Hughes, H. A. 1982. Fundamentals of machine operations- crop chemicals. John Deere Technical Services, Moline.

Hughes, P. S. 1975. The biology of *Archytas marmoratus* (Townsend). Ann. Entomol. Soc. Amer. 68: 759-767.

Humber, R. A. 1989. Synopsis of a revised classification for the Entomophthorales (Zygomycotina). Mycotaxon 34: 441-460.

Hummel, H. E., L. K. Gaston, H. H. Shorey, R. S. Kaae, K. J. Byrne, and R. M. Silverstein. 1973. Clarification of the chemical status of the pink bollworm sex pheromone. Science 181: 873-875.

Hung, A. C. F., M. R. Barlin, and S. B. Vinson. 1977. Identification, distribution, and biology of fire ants in Texas. Texas Agric. Exp. Bull. B-1185.

Hung, A. C. F., D. L. Vincent, J. D. Lopez, and E. G. King. 1985. *Trichogramma* (Hymenoptera: Trichogrammatidae) fauna in certain areas of Arkansas and North Carolina. Southwest. Entomol. Suppl. 8: 11-20.

Hunter, R. C., T. F. Leigh, C. Lincoln, B. A. Waddle, and L. A. Bariola. 1965. Evaluation of a selected cross-selection of cottons for resistance to the boll weevil. Ark. Agric. Exp. Stn. Bull. 700.

Hunter, W. D. 1904a. The most important step in the cultural system of controlling the boll weevil. USDA Bur. Entomol. Circ. 56.

Hunter, W. D. 1904b. Information concerning the Mexican cotton boll weevil. USDA Farmers' Bull. 189.

Hunter, W. D. 1905. The control of the boll weevil, including results of recent investigations. USDA Farmers Bull. 216.

Hunter, W. D. 1907. The most important step in the control of the boll weevil. USDA Bur. Entomol. Circ. 95.

Hunter, W. D. 1909a. What can be done in destroying the cotton boll weevil during the winter. USDA Bur. Entomol. Circ. 107.

Hunter, W. D. 1909b. The boll weevil problem with special reference to means of reducing damage. USDA Farmers' Bull. 344.

Hunter, W. D. 1910. The status of the boll weevil in 1909. USDA Bur. Entomol. Circ. 122.

Hunter, W. D. 1912. The boll weevil problem. USDA Farmers' Bull. No. 512.

Hunter, W. D. 1912. The control of the boll weevil. USDA Farmers' Bull. 500.

Hunter, W. D. 1926. The pink bollworm with special reference to steps by the Deparment of Agriculture to prevent establishment in the United States. USDA Bull. 1397.

Hunter, W. D., and B. R. Coad. 1923. The boll weevil problem. USDA Farmers Bull. 1329.

Hunter, W. D., and W. E. Hinds. 1905. The Mexican cotton boll weevil: a revision and amplification of Bull. 45, to include the most important observations made in 1904. USDA Bureau of Entomol. Bull. 51.

Hunter, W. D., and W. D. Pierce. 1912. The Mexican cotton boll weevil: a summary of the investigation of this insect up to Dec. 31, 1911. USDA Bur. Entomol. Bull. 51.

Husain, M. A., and K. N. Trehan. 1933. Observations on the life history, bionomics and control of the cotton whitefly *Bemisia gossypiperda*, (M. & L.). Indian J. Agric. Sci. 3: 701-753.

Husain, M. A., K. N. Trehan, and P. A. Verma. 1936. Studies on *Bemisia gossypiperda*, M. & L. (the whitefly of cotton) in the Punjab. Indian J. of Agric. Sci. 6: 893-903.

Hussey, N. W., and W. J. Parr. 1963. Dispersal of the glasshouse red spider mite *Tetranychus urticae* Koch (Acarina: Tetranychidae). Entomol. Exp. Appl. 6: 207-214.

Hutchins, S. H. 1993. Techniques for sampling arthropods in integrated pest management, pp. 73-97. *In* L. P. Pedigo, and G. D. Buntin (eds.), Handbook of Sampling Methods for Arthropods in Agriculture. CRC Press, Ann Arbor.

Hutchins, S. H., and P. J. Gehring. 1993. Perspective on the value, regulation, and objective utilization of pest control technology. Am. Entomol. 39: 12-15.

Hutchinson, J. 1962. The history and relationships of the world's cottons. Endeavor 11: 5-15.

Hutchison, W. D., C. A. Beasley, and T. J. Henneberry. 1988. Efficacy of selected insecticides on pink bollworm oviposition in cotton, pp. 309-311. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Hutchison, W. D., C. A. Beasley, T. J. Henneberry, and J. M. Martin. 1987. An assessment of pink bollworm egg sampling as a new management tool: a 640 acre pilot test, pp. 247-276. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Hutchison, W. D., C. A. Beasley, T. J. Henneberry, and J. M. Martin. 1991. Timing insecticide applications for pink bollworm (Lepidoptera: Gelechiidae) management: Comparison of egg and larva treatment thresholds. J. Econ. Entomol. 84: 470-475.

Hutchison, W. D., G. D. Butler Jr., and J. M. Martin. 1986. Age-specific developmental times for pink bollworm (Lepidoptera: Gelechiidae): three age classes of eggs, five larval instars, and pupae. Ann. Entomol. Soc. Amer. 79: 482-487.

Hutchison, W. D., M. Moratorio, and J. M. Martin. 1990. Morphology and biology of *Trichogrammatoidea bactrae* (Hymenoptera: Trichogrammatidae), imported from Australia as a parasitoid of pink bollworm (Lepidoptera: Gelechiidae) eggs. Ann. Entomol. Soc. Am. 83: 46-54.

Hutson, D. H., and T. R. Roberts. 1985. Insecticides, pp. 1-34. *In* D. H. Hutson, and T. R. Roberts (eds.), Insecticides. John Wiley and Sons, New York.

Hydorn, S. B. 1971. Food preference of *Chrysopa rufilabris* Burmeister in North Central Florida. M.S. Thesis, University of Florida.

Hyer, A. H., E. C. Jorgenson, R. H. Garber, and S. Smith. 1979. Resistance to root-knot nematode and control of root-knot nematode-fusarium wilt disease complex in cotton. Crop Sci. 19: 898-901.

Iftner, D. C., and F. R. Hall. 1983. Effects of fenvalerate and permethrin on *Tetranychus urticae* Koch (Acarina: Tetranychidae) dispersal behavior. Environ. Entomol. 12: 1782-1786.

Iglinsky, W., and C. F. Rainwater. 1950. Observations and life history notes on *Orius insidiosus* (Say), an enemy of a spider mite on cotton in Texas. J. Econ. Entomol. 43: 567-568.

Ignoffo, C. M. 1966. Insect viruses, pp. 618. *In* C. N. Smith (ed.), Insect colonization and mass production. Academic Press, New York.

Ignoffo, C. M. 1981. The fungus *Nomuraea rileyi* as a microbial insecticide, pp. 513-538. *In* H. D. Burges (ed.), Microbial control of pests and plant dieseases 1970-1980. Academic Press, New York.

Ignoffo, C. M., and J. R. Adams. 1966. A cytoplasmic-polyhedrosis virus of the pink bollworm. J. Invertebr. Pathol. 8: 59-66.

Ignoffo, C. M., and O. F. Batzer. 1971. Microencapsulation and ultraviolet protectants to increase stability of an insect virus. J. Econ. Entomol. 64: 850-853.

Ignoffo, C. M., and O. P. Boening. 1970. Compartmental disposable plastic trays for rearing insects. J. Econ. Entomol. 63: 1696-1697.

Ignoffo, C. M., J. R. Bradley, F. R. Gilliland, F. A. Harris, L. A. Falcon, L. V. Larson, R. L. McGarr, P. P. Sikorowski, T. F. Watson, and W. C. Yearian. 1972. Field studies on stability of the *Heliothis* nucleopolyhedrosis virus at various sites throughout the cotton belt. Environ. Entomol. 1: 388-390.

Ignoffo, C. M., A. J. Chapman, and D. F. Martin. 1965. The nuclear polyhedrosis virus of *Heliothis zea* and *Heliothis virescens*. III. The effectiveness of the virus against field populations of *Heliothis* on cotton, corn and grain sorghum. J. Invertebr. Pathol. 7: 227-235.

Ignoffo, C. M., and C. Garcia. 1965. Infection of the cabbage looper, bollworm, tobacco budworm, and pink bollworm with spores of *Mattesia grandis* McLaughlin collected from boll weevils. J. Invertebr. Pathol. 7: 260-262.

Ignoffo, C. M., D. L. Hostetter, and D. B. Smith. 1976. Gustatory stimulant, sunlight protectant, evaporation retardant: three characteristics of a microbial insecticide adjuvant. J. Econ. Entomol. 69: 207-210.

Immaraju, J. A., J. G. Morse, and R. F. Hobza. 1990. Field evaluation of insecticide rotation and mixtures as strategies for citrus thrips (Thysanoptera: Thripidae) resistance management in California. J. Econ. Entomol. 83: 306-314.

Ingram, W. R. 1994. *Pectiniphora* (Lepidoptera: Gelechiidae), pp. 107-149. *In* G. A. Matthews, and J. P. Tunstall (eds.), Insect Pests of Cotton. University Press, Cambridge.

Irwin, M. E., R. E. Gill, and D. Gonzales. 1974. Field-cage studies of native egg predation of the pink bollworm in southern California cotton. J. Econ. Entomol. 67: 193-196.

Isely, D. 1926. Early summer dispersion of boll weevil with special reference to dusting. Ark. Agr. Exp. Stn. Bull. 204.

Isely, D. 1926. Early summer dispersion of the boll weevil. J. Econ. Entomol. 19: 108-112.

Isely, D. 1928. Oviposition of the boll weevil in relation to food. J. Econ. Entomol. 21: 152-155.

Isely, D. 1928. The relation of leaf color and leaf size to boll weevil oviposition. J. Econ. Entomol. 21: 553-559.

Isely, D. 1929. 41st Arrival Report, B-245. Ark. Agr. Exp. Sta.

Isely, D. 1930. 42nd Annual Report, B-257. Ark. Agr. Exp. Sta.

Isely, D. 1932. Abundance of the boll weevil in relation to summer weather and to food. Ark. Agric. Exp. Stn. Bull. 271.

Isely, D. 1933. Control of the boll weevil in Arkansas. Univ. of Arkansas Coop. Ext. Serv. Circ. 162.

Isely, D. 1934. Relationship between early varieties of cotton and boll weevil injury. J. Econ. Entomol. 27: 762-766.

Isely, D. 1935. Relation of hosts to abundance of cotton bollworm. Ark. Agric. Exp. Sta. Bull. 320.

Isely, D. 1946. The cotton aphid. Ark. Agr. Exp. Sta. Bull. 462.

Isely, D. 1950. Control of the boll weevil and the cotton aphid in Arkansas. Ark. Agr. Exp. Sta. Bull. 496.

Isely, D., and W. J. Baerg. 1924. The boll weevil problem in Arkansas. Ark. Agr. Exp. Sta. Bull. 190.

Isenhour, D. J., and K. V. Yeargan. 1981. Effect of temperature on the development of *Orius insidiosus*, with notes on laboratory rearing. Ann. Entomol. Soc. Amer. 74: 114-116.

Ishaaya, I., and J. E. Casida. 1981. Pyrethroid esterases may contribute to natural pyrethroid tolerance of larvae of the common green lacewing. Environ. Entomol. 10: 681-684.

Isler, D. A., and F. A. Fenton. 1931. Preliminary report on controlling the pink bollworm in winter. J. Econ. Entomol. 24: 795-807.

Ivy, E. E., and A. L. Scales. 1954. Are cotton insects becoming resistant to insecticides? J. Econ. Entomol. 47: 981-984.

Jackson, B. S., and G. F. Arkin. 1982. Fruit growth in a cotton simulation model, pp. 61-64. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Jackson, C. G. 1980. Entomophagous insects attacking the pink bollworm, pp. 71-75. *In* H. M. Graham (ed.), Pink bollworm control in the Western United States USDA, Science and Education Administration, ARM-W-16.

Jackson, C. G., D. E. Bryan, E. G. Neeman, and A. L. Wardecker. 1970. Biological control: results of field cage test with parasites of *Heliothis* spp. Third Qtr. Rpt., Cotton Insects Biological Control Investigations. U.S. Department of Agriculture, Tucson, AZ.

Jackson, C. G., D. E. Bryan, and R. Patana. 1969. Laboratory studies of *Eucelatoria armigera*, a tachinid parasite of *Heliothis* spp. J. Econ. Entomol. 62: 607-610.

Jacobs, R. G., C. A. Kouskolekas, and H. R. Gross. 1984. Effects of permethrin and endosulfan residues on *Triogramma pretiosum*, an egg parasitoid of *Heliothis zea*. Environ. Entomol. 13: 355-358.

Jacobson, M. 1969. Sex pheromone of the pink bollworm moth: biological masking by its geometrical isomer. Science 163: 190-191.

Jacques, R. P. 1977. Stability of entomopathogenic viruses, pp. 99-116. *In* Environmental stability of microbial insecticides. Entomology Society of America, Misc. Pub. 10. Entomology Society of America, College Park.

James, H. C. 1953. Biological control. Investigations and application of results. Jamaica Dept. Agr. Bull., N. Ser. 53: 26-27.

Jenkins, J. N. 1982a. Plant pest interaction with environmental stress and breeding for pest resistance: insects, pp. 365-373. *In* D. Christiansen (ed.), Breeding plants for less favorable environments. John Wiley & Sons, New York.

Jenkins, J. N. 1982b. Present state of the art and science of cotton breeding for insect resistance in the southeast, pp. 117-125. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Jenkins, J. N. 1990. Managing modern cultivars, *In* Proc. Beltwide Cotton Prod. Res. Conf.

Jenkins, J. N., P. A. Hedin, W. L. Parrott, J. C. McCarty Jr., and W. H. White. 1983. Cotton allelochemics and the growth of tobacco budworm larvae. Crop Sci. 23: 1195-1198.

Jenkins, J. N., F. G. Maxwell, J. C. Keller, and W. L. Parrott. 1963. Investigations of the water extracts of *Gossypium*, *Abelmoschus*, *Cucumis*, and *Phaseolus* for an arrestant and feeding stimulant for *Anthonomus grandis* Boh. Crop Sci. 3: 215-219.

Jenkins, J. N., F. G. Maxwell, and H. N. Lafever. 1966. The comparative preference of insects for glanded and glandless cottons. J. Econ. Entomol. 59: 352-356.

Jenkins, J. N., F. G. Maxwell, and W. L. Parrott. 1964. A technique for measuring certain aspects of antibiosis in cotton to the boll weevil. J. Econ. Entomol. 57: 679-681.

Jenkins, J. N., F. G. Maxwell, W. L. Parrott, and W. T. Buford. 1969. Resistance to boll weevil (*Anthonomus grandis* Boh.). Crop Sci. 9: 369-372.

Jenkins, J. N., J. C. McCarty Jr., and W. L. Parrott. 1990a. Effectiveness of fruiting sites in cotton: yield. Crop. Sci. 30: 365-369.

Jenkins, J. N., J. C. McCarty Jr., and W. L. Parrott. 1990b. Fruiting efficiency in cotton: Boll size and boll set percentage. Crop. Sci. 30: 857-860.

Jenkins, J. N., and W. L. Parrott. 1971. Effectiveness of frego bract as a boll weevil resistance character in cotton. Crop Sci. 11: 739-743.

Jenkins, J. N., and W. L. Parrott. 1976. Plant bug resistance in upland cotton, pp. 87. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Jenkins, J. N., W. L. Parrott, and J. W. Jones. 1975. Boll weevil oviposition behavior: multiple punctured squares. Environ. Entomol. 4: 861-867.

Jenkins, J. N., W. L. Parrott, A. J. Kappelman Jr., and R. L. Shepherd. 1979a. Registration of JPM-781-78-3 cotton germplasm. Crop Sci. 19: 932.

Jenkins, J. N., J. C. McCarty, W. L. Parrott, and A. J. Kappelman Jr. 1979b. Registration of 11 cotton germplasms. Crop Sci. 19: 912-922.

Jenkins, J. N., W. L. Parrott, J. C. McCarty Jr., F. E. Callahan, S. A. Berberich, and R. W. Deaton. 1993. Growth and survival of *Heliothis virescens* (Lepidoptera: Noctuidae) on transgenis cotton containing a translated form of the Delta endotoxin from *Bacillus thuringiensis*. J. Econ. Entomol. 86: 181-185.

Jenkins, J. N., W. L. Parrott, J. C. McCarty Jr., and A. T. Earnheart. 1978. Evaluation of primitive races of *Gossypium hirsutum* L. for resistance to boll weevil. Miss. Agric. & For. Exp. Stn. Tech. Bull. 91.

Jenkins, J. N., W. L. Parrott, J. C. McCarty Jr., and R. L. Shepherd. 1988a. Registration of two noncommercial germplasm lines of upland cotton tolerant to tobacco budworm. Crop Sci. 28: 870.

Jenkins, J. N., W. L. Parrott, J. C. McCarty Jr., and R. L. Shepherd. 1988b. Registration of three noncommercial germplasm lines of upland cotton tolerant to tobacco budworm. Crop Sci. 28: 869.

Jenkins, J. N., W. L. Parrott, J. C. McCarty Jr., and R. L. Shepherd. 1988c. Registration of three noncommerical germplasm lines of upland cotton tolerant to tobacco budworm and the tarnished plant bug. Crop Sci. 28: 869-70.

Jenkins, J. N., W. L. Parrott, J. C. McCarty Jr., and W. H. White. 1982. Breeding cotton for resistance to the tobacco budworm: techniques to achieve uniform field infestations. Crop Sci. 22: 400-404.

Jenkins, J. N., W. L. Parrott, J. C. McCarty Jr., and W. H. White. 1984. Registration of MHR-1 tobacco budworm resistant cotton germplasm. Crop Sci. 24: 625-626.

Jenkins, J. N., W. L. Parrott, and J. C. McCarty Jr.. 1991. Field performance of transgenic cotton containing the B.t. gene, pp. 576. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Jenkins, J. N., W. L. Parrott, J. C. McCarty Jr., and L. Dearing. 1986. Performance of cottons when infested with tobacco budworm. Crop Sci. 26: 93-95.

Jenkins, J. N., W. L. Parrott, J. C. McCarty Jr., and L. N. Latson. 1977. Evaluation of cotton, *Gossypium hirsutum* L., lines for resistance to the tarnished plant bug, *Lygus lineolaris*. Miss. Agr. For. Exp. Stn. Bull. 89.

Jenkins, J. N., R. L. Shepherd, and J. C. McCarty Jr. 1987. Breeding potential of non cultivated cotton germplasm tolerant to *Heliothis virescens*: genetic analysis of fiber components, pp. 105. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Jensen, M. P., L. A. Crowder, and T. F. Watson. 1984. Selection for permethrin resistance in the tobacco budworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 77: 1409-1411.

Jepson, L. R., H. K. Hartford, and E. W. Baker. 1975. Mites injurious to economic plants. University of California Press, Berkeley.

Jimenez, E., L. O. Roth, and J. H. Young. 1976. Droplet size and spray volume influence on control of the bollworm. J. Econ. Entomol. 69: 327-329.

Johnson, A. W., and D. G. Manley. 1983. Parasitism of tobacco budworm on tobacco in South Carolina. J. Ga. Entomol. Soc. 18: 1-6.

Johnson, A. W., J. R. Young, E. D. Threadgill, C. C. Dowler, and D. R. Sumner. 1986. Chemigation for crop production management. Plant Disease 70: 998-1004.

Johnson, C. G. 1966. A functional system of adaptive dispersal by flight. Annu. Rev. Entomol. 11: 233-260.

Johnson, C. G. 1969. Migration and dispersal of insects by flight. Methuen & Co. LTD, London.

Johnson, C. G., A. J. Haine, C. Taylor, and L. R. Taylor. 1957. Molting rhythm in alienicolae of *Aphis fabae* Scop., in the field. Ann. Appl. Bio. 45: 702-708.

Johnson, D. R. 1983. Relationship between tobacco budworm (Lepidoptera: Noctuidae) catches when using pheromone traps and egg counts in cotton. J. Econ. Entomol. 76: 182-183.

Johnson, D. R. 1990. Cotton insect pest management scouting manual. University of Arkansas Cooperative Extension Service. EC561.

Johnson, D. R., and M. E. Gilreath. 1982. Boll weevil, *Anthonomus grandis grandis* Boheman, pheromone trapping as an index of population trends. J. Ga. Entomol. Soc. 17: 429-433.

Johnson, D. R., and B. F. Jones. 1988. Cotton insect control, pp. 46-49. *In* Insecticide recommendations for Arkansas. Univ. Arkansas Coop. Ext. Serv. Pub. MP 144.

Johnson, D. R., J. J. Kimbrough, and J. S. McConnell. 1988. The effect of thrips on cotton as influenced by insecticides, irrigation and variety, pp. 144-145. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Johnson, D. R., J. J. Kimbrough, and M. L. Wall. 1993. Cotton insect management. Univ. of Arkansas Coop. Ext. Serv. Leaf. 52.

Johnson, D. R., J. R. Phillips, N. P. Tugwell, and L. H. Williams. 1985. Key to healthy, plant bug damaged and physiological shed squares. Univ. of Ark. Coop. Ext. Serv. Fact Sheet 7003.

Johnson, D. R., and G. E. Studebaker. 1991. Cotton aphid control and management in Arkansas, pp. 689-690. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Johnson, D. R., and N. P. Tugwell. 1988. Monitoring plant bug populations using small square set and square slicing, pp. 325-26. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Johnson, M. W., R. E. Stinner, and R. L. Rabb. 1975. Ovipositional response of *Heliothis zea* (Boddie) to its a major hosts in North Carolina. Environ. Entomol. 4: 291-297.

Johnson, M. W., N. C. Toscano, H. T. Reynolds, E. S. Sylvester, K. Kilo, and E. T. Natwick. 1982. Whiteflies cause problems for southern California growers. Calif. Agri. 35: 24-26.

Johnson, S. J., E. G. King, and J. R. Bradley Jr.(eds.). 1986. Theory and tactics of *Heliothis* population management: I-cultural and biological control. South. Coop. Ser. Bull. 316.

Johnson, W. L., W. H. Cross, and W. L. McGovern. 1976. Long-range dispersal of marked boll weevils in Mississippi during 1974. Ann. Entomol. Soc. Amer. 69: 421-422.

Johnson, W. L., W. H. Cross, W. L. McGovern, and H. C. Mitchell. 1973. Biology of *Heterolaccus grandis* in a laboratory culture and its potential as an introduced parasite of the boll weevil in the United States. Environ. Entomol. 2: 112-118.

Johnston, J. H. 1975. Public policy of cattle tick control in New South Wales. Rev. Marketing and Agricultural Economics 43: 3-39.

Johnstone, D. R. 1977. A technique of estimating the total insecticide spray collection by individual cotton plants and a comparison of recovery of sprays of dyed water and two ulv formulations of traizophos. Cot. Fib. Trop. 32: 67-70.

Johnstone, D. R., C. H. Rendell, and J. A. Sutherland. 1977. The short-term fate of droplets of coarse aerosol size in ulv insecticide application on to a tropical field crop. J. Aerosol Sci. 8: 395-407.

Jones Jr., W. A., J. E. Powell, and E. G. King Jr. 1985. Stoneville Research Quarantine Facility: a regional and national center for support of research on biological control of arthropod and weed pests. Bull. Entomol. Soc. Amer. 31: 20-26.

Jones Jr., W. A., and M. J. Sullivan. 1982. Role of host plants in population dynamics of stink bug pests of soybean in South Carolina. Environ. Entomol. 11: 867-875.

Jones, D., and W. L. Sterling. 1978. Locomotory activity and distribution of overwintering boll weevils in east Texas leaf litter. Southwest. Entomol. 3: 315-321.

Jones, D., and W. L. Sterling. 1979. Manipulation of red imported fire ants in a trap crop for boll weevil suppression. Environ. Entomol. 8: 1073-1077.

Jones, D., and W. L. Sterling. 1979. Temperature thresholds for spring emergence and flight of the boll weevil. Environ. Entomol. 8: 1118-1122.

Jones, F. G., and R. A. Nabors. 1988. Cotton insect control. Univ. of Missouri Coop. Ext. Serv. Ag Guide 4252.

Jones, J. E. 1982. The present state of the art and science of cotton breeding for leaf-morphological types, pp. 93-99. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Jones, J. E., J. P. Beasley, J. I. Dickson, and W. D. Caldwell. 1988. Registration of four cotton germplasm lines with resistance to reniform and root-knot nematodes. Crop Sci. 28: 199-200.

Jones, J. E., and J. W. Brand. 1981. Influence of red plant color genes on boll weevil nonpreference and agronomic performance, pp. 76-77. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Jones, J. E., D. F. Clower, E. Burris, J. G. Marshall, and S. J. Stringer. 1983. Progress in breeding frego-nectariless cottons for reduced plant bug sensitivity, pp. 81-83. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Jones, J. E., D. F. Clower, M. R. Milam, W. D. Caldwell, and D. R. Melville. 1975. Resistance in upland cotton to the banded-wing white fly, *Trialeurodes abutilonea* (Haldeman), pp. 98-99. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Jones, J. E., J. I. Dickson, and J. P. Beasley. 1987a. Preference and nonpreference of boll weevils to selected cotton, pp. 98-102. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Jones, J. E., E. Burris, W. D. Caldwell, J. G. Marshall, J. I. Dickson, and D. F. Clower. 1987b. Field performance of some new cotton strains with resistance to *Heliothis* spp., pp. 94-95. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Jones, J. E., J. I. Dickson, E. Burris, D. F. Clower, W. D. Caldwell, J. G. Marshall, and S. J. Stringer. 1988. Registration of three insect resistant cotton germplasm lines. Crop Sci. 28: 200.

Jones, J. W., H. D. Bowen, J. R. Bradley, R. E. Stinner, and R. S. Sowell. 1975a. The boll weevil (Coleoptera: Curculionidae) feeding process: a simulation model. Ecol. Modelling 1: 289-302.

Jones, J. W., H. D. Bowen, R. E. Stinner, J. R. Bradley Jr., R. S. Sowell, and J. S. Bacheler. 1975b. Female boll weevil oviposition and feeding processes: a simulation model. Environ. Entomol. 4: 815-821.

Jones, J. W., H. D. Bowen, R. E. Stinner, J. R. Bradley Jr., and J. S. Bacheler. 1977. Simulation of boll weevil population as influenced by weather, crop status and management practices. Trans. ASAE 20: 121-125, 131.

Jones, J. W., L. G. Brown, and J. D. Hesketh. 1980. COTCROP: a computer model for cotton growth and yield, pp. 209-241. *In* J. D. Hesketh, and J. W. Jones (eds.), Predicting photosynthesis for ecosystems models, Vol. 3. CRC Press, Inc., Boca Raton.

Jones, J. W., R. F. Colwick, G. L. Barker, and R. W. McClendon. 1979. Optimum time for harvesting cotton: a new concept. Trans. ASAE 22: 291-296.

Jones, J. W., J. D. Hesketh, E. J. Kamprath, and H. D. Bowen. 1974. Development of a nitrogen balance cotton growth model: a first approximation. Crop. Sci. 14: 541-546.

Jones, P. 1989. Agricultural applications of expert systems concepts. Agric. Systems 31: 3-18.

Jones, R. L. 1989. Semiochemicals mediating *Microplitis croceipes* habitat, host, and mate finding behavior, pp. 53-57. *In* J. E. Powell, D. L. Bull, and E. G. King (Eds.), Biological control of *Heliothis* spp. by *Microplitis croceipes*. Southwest. Entomol. Suppl. 12.

Jones, R. L., W. J. Lewis, M. Beroza, B. A. Bierl, and A. N. Sparks. 1973. Host seeking stimulants (kairomones) for the egg parasite *Trichogramma evanescens*. Environ. Entomol. 2: 593-596.

Jones, R. L., W. J. Lewis, M. C. Bowman, M. Beroza, and B. Bierl. 1971. Host-seeking stimulant for parasite of corn earworm: Isolation, identification, and synthesis. Science 173: 842-843.

Jones, R. L., W. J. Lewis, H. R. Gross Jr., and D. A. Nordlund. 1976. Use of kairomones to promote action by beneficial insect parasites, pp. 119-134. *In* M. Beroza (ed.), Pest management with insect sex attractants. ACS Symp. Ser. 23. American Chemical Society, Washington, DC.

Jones, S. L., P. D. Lingren, and M. J. Bee. 1977. Diel preiodicity of feeding, mating, and oviposition of adult *Chrysopa carnea*. Ann. Entomol. Soc. Amer. 70: 43-47.

Jones, S. L., R. K. Morrison, J. R. Ables, and D. L. Bull. 1979. A new and improved technique for the field release of *Trichogramma pretiosum*. Southwest. Entomol. 4: 14-19.

Jones, T. H. 1918. The southern green plant bug. USDA Bur. Entomol. Bull. 689.

Joyce, R. J. V. 1982. A critical review of the role of chemical pesticides, pp. 173-188. *In* W. Reed and V. Kumble (eds.), Proc. Interul. Workshop on *Heliothis* Management. ICRISAT, Patancheru, A.P., India.

Kaae, R. S., and H. H. Shorey. 1973. Sex pheromones of Lepidoptera: influence of environmental conditions on the location of pheromone communication and mating on *Pectinophora gossypiella*. Environ. Entomol. 2: 1081-1084.

Kaae, R. S., H. H. Shorey, L. K. Gaston, and D. Sellers. 1977. Sex pheromones of Lepidoptera: seasonal distribution of male *Pectinophora gossypiella* in a cotton growing area. Environ. Entomol. 6: 284-286.

Kadir H.A., and C. O. Knowles. 1991. Toxicological studies of the thiourea diafenthiuron in damondback moths (Lepidoptera: Yponomeutidae), twospotted spider mites (Acari: Tetranychidae), and bulb mite (Acari: Acaridae). J. Econ. Entomol. 84: 780-784.

Kahn, A., W. M. Brooks, and H. Hirschman. 1976. *Chromonema heliothidis* n. ge., n. sp. (Steinernematidae, Nematoda),a parasite of *Heliothis zea* (Noctuidae, Lepidoptera), and other insects. J. Nematol. 8: 159-168.

Kamal, M. 1935. Recent advances in the control of the pink bollworm (*Platyhedra gossypiella*) by natural enemies. 6th Intl. Congr. Entomol. Proc. 2: 567-581.

Kamal, M. 1951. Biological control projects in Egypt, with a list of introduced parasites and predators. Bull. Soc. Fouad I Entomol. 35: 205-220.

Kamrin, M. A. 1987. Health implications of ground water contaminants, pp. 225-233. *In* F. M. D'Itri, and L. G. Wolfson (eds.), Rural ground water contamination.

Kanga, L. B., and F. W. Plapp. 1992. Development of a glass vial technique for monitoring resistance to organphosphate and carbamate insecticides in the tovacco budworm and the boll weevil, pp. 731-734. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Kanga, L. H. B., F. W. Plapp Jr., M. L. Wall, and G. W. Elzen. 1993. Monitoring for resistance to nonpyrethroid insecticides in the tobacco budworm, pp. 802-807. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Kappelman Jr., A. L. 1982. Registration of three okra-leaf frego-bract disease resistant cotton germplasms. Crop Sci. 22: 693-694.

Karban, R., R. Adamchak, and W. C. Schnathorst. 1987. Induced resistance and interspecific competition between spider mites and a vascular wilt fungus. Sci. 235: 678-680.

Karlson, P., and A. Butenandt. 1959. Pheromones (ectohormones) in insects. Annu. Rev. Entomol. 4: 39-58.

Karlson, P., and M. Luscher. 1959. "Pheromones": a new term for a class of biologically active substances. Nature 183: 1835.

Karunaratne, K. M., and F. W. Plapp. 1993. Use of *Bacillus thuringiensis* for tobacco budworm control: effect of low dose rates, pp. 835-837. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Kaya, H. K. 1987. Diseases caused by nematodes, pp. 453-470. *In* J. R. Fuxa, and Y. Tanada (eds.), Epizootiology of insect diseases. John Wiley & Sons, New York.

Keller, J. C., F. G. Maxwell, and J. N. Jenkins. 1962. Cotton extracts as arrestants and feeding stimulants for the boll weevil. J. Econ. Entomol. 55: 800-801.

Keller, J. C., F. G. Maxwell, J. N. Jenkins, and T. B. Davich. 1963. A boll weevil attractant from cotton. J. Econ. Entomol. 56: 110-111.

Keller, J. C., E. B. Mitchell, G. H. McKibben, and T. B. Davich. 1964. A sex attractant for female boll weevils from males. J. Econ. Entomol. 57: 609-610.

Keller, J. C., L. W. Sheets, N. Green, and M. Jacobson. 1969. *cis*-7-Hexadecen-1-ol acetate (hexalure), a synthetic sex attractant for pink bollworm males. J. Econ. Entomol. 62: 1520-1521.

Keller, M. A. 1986. Overwintering of *Trichogramma exiguum* in North Carolina. Environ. Entomol. 15: 659-661.

Keller, M. A., and W. J. Lewis. 1985. Movements by *Trichogramma pretiosum* (Hymenoptera: Trichogrammatidae) released into cotton. Southwest. Entomol. Suppl. 8: 99-109.

Kelly, S. E., and T. F. Watson. 1987. Tobacco budworm and pyrethroid resistance, pp. 30-32. *In* Proc. Holtville Cotton Insect and Production Meeting, Colorado River Cotton Growers Association, Holtville.

Kelton, L. A. 1963. Synopsis of the genus *Orius* Wolff in America North of Mexico (Heteroptera: Anthocoridae). Can. Entomol. 95: 631-636.

Kelton, L. A. 1975. The lygus bugs (genus *Lygus* Hahn) of North America (Heteroptera: Miridae). Entomol. Soc. Canada Mem. 95: 1-101.

Kemp, W. P., J. A. Onsager, and H. E. Lemmon. 1988. Rangeland grasshopper treatment selection: an expert system for decision support in resource management. AI Applications 2: 1-8.

Kennedy, G. G., and D. C. Margolies. 1985. Mobile arthropod pests: management in diversified agroecosystems. Bull. Entomol. Soc. Amer. 31: 21-27.

Kennedy, G. G., and D. R. Smitley. 1985. Dispersal, pp. 233-242. *In* W. Helle, and M. W. Sabelis (eds.), Spider mites and their control. Elsevier Press, Amsterdam.

Kenneth, R., and I. Olmert. 1973. Some intrinsic and external factors influencing infectibility of *Spodoptera littoralis* (Noctuidae) by *Beauveria bassiana*, pp. 73. *In* Proc. 5th Intl. Colloq. on Insect Pathology and Microbiology, Sept. 1973, Oxford.

Kerby, T. 1988. Five ways to shorten the season. Cotton Grower. Memphis, Tennessee.

Kerby, T. A., K. G. Cassman, and M. Keeley. 1990. Genotype and plant densities for narrow-row cotton. I. Height, nodes, earliness and location of yield. Crop. Sci. 30: 644-649.

Kerby, T. A., K. G. Cassman, L. Urie, and M. Keeley. 1988. Phenotypes and a production system for high yielding 30-inch cotton, pp. 119-120. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Kerby, T. A., S. Johnson, and H. Yamada. 1984. Fruiting pattern modification by irrigation regime, nitrogen levels, and Pix, pp. 65. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Kerkut, G. A., and L. I. Gilbert. 1985. Comprehensive insect physiology, biochemistry and pharmacology. Vol. 12. insect control. Pergamon Press, New York.

Kerns, D. L., and M. J. Gaylor. 1991. Induction of cotton aphid outbreaks by the insecticide sulprofos, pp. 699-701. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Kerns, D. L., and M. J. Gaylor. 1991. Insecticide resistance in field populations of cotton aphids and relative susceptibility of its parasitoid *Lysiphlebus testaceipes*, pp. 682-685. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Khalifa, H., and O. I. Gameel. 1982. Control of cotton stickiness through breeding cultivars resistant to whitefly (*Bemisia tabaci* (Genn.)) infestation, pp. 181-186. *In* Improvement of oilseed and other industrial crops. FAO/IAFA, Vienna, Austria.

Khasawinah, A. M. A., R. B. March, and T. R. Fukuto. 1978. Insecticidal properties, anticholinesterase activities, and metabolism of methamidophos. Pestic. Biochem. Physiol. 9: 211-221.

Kiman, Z. B., and K. V. Yeargan. 1985. Development and reproduction of the predato *Orius insidiosus* (Hemiptera: Anthocoridae) reared on diets of selected plant material and arthropod prey. Ann. Entomol. Soc. Amer. 78: 464-467.

King, A. B. S. 1994. *Heliothis/Helicoverpa* (Lepidoptera: Noctuidae), pp. 39-106. *In* G. A. Matthews, and J. P. Tunstall (eds.), Insect Pests of Cotton. University Press, Cambridge.

King, D. S., and R. A. Humber. 1981. Identification of the entomophthorales, pp. 107-127. *In* H. D. Burges (ed.), Microbial control of pests and plant diseases 1970-1980. Academic Press, New York.

King, E. E., and H. C. Lane. 1969. Abscission of cotton flower buds and petioles caused by protein from boll weevil larvae. Plant Physiol. 44: 903-906.

King, E. G. 1986. Insecticide use in cotton and the value of predators and parasites for managing *Heliothis*, pp. 155-162. *In* Proc. Beltwide Cotton Prod. Res. Conf.

King, E. G. 1993. Augmentation of parasites and predators for suppression of arthropod pests, pp. 90-100. *In* R. D. Lumbsden, and J.L. Vaughn (eds.), Pest management: Biologically Based Technologies: Proceedings of the Beltsville Symposium XVIII. Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Maryland, May 2-6, 1993. American Chemical Society, Washington, D.C.

King, E. G., D. L. Bull, L. F. Bouse, and J. R. Phillips (eds.). 1985a. Biological control of bollworm and tobacco budworm in cotton by augmentative releases of *Trichogramma*. Southwest. Entomol. Suppl. 8.

King, E. G., R. J. Coleman, J. R. Phillips, and W. A. Dickerson. 1985b. *Heliothis* spp. and selected natural enemy populations in cotton: a comparison of three insect control programs in Arkansas (1981-82) and North Carolina (1983). Southwest. Entomol. Suppl. 8: 71-98.

King, E. G., J. E. Powell, and R. J. Coleman. 1985c. A high incidence of parasitism of *Heliothis* spp. larvae in cotton in southeastern Arkansas. Entomophaga 30: 419-426.

King, E. G., and R. J. Coleman. 1989. Potential for biological control of *Heliothis* species. Ann. Rev. Entomol. 34: 53-76.

King, E. G., J. R. Coulson, and R. J. Coleman. 1988a. ARS National Biological Control Program, Proc. Workshop on Research Priorities, July 14-15, 1987. Beltsville, Maryland.

King, E. G., and G. G. Hartley. 1985. *Heliothis virescens*, pp. 323-328. *In* P. Singh, and R. F. Moore (eds.), Handbook of Insect Rearing, Vol. 2 Elsevier, New York.

King, E. G., G. G. Hartley, D. F. Martin, and M. L. Laster. 1985. Large-scale rearing of a sterile backcross of the tobacco budworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 78: 1166-1172.

King, E. G., and R. D. Jackson (eds.). 1989. Proc. Workshop on Biological Control of *Heliothis*: Increasing the Effectiveness of Natural Enemies, 11-15 Nov. 1985, New Delhi, India. FERRO, USDA.

King, E. G., and N. C. Leppla. 1984. Advances and challenges in insect rearing. USDA, Agric. Res. Serv., New Orleans.

King, E. G., J. R. Phillips, and R. B. Head. 1986. 39th annual conference report on cotton insect research and control, pp. 127-135. *In* Proc. Beltwide Cotton Prod. Res. Conf.

King, E. G., J. R. Phillips, and R. B. Head. 1987. 40th annual conference report on cotton insect research and control, pp. 170-193. *In* Proc. Beltwide Cotton Prod. Res. Conf.

King, E. G., J. R. Phillips, and R. B. Head. 1988. 41st annual conference report on cotton insect research and control, pp. 188-203. *In* Proc. Beltwide Cotton Prod. Res. Conf.

King, E. G., and J. E. Powell. 1989. Biological control of *Heliothis* spp. emphasizing the present and potential role of *Microplitis croceipes*, pp. 1-9. *In* J. E. Powell, D. L. Bull, and E. G. King (Eds.), Biological control of *Heliothis* spp. by *Microplitis croceipes*. Southwest. Entomol. Suppl. 12.

King, E. G., and J. E. Powell. 1992. Propagation and release of natural enemies for control of cotton insect and mite pests in the United States, including status and prospects for using *Microplitis croceipes*, pp. 47-60. *In* R. S. Soper, N. A. Fillippov, and S. N. Alimukhamedov (eds.), Cotton-integrated Pest Management: Proc. Symp. USDA, ARS-106.

King, E. G., J. E. Powell, and J. W. Smith. 1982. Prospects for utilization of parasites and predators for management of *Heliothis* spp., pp. 103-122. *In* W. Reed and V. Kumble (eds.), Proc. Internl. Workshop on *Heliothis* Management. ICRISAT, Patancheru, A.P., India.

Kinsley, P. C., and B. J. Harrington. 1982. Factors influencing termination of reproductive diapause in *Orius insidiosus* (Hemiptera: Anthocoridae). Environ. Entomol. 11: 461-462.

Kinzer, R. E. 1976. Development and evaluation of techniques for using *Chrysopa carnea* Stephens to control *Heliothis* spp. in cotton. Ph.D. dissertation, Texas A&M University, College Station.

Kiritani, K., and N. Kakiya. 1975. An analysis of the predator-prey system in the paddy field. Res. Popul. Ecol. Kyoto Univ. 17: 29-38.

Kiritani, K., S. Kawahara, T. Sasaba, and F. Nakasuji. 1972. Quantitative evaluation of predation by spiders on the green rice leafhopper, *Nephotettix cincticeps* Uhler, by a sight-count method. Res. Popul. Ecol. Kyoto Univ. 13: 187-200.

Kittock, D. L., T. J. Henneberry, and L. A. Bariola. 1979. Chemical termination for insect control in cotton: past, present and future, pp. 62-64. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Kittock, D. L., J. R. Mauney, H. F. Arle, and L. A. Bariola. 1973. Termination of late season cotton fruiting with growth regulators as an insect-control technique. J. Environ. Quality 2: 405-408.

Klun, J. A., J. R. Plimmer, B. A. Bierl-Leonhardt, A. N. Sparks, and O. L. Chapman. 1979. Trace chemicals: the essence of sexual communication systems in *Heliothis* species. Science 209: 1328-1330.

Knapp, S. A. 1911. Demonstrations work on southern farms. USDA Farmers' Bull. 422.

Knight, B., J. N. Jenkins, and J. C. McCarty Jr. 1988. Effects of fruiting position on yield and fiber quality in commercial cotton, pp. 121. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Knight, H. H. 1941. The plant bugs, or Miridae, of Illinois. Bull. Ill. St. Nat. Hist. Surv. 22.

Knipling, E. F. 1955. Possibilities of insect control or eradication through use of sexually sterile males. J. Econ. Entomol. 48: 457-462.

Knipling, E. F. 1960. Requirements and possibilities of boll weevil control and eradication in relation to the population dynamics of the insect, pp. 11.Annual Cotton Insect Control Conference, Memphis, TN (Mimeo).

Knipling, E. F. 1968. Technically feasible approaches to boll weevil eradication, pp. 14-18. *In* Summary Proceedings, 1968 Beltwide Cotton Production-Mechanization Conference.

Knipling, E. F. 1970. Suppression of pest Lepidoptera by using partially sterile males: a theoretical appraisal. Bio. Sci. 20: 465-474.

Knipling, E. F. 1971. Use of population models to appraise the role of larval parasites in suppressing *Heliothis* populations. USDA Tech. Bull. 1434.

Knipling, E. F. 1978. Eradication of plant pests - Pro. Advances in technology for insect population eradication and suppression. Bull. Entomol. Soc. Amer. 24: 44-52.

Knipling, E. F. 1979. The basic principles of insect population suppression and management. USDA Agric. Handb. 512.

Knipling, E. F. 1983. Analysis of technology available for eradication of the boll weevil, pp. 409-435. *In* R. L. Ridgway, E. P. Lloyd, and W. H. Cross (eds.), Cotton Insect Management with Special Reference to the Boll Weevil. USDA Agr. Handb. No. 589.

Knipling, E. F. 1992. Principles of insect parasitism analyzed from new perspectives. Practical implications for regulating insect populations by biological means. USDA, ARS, Washington, DC.

Knipling, E. F., and W. Klassen. 1976. Relative efficiency of various genetic mechanisms for suppression of insect populations. USDA, ARS, Tech. Bull. 1553.

Knipling, E. F., and J. U. McGuire Jr. 1968. Population models to appraise the limitations and potentialities of *Trichogramma* in managing host insect populations. USDA Tech. Bull. 1386.

Knipling, E. F., and E. A. Stadelbacher. 1983. The rational for areawide management of *Heliothis* (Lepidoptera: Noctuidae) populations. Bull. Entomol. Soc. Amer. 29: 29-27.

Knowles, C. O. 1982. Structure-activity relationships among amidine acaricides and insecticides, pp. 243-277. *In* J. R. Coats (ed.), Insecticide mode of action. Academic Press, New York.

Knowles, C. O. 1987. Effects of formamidines on acarine dispersal and reproduction, pp. 174-190. *In* R. M. Hollingworth, and M. B. Green (eds.), Sites of action for neurotoxic pesticides. American Chemical Society, Washinton, D.C.

Knowles, C. O., and G. N. El-Sayed. 1985. Formamidine enhancement of acaricide toxicity to *Tetranychus urticae* Koch (Acari: Tetranychidae). J. Econ. Entomol. 78: 308-310.

Knutson, A., R. D. Parker, R. L. Huffman, C. G. Sansone, and J. Swart. 1993. Managment of cotton insects in the Southern, Eastern and Blackland areas of Texas 1993-1994. Texas Agric. Ext. Serv. B-1204.

Kogan, M., C. G. Helm, J. Kogan, and E. Brewer. 1989. Distribution and economic importance of *Heliothis virescens* and *Heliothis zea* in North, Central, and South America and of their natural enemies and host plants, pp. 241-298. *In* E. G. King and R. D. Jackson (eds.), Proc. Workshop on Biological Control of *Heliothis*: Increasing the Effectiveness of Natural Enemies. FERRO, USDA.

Konno, Y., and J. G. Scott. 1991. Biochemistry and genetics of abamectin resistance in the house fly. Pestic. Biochem. Physiol. 41: 21-28.

Konolige, K., and N. Nilsson. 1980. Multiple agent planning systems, pp. 138-142. *In* Proc. First Ann. Natl. Conf. on Art. Intell., AAAI, Menlo Park.

Korman, A., J. Mallet, J. Goodenough, J. Graves, J. Hayes, D. Hendricks, R. Luttrell, S. Pair, and M. Wall. 1993. Population structure in *Heliothis virescens* (Lepidoptera: Noctuidae): An estimate of gene flow. Ann. Entomol. Soc. Amer. 86: 182-188.

Kosmidou-Dimitropoulou, K., J. D. Berlin, and P. R. Morey. 1980. Capitate hairs on cotton leaves and bracts. Crop Sci. 20: 534-537.

Kostroun, D. A., and F. W. Plapp. 1992. Resistance management of the tobacco budworm, Heliothis virescens (F.) using insecticide combinations, pp. 749-750. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Krenz, R., C. Michael, G. Garst, D. Fawcett, and S. Rogers. 1976. Cost of producing food grains, feed grains, oil seeds, and cotton, selected years. USDA, Econ. Res. Serv., AER-338.

Krombein, K. V., P. D. Hurd Jr., and D. R. Smith. 1979. Catalog of *Hymenoptera* in America north of Mexico. Smithsonian Institution Press, Washington, DC.

Kuhn, D. G., R. W. Addor, R. E. Diehl, J. A. Furch, V. M. Kamhi, K. E. Henegar, K. A. Kremer, G. T. Lowen, B. C. Black, T. P. Miller, and M. F. Treacy. 1993. Insecticial pyrroles, pp. 219-232. *In* W. Draber, and T. Fujita (eds.), Rational approaches to structure, activity, and ecotoxicity of agrochemicals. CRC Press, Boca Raton, FL.

Kuhr, R. J. 1973. The metabolic fate of methomyl in the cabbage looper. Pestic. Biochem. Physiol. 3: 113-119.

Kuhr, R. J., and H. W. Dorough. 1976. Carbamate insecticides: chemistry, biochemistry and toxicology. CRC Press, Ohio.

Kuno, E. 1991. Sampling and analysis of insect populations. Annu. Rev. Entomol. 36: 285-302.

Kurstak, E., and P. Tijssen. 1982. Microbial and viral pesticides: modes of action, safety, and future prospects, pp. 3-32. *In* E. Kurstak (ed.), Microbial and viral pesticides. Marcel Dekker, New York.

Lacewell, R. D., D. G. Bottrell, R. V. Billingsley, D. R. Rummel, and J. L. Larson. 1974. Texas High Plains reproductive/diapause boll weevil control program: preliminary estimate of the impact. Texas Agric. Exp. Sta. MP-1165,

Lacewell, R. D., and S. M. Masud. 1985. Economic and environmental implications of IPM, pp. 79-92. *In* R. E. Frisbie and P. L. Adkisson (eds.), CIPM: Integrated Pest Management on Major Agricultural Systems. Texas Agric. Exp. Stn. MP-1616.

Lacewell, R. D., and S. M. Masud. 1988. Economic analysis of cotton IPM programs. Texas A&M University, Department of Agricultural Economics Mimeograph.

Lacewell, R. D., and C. R. Taylor. 1980. Economic analysis of cotton pest management programs. Texas Agric. Exp. Sta. TA 15972.

LaChance, L. E. 1979. Genetic strategies affecting the success and economy of the sterile insect release methods, pp. 8-19. *In* M. A. Hoy, and J. J. McKelvey (eds.), Genetics in relation to insect management. The Rockefeller Foundation, New York.

LaChance, L. E. 1985. Genetic methods for the control of Lepidoptera species. USDA-ARS Ser. 28.

LaChance, L. E., R. A. Bell, and R. D. Richard. 1973. Effect of low doses of gamma irradiation on reproduction of male pink bollworms and their F1 progeny. Environ. Entomol. 2: 653-658.

LaChance, L. E., and E. F. Knipling. 1962. Control of insect populations through genetic manipulations. Ann. Entomol. Soc. Amer. 55: 515-520.

LaChance, L. E., and R. L. Ruud. 1979. Interstrain and interspecific crosses between *Pectinophora gossypiella* and *P. scutigera*. J. Econ. Entomol. 72: 618-620.

LaFarge, A. D. 1985. How do you break the resistance cycle? Agrichemical Age. August/September: 12D and 44D.

Lagadic, L., and L. Bernard. 1993. Topical and oral activities of imidacloprid and cyfluthrin against laboratory strains of *Heliothis virescens* and *Spodoptera littoralis*. Pestic. Sci. 38: 323-328.

Laing, J. 1937. Host-finding by insect parasites. I. Observations on the finding of hosts by *Alysia manducator*, *Mormoniella vitripennis* and *Trichogramma evanescens*. J. Anim. Ecol. 6: 289-317.

Lambert, L., J. N. Jenkins, W. L. Parrott, and J. C. MCarty. 1982. Greenhouse technique for evaluating resistance to the bandedwinged whitefly (Homoptera: Aleyrodidae) used to evaluate thirty-five foreign cotton cultivars. J. Econ. Entomol. 75: 1166-1168.

Lambert, L., J. N. Jenkins, W. L. Parrott, and J. C. McCarty Jr. 1980. Evaluation of foreign and domestic cotton cultivars and strains for boll weevil resistance. Crop Sci. 20: 804-806.

Lambert, L., J. N. Jenkins, W. L. Parrott, and J. C. McCarty. 1982. Effect of 43 foreign and domestic cotton cultivars and strains on growth of tobacco budworm larvae. Crop Sci. 22: 543-545.

Lambert, W. R. 1983. Impact of IPM on acreage scouted and insecticide use, pp. 229-230. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Lambert, W. R. 1984. Thrips and whitefly in the southeast, pp. 180-181. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Lambert, W. R. 1985. The thrips problem, pp. 130-131. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Landivar, J. A., D. N. Baker, and J. N. Jenkins. 1983a. Application of GOSSYM to genetic feasibility studies. I. Analyses of fruit abscission and yield in okra-leaf cottons. Crop Sci. 23: 497-504.

Landivar, J. A., D. N. Baker, and J. N. Jenkins. 1983b. Application of GOSSYM to genetic feasibility studies. II. Analyses of increasing photosynthesis, specific leaf weight and longevity of leaves in cotton. Crop Sci. 23: 504-510.

Landivar, J. A., B. R. Eddleman, J. H. Benedict, D. J. Lawler, D. Ring, and D. T. Gardiner. 1991. ICEMM, an integrated crop ecosystem management model: agronomic component, pp. 453-457. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Lankas, G. R., and L. R. Gordon. 1989. Toxicology, pp. 89-112. *In* W. C. Campbell (ed.), Ivermectin and avermectin. Springer-Verlag, New York.

Larson, D. L., and R. T. Huber. 1975. A simulation of the pink bollworm-cotton plant interaction. Ariz. Agric. Exp. Stn. Tech. Pap. 142.

Larson, J. L., R. D. Lacewell, J. D. Casey, L. N. Namken, M. D. Heilman, and R. D. Parker. 1975. Impact of short season cotton production in Texas Lower Rio Grande Valley on producer returns, insecticide use and energy consumption. Texas Agr. Exp. Sta. MP. 1204.

Larson, L. L., E. E. Kenaga, and R. W. Morgan. 1985. Commercial and experimental organic insecticides. Entomological Society of America, College Park.

Lasota, J. A., and R. A. Dybas. 1991. Avermectins, a novel class of compounds: implications for use in arthropod pest control. Annu. Rev. Entomol. 36: 91-117.

Laster, M. L. 1972. Interspecific hybridization of *Heliothis virescens* and *H. subflexa*. Environ. Entomol. 1: 682-687.

Laster, M. L., J. E. Carpenter, M. D. Huettel, S. G. Miller, F. I. Proshold, R. T. Roush, J. C. Schneider, and A. N. Sparks. 1988a. Autocidal systems for *Heliothis* control, pp. 74-103. *In* G. A. Herzog, S. Ramaswamy, G. Lentz, J. L. Goodenough, and J. J. Hamm (eds.), Theory and tactics of *Heliothis* population management. III- Emerging control tactics and techniques. S. Coop. Ser. Bull. No. 337.

Laster, M. L., E. G. King, and R. E. Furr. 1988b. Interspecific hybridization of *Heliothis subflexa* and *H. virescens* (Lepidoptera: Noctuidae) from Argentina. Environ. Entomol. 17: 1016-1018.

Laster, M. L., and R. E. Furr. 1972. *Heliothis* populations in cotton-sesame interplantings. J. Econ. Entomol. 65: 1524-1525.

Laster, M. L., C. E. Goodpasture, E. G. King, and P. Twine. 1985. Results from crossing the bollworm *Helicoverpa armigera* x *H. zea* in search of backcross sterility, pp. 146-147. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Laster, M. L., D. F. Martin, S. D. Pair, and R. E. Furr. 1978. Infusion of hybrid *Heliothis* male sterility into *H. virescens* populations in field cages. Environ. Entomol. 7: 364-366.

Laster, M. L., D. F. Martin, and D. W. Parvin Jr. 1976. Potential for suppressing tobacco budworm (Lepidoptera: Noctuidae) by genetic sterilization. Miss. Agr. Forestry Expt. Sta. Tech. Bull. 82.

Laster, M. L., S. D. Pair, and D. F. Martin. 1982. Acceptance and development of *Heliothis subflexa* and *H. virescens* (Lepidoptera: Nocutidae) and their hybrid and backcross progeny on several plant species. Environ. Entomol. 11: 979-980.

Laster, M. L., and J. L. Roberson. 1990. *Heliothis* pupal handling and placement methods for improved moth emergence in wide-area release programs, pp. 311-312. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Latson, L. N., J. N. Jenkins, W. L. Parrott, and F. G. Maxwell. 1977. Behavior of the tarnished plant bug, *Lygus lineolaris*, on cotton, *Gossypium hirsutum* L., and horseweed, *Erigeron canadensis*. Miss. Agri. and For. Exp. Stn., Tech. Bull. 85.

Latta, R., L. Anderson, E. Rogers, V. LaMer, S. Hochberg, H. Lauterbach, and I. Johnson. 1947. The effect of particle size and velocity on movement of DDT aerosols in a wind tunnel on the mortality of mosquitoes. J. Wash. Acad. Sci. 37: 397-407.

Laughlin, J. M., and R. E. Gold. 1987. The vaporization of methyl parathion from contaminated cotton fabrics. Textile Chemists and Colorists 19: 39-42.

Lavy, T. L., J. D. Mattice, R. R. Fynn, and M. Davis. 1982. Limiting applicator exposure to pesticides. World of Ag. Aviation 9: 33-37.

Law, J. H., and F. E. Regnier. 1971. Pheromones. Annu. Rev. Biochem. 40: 533-548.

Law, S. E., and H. D. Bowen. 1966. Charging liquid spray by elctrostatic induction. Trans. ASAE 9: 501-506.

Lawrance, N. A. 1972. An economic evaluation of cotton pest management in Pinal County, Arizona. Master's thesis. Agric. Expt. Sta., Dept. of Agric. Econ., University of Arizona, Tucson, AZ.

Lawrence, R. K., and T. F. Watson. 1979. Predator-prey relationship of *Geocoris punctipes* and *Heliothis virescens*. Environ. Entomol. 8: 245-248.

Lazurus, W. F., and B. L. Dixon. 1984. Agricultural pests as common property: control of the corn rootworm. Am. J. Agri. Econ. 66: 456-465.

Lee, J. A. 1977. Registration of North Carolina 1 and 2 smoothleaf cotton germplasm. Crop Sci. 17: 826.

Lee, J. G. 1889. Report of the North Louisiana Experiment Station, Calhoun, La. Louisiana Agr. Exp. Sta. Bull. 27 (1st Ser.).

Lee, J. G. 1890. Results of 1890 obtained on the North Louisiana Agricultural Experiment Station. Louisiana Agric. Exp. Stn. Bull. 8 (2nd Ser.).

Lee, J. G. 1892. Report of results for 1892 at Calhoun, La. Louisiana Agr. Exp. Sta. Bull. 21 (2nd Ser.).

Lee, J. G. 1892. Results of 1891 obtained on the North Louisiana Experiment Station, Calhoun, La. Louisiana Agric. Exp. Sta. Bull. 16 (second series).

Lee, J. G. 1894. Report of results for 1893 at Calhoun, La. Louisiana Agric. Exp. Stn. Bull. 29 (2nd Ser.).

Leeper, J. R., R. T. Roush, and H. T. Reynolds. 1986. Pesticide resistance: strategies and tactics for management. National Academy of Sciences 335-346.

Leftwich, R., and R. Eckert. 1982. The price system and resources allocation. Dryden Press, Chicago.

Legaspi Jr., B. A. C., W. L. Sterling, A. W. Hartstack Jr., and D. A. Dean. 1989. Testing the interactions of pest-predator-plant components of the TEXCIM model. Environ. Entomol. 18: 157-163.

Leggett, J. E., W. A. Dickerson, K. P. Burnham, S. H. Roach, A. R. Hopkins, and F. R. Planer. 1988. Boll weevil (Coleoptera: Curculionidae): emergence profile of overwintered weevils measured by grandlure-baited traps and predicting total emergence. Environ. Entomol. 17: 903-910.

Legner, E. F. 1979. Emergence patterns and dispersal in *Chelonus* spp. near *curvimaculatus* and *Pristomerus hawaiiensis* parasitic on *Pectinophora gossypiella*. Ann. Entomol. Soc. Amer. 72: 681-686.

Legner, E. F., and R. A. Medved. 1979. Influence of parasitic hymenoptera on the regulation of pink bollworm, *Pectinophora gossypiella*, on cotton in the Lower Colorado desert. Environ. Entomol. 922-930.

Leicht, W. 1993. Imadicloprid - a chloronicotinyl insecticide. Pestic. Outlook 4: 17-21.

Leigh, T. F. 1963. Considerations of distribution, abundance and control of acarine pests of cotton. Adv. Acarology 1: 14-20.

Leigh, T. F. 1963. Life history of *Lygus hesperus* (Hemiptera: Miridae) in the laboratory. Ann. Entomol. Soc. Amer. 56: 865-867.

Leigh, T. F. 1966. A reproductive diapause in *Lygus hesperus* Knight. J. Econ. Entomol. 59: 1280-1281.

Leigh, T. F. 1969. Chemical and microbial insecticide studies for cotton insect control, pp. 53-81. *In* Proc. Cotton Symposium. Univ. of Calif., Berkeley.

Leigh, T. F. 1984. Spider mite (Acarina: Tetranychidae) infestation development on cotton, pp. 756-760. *In* D. A. Griffiths, and C. E. Bowman (eds.), Acarology VI, Vol. 2.

Leigh, T. F. 1984. Thrips and whitefly in the far west, pp. 181-182. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Leigh, T. F. 1985. Cotton, pp. 349-358. *In* W. Helle, and M. W. Sabelis (eds.), Spider mites: their biology, natural enemies and control. Elsevier, Amsterdam.

Leigh, T. F. 1988. Spider mites on Australian cotton. Australian Cotton Grower. Aug.-Oct.

Leigh, T. F., and V. E. Burton. 1976. Spider mite pests of cotton. Univ. of Calif., Division of Agric. Sci., Leaflet 2888.

Leigh, T. F., and D. Gonzalez. 1976. Field cage evaluation of predators for control of *Lygus hesperus* Knight on cotton. Environ. Entomol. 5: 948-952.

Leigh, T. F., D. W. Grimes, W. L. Dickens, and C. E. Jackson. 1974. Planting pattern, plant population, irrigation, and insect interactions in cotton. Environ. Entomol. 3: 492-496.

Leigh, T. F., and R. E. Hunter. 1969. Predacious spiders in California cotton. Calif. Agric. 23: 4-5.

Leigh, T. F., A. H. Hyer, J. H. Benedict, and P. F. Wynholds. 1985. Observed population increase, nymphal weight gain, and oviposition nonpreference as indicators of *Lygus hesperus* (Heteroptera: Miridae) resistance in glandless cotton. J. Econ. Entomol. 78: 1109-1113.

Leigh, T. F., and C. E. Jackson. 1968. Topical toxicity of several chlorinated hydrocarbon, organphosphrous, and carbamate insecticides to *Lygus hesperus*. J. Econ. Entomol. 61: 328-330.

Leigh, T. F., C. E. Jackson, P. F. Wynholds, and J. A. Cota. 1977. Toxicity of selected insecticides applied topically to *Lygus hesperus*. J. Econ. Entomol. 70: 42-44.

Leigh, T. F., T. A. Kerby, and P. F. Wynholds. 1988. Cotton square damage by the plant bug *Lygus hesperus* (Hemiptera: Heteroptera: Miridae) and abscission rates. J. Econ. Entomol. 81: 1328-1337.

Lemmon, H. E. 1986. COMAX: an expert system for cotton crop management. Science 233: 29-33.

Lenteren, J. C. v. 1981. Host discrimination by parasitoids, pp. 306. *In* D. A. Nordlund, R. L. Jones, and W. J. Lewis (eds.), Semiochemicals: their role in pest control. Wiley, New York.

Lentz, G. L., T. F. Watson, and R. V. Carr. 1974. Dosage-mortality studies on laboratory-reared larvae of the tobacco budworm and the bollworm. J. Econ. Entomol. 67: 719-720.

Leonard, B. R., J. B. Graves, P. Clay, C. A. White, and E. Burris. 1993. Management of bollworm and tobacco budworm with insecticides in northeast Louisiana in 1992, pp. 1029-1934. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Leonard, B. R., J. B. Graves, T. C. Sparks, and A. M. Pavloff. 1987. Susceptibility of bollworm and tobacco budworm larvae to pyrethroid and organophosphate insecticides, pp. 320-324. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Leonard, B. R., J. B. Graves, T. C. Sparks, and A. M. Pavloff. 1988a. Evaluation of field populations of tobacco budworm and bollworm (Lepidoptera: Noctuidae) for resistance to selected insecticides. J. Econ. Entomol. 81: 1521-1528.

Leonard, B. R., T. C. Sparks, and J. B. Graves. 1988b. Insecticide cross-resistance in pyrethoid-resistant strains of tobacco budworm, *Heliothis virescens* (F.) (Lepidoptera: Noctuidae). J. Econ. Entomol. 81: 1529-1535.

Leonard, B. R., M. B. Layton, J. L. Baldwin, and D. R. Johnson. 1994. 1993 Mid-South experiences and insecticide resistance management guidelines for 1994, pp. 116-121. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Leonhardt, B. A. 1990. Controlled-release systems for the delivery of insect pheromones, pp. 169-179. *In* R. M. Wilkins (ed.), Controlled release and pest management. Taylor and Francis, London.

Leonhardt, B. A., R. T. Cunningham, W. A. Dickerson, V. C. Mastro, R. L. Ridgway, and C. P. Schwalbe. 1990. Dispenser design and performance criteria for insect attractants, pp. 113-129. *In* R. L. Ridgway, R. M. Silverstein, and M. N. Inscoe (eds.), Behavior-modifying Chemicals for Insect Management: Applications of Pheromones and Other Attractants. Marcel Dekker, Inc., New York.

Leonhardt, B. A., R. T. Cunningham, R. E. Rice, and E. M. Harte. 1987. Performance of controlled-release formulations of trimedlure to attract the Mediterranean fruit fly (*Ceratitis capitita*). Entomol. Exp. Appl. 44: 45-51.

Leonhardt, B. A., R. T. Cunningham, R. E. Rice, E. M. Harte, and T. P. McGovern. 1985. Performance of controlled-release formulations of trimedlure, the attractant for the Mediterranean fruit fly. Proc. 12th Internatl. Symp. Controlled Release Bioactive Materials. Geneva, Switzerland.

Leonhardt, B. A., W. A. Dickerson, R. L. Ridgway, and E. D. DeVilbiss. 1988. Laboratory and field evaluation of controlled release dispensers containing grandlure, the pheromone of the boll weevil (Coleoptera: Curculionidae). J. Econ. Entomol. 81: 937-943.

Leonhardt, B. A., R. T. Cunningham, R. E. Rice, E. M. Harte, and J. Hendrichs. 1989. Design, effectiveness, and performance criteria of dispenser formulations of trimedlure, an attractant of the Mediterranean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 82: 860-867.

Leppla, N. C., and T. R. Ashley. 1978. Facilities for insect research and production. USDA Tech. Bull. No. 1576.

Leppla, N. C., and T. R. Ashley. 1989. Quality control in insect mass production: a review and model. Bull. Entomol. Soc. Amer. 35: 33-44.

Leser, J. F. 1986a. Thrips management: problems and progress, pp. 175-178. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Leser, J. F. 1986b. Managing pests in High Plains cotton, pp. 47-52. *In* Summary Proceedings Western Cotton Production Conference, Lubbock, Texas.

Leser, J. F. 1989. Focus on entomology. Tex. Agric. Ext. Serv. 28(9).

Leser, J. F., C. T. Allen, E. P. Boring III, and T. W. Fuchs. 1986. Management of cotton insects in the High Plains, Rolling Plains and Trans-Pecos areas of texas. Tex. Agric. Ext. Serv. B-1209.

Leser, J. F., E. P. Boring III, T. W. Fuchs, and C. W. Neeb. 1981. Management of cotton insects in the High Plains, Rolling Plains and Trans-Pecos areas of Texas. Tex. Agric. Ext. Serv. B-1209.

Leser, J. F., T. W. Fuchs, C. T. Allen, and E. P. Boring III. 1988. Management of cotton insects in the High Plains, Rolling Plains and Trans Pecos areas of Texas. Tex. Agric. Ext. Serv. B-1209.

Leslie, P. H. 1945. On the use of matrices in certain population mathematics. Biometrika 35: 213-245.

Levin, M. D. 1970. The effects of pesticides on beekeeping in the United States. Am. Bee J. 110: 8-9.

Levins, R. A., and M. W. Parker. 1983. Short run aspects of a genetics control program for *Heliothis virescens* (Lepidoptera: Noctuidae). Ecol. Modelling 19: 213-220.

Levins, R. A., M. W. Parker, and D. W. Parvin. 1981. User's manual for a simulation model of genetic control of the tobacco budworm. Dept. Agric. Econ., Mississippi State Univ., AEC Tech. Publ. No. 31.

Lewis, C. F., and T. R. Richmond. 1968. Cotton as a crop, pp. 1-22. *In* F. C. Elliot, M. Hoover, and W. K. Porter Jr. (eds.), Advances in production and utilization of quality cotton: principles and practices. The Iowa State Press, Ames.

Lewis, W. J. 1970a. Life history and anatomy of *Microplitis croceipes* (Hymenoptera: Braconidae) a parasite of *Heliothis* spp. (Lepidoptera: Noctuidae). Ann. Entomol. Soc. Amer. 63: 67-70.

Lewis, W. J. 1970b. Study of species and instars of larval *Heliothis* parasitized by *Microplitis croceipes*. J. Econ. Entomol. 63: 363-365.

Lewis, W. J., M. Beevers, D. A. Nordlund, H. R. Gross Jr., and K. S. Hagen. 1979. Kairomones and their use for management of entomophagous insects. IX. Investigation of various kairomone treatment patterns for *Trichogramma* spp. J. Chem. Ecol. 5: 673-680.

Lewis, W. J., and J. R. Brazzel. 1966. Biological relationships between *Cardiochiles nigriceps* and the *Heliothis* complex. J. Econ. Entomol. 59: 820-823.

Lewis, W. J., and J. R. Brazzel. 1968. A three-year study of parasites of the bollworm and the tobacco budworm in Mississippi. J. Econ. Entomol. 61: 673-676.

Lewis, W. J., J. R. Brazzel, and S. B. Vinson. 1967. *Heliothis subflexa* a host of *Cardiochiles nigriceps*. J. Econ. Entomol. 60: 615-616.

Lewis, W. J., H. R. Gross Jr., and D. A. Nordlund. 1985. Behavioral manipulation of *Trichogramma* (Hymenoptera: Trichogrammatidae). Southwest. Entomol. Suppl. 8: 49-55.

Lewis, W. J., and R. L. Jones. 1971. Substance that stimulates host-seeking by *Microplitis croceipes* (Hymenoptera: Braconidae), a parasite of *Heliothis* species. Ann. Entomol. Soc. Amer. 64: 471-473.

Lewis, W. J., R. L. Jones, D. A. Nordlund, and H. R. Gross Jr. 1975. Kairomones and their use for management of entomophagous insects. II. Mechanisms causing increase in rate of parasitization by *Trichogramma* spp. J. Chem. Ecol. 1: 349-360.

Lewis, W. J., and D. A. Nordlund. 1980. Employment of parasitoids and predators for fall armyworm control. Fla. Entomol. 63: 433-438.

Lewis, W. J., D. A. Nordlund, H. R. Gross Jr., R. L. Jones, and S. L. Jones. 1977. Kairomones and their use for management of entomophagous insects. V. moth scales as a stimulus for predation of *Heliothis zea* (Boddie) eggs by *Chrysopa carnea* Stephens larvae. J. Chem. Ecol. 3: 483-487.

Lewis, W. J., D. A. Nordlund, R. C. Gueldner, P. E. A. Teal, and J. H. Tumlinson. 1982. Kairomones and their use for management of entomophagous insects. XIII. Kairomonal activity for *Trichogramma* spp. of abdominal tips, excretion, and a synthetic sex pheromone blend of *Heliothis zea* (Boddie) moths. J. Chem. Ecol. 8: 1323-1331.

Lewis, W. J., and J. W. Snow. 1971. Fecundity, sex ratios, and egg distribution by *Microplitis croceipes*, a parasite of *Heliothis*. J. Econ. Entomol. 64: 6-8.

Lewis, W. J., and S. B. Vinson. 1968. Egg and larval development of *Cardiochiles nigriceps*. Ann. Entomol. Soc. Amer. 61: 561-565.

Lewis, W. J., and S. B. Vinson. 1968. Immunological relationships between the parasite *Cardiochiles nigriceps* Vierick and certain *Heliothis* species. J. Insect Physiol. 14: 631-626.

Lewis, W. J., and S. B. Vinson. 1971. Suitability of certain *Heliothis* (Lepidoptera: Noctuidae) as hosts of the parasite *Cardiochiles nigriceps*. Ann. Entomol. Soc. Amer. 64: 970-972.

Li, L. Y. 1982. *Trichogramma* sp. and their utilization in People's Republic of China. Les Trichogrammes, Colloq. INRA (France) 9.

Libby, L. W., and T. J. Kovan. 1987. Rural ground water contamination: Impacts of and potential benefits from land use planning and zoning, pp. 351-375. *In* F. M. D'Itri, and L. G. Wolfson (eds.), Rural Groundwater Contamination. Lewis Publishers, Inc., Chelsea, Michigan.

Lidell, M. C., G. A. Niles, and J. K. Walker. 1986. Response of nectariless cotton genotypes to cotton fleahopper (Heteroptera: Miridae) infestation. J. Econ. Entomol. 79: 1372-1376.

Lim, K. P., and R. K. Stewart. 1976. Parasitism of the tarnished plant bug, *Lygus lineolaris* (Hemiptera: Miridae), by *Peristenus pallipes* and *P. pseudopallipes* (Hymenoptera: Braconidae). Can. Entomol. 108: 601-608.

Lincoln, C. 1951. Boll weevil infestations and control in eastern Arkansas in 1950. J. Econ. Entomol. 44: 766-769.

Lincoln, C. 1972. Seasonal abundance, pp. 2-7. *In* Distribution, abundance, and control of *Heliothis* species in cotton and other host plants. S. Coop. Ser. Bull. 169.

Lincoln, C. 1978. Procedures for scouting and monitoring for cotton insects. Ark. Agr. Exp. Stn. Bull. 829.

Lincoln, C., W. P. Boyer, C. Dowell, Barnes, and G. Dean. 1970. Six years experience with point sample cotton insect scouting in Arkansas. Ark. Agr. Exp. Station Bull. 754.

Lincoln, C., W. P. Boyer, and F. D. Miner. 1975. The evolution of insect pest management in cotton and soybeans: past experiences, present status, and future outlook in Arkansas. Environ. Entomol. 4: 1-7.

Lincoln, C., G. C. Dowell, W. P. Boyer, and R. C. Hunter. 1963. The point sample method of scouting boll weevil. Ark. Agric. Exp. Stn. Bull. 66.

Lincoln, C., and J. B. Graves. 1978. Insecticides: resistance and new insecticides, formulation and application technology, pp. 74-83. *In* The boll weevil: management strategies. S. Coop. Ser. Bull. 228.

Lincoln, C., and C. R. Parencia Jr. 1977. Insect pest management in perspective. Bull. Entomol. Soc. Amer. 23: 9-14.

Lincoln, C., J. R. Phillips, W. H. Whitcomb, G. C. Dowell, W. P. Boyer, K. O. Bell Jr., G. L. Dean, E. J. Matthews, J. B. Graves, L. D. Newsom, D. F. Clower, J. R. Bradley Jr., and J. L. Bagent. 1967. The bollworm-tobacco budworm problem in Arkansas and Louisiana. Ark. Agr. Exp. Stn. Bull. 720.

Lindegren, J. E., T. J. Henneberry, J. R. Raulston, L. J. F. Jech, and K. A. Valero. 1994. Current status of pink bollworm control with entomopathogenic nematodes, pp. 1242-1243. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Linden, T. 1954. Cotton. (Reprinted in) Viewpoints 250:(1) 1.

Lindig, O. H. 1976. Mass rearing of boll weevils, pp. 50-52. *In* Proc. Conf. on Boll Weevil Suppression, Management and Elimination Technology. USDA, ARS-S-71.

Lindig, O. H. 1984. Development of boll weevil diets, pp. 53-83. *In* P. P. Sikorowski, J. G. Griffin, J. Roberson, and O. H. Lindig (eds.), Boll weevil mass rearing technology. Univ. Press of Miss., Jackson.

Lindig, O. H., J. Roberson, and J. E. Wright. 1979. Evaluation of three larval and adult boll weevil diets. J. Econ. Entomol. 72: 450-452.

Lindquist, A. W. 1955. The use of gamma irradiations for control or eradication of the screw-worm. J. Econ. Entomol. 48: 467-469.

Lindquist, D. A., L. J. Gorzycki, M. S. Mayer, A. L. Scales, and T. B. Davich. 1964. Laboratory studies on sterilization of the boll weevil with apholate. J. Econ. Entomol. 57: 745-750.

Lingren, P. D. 1969. Approaches to the management of *Heliothis* spp in cotton with *Trichogramma* spp, pp. 207-217. *In* Proceedings, Tall Timbers Conference on Ecol. Anim. Contr. Habitat Mng. 1.

Lingren, P. D. 1977. *Campoletis sonorensis*: maintenance of a population on tobacco budworm in a field cage. Environ. Entomol. 6: 72-76.

Lingren, P. D. 1983. Behavior of pink bollworm (Lepidoptera: Gelichiidae) adults during eclosion to departure from site of emergence. Ann. Entomol. Soc. Amer. 76: 657-660.

Lingren, P. D., and D. E. Bryan. 1965. Dosage-mortality data on the bollworm, *Heliothis zea*, and the tobacco budworm, *Heliothis virescens*, in Oklahoma. J. Econ. Entomol. 58: 14-18.

Lingren, P. D., G. L. Greene, D. R. Davis, A. H. Baumhover, and T. J. Henneberry. 1977. Nocturnal behavior of four lepidopteran pests that attack tobacco and other crops. Ann. Entomol. Soc. Amer. 70: 161-167.

Lingren, P. D., and M. J. Lukefahr. 1977. Effects of nectariless cotton on caged populations of *Campoletis sonorensis*. Environ. Entomol. 6: 586-588.

Lingren, P. D., J. R. Raulston, T. N. Shaver, and E. V. Wann. 1990. Mortality of newly emerged adult corn earworms following treatment with a feeding stimulant bait, pp. 128-132. *In* Proceedings, 9th Annual Oklahoma Horticultural Industries Show, January 5-6, 1990, Tulsa, OK.

Lingren, P. D., J. R. Raulston, and A. N. Sparks. 1977. Interception of male tobacco budworm by barriers of released, laboratory-reared sterile females. Environ. Entomol. 6: 217-221.

Lingren, P. D., J. R. Raulston, A. N. Sparks, and F. I. Proshold. 1979. Tobacco budworm: nocturnal behavior of laboratory-reared irradiated and native adults in the field. SEA-ARS-W-5 Series: 17.

Lingren, P. D., and R. L. Ridgway. 1967. Toxicity of five insecticides to several insect predators. J. Econ. Entomol. 60: 1639-1641.

Lingren, P. D., R. L. Ridgway, C. B. Cowan, J. W. Davis, and W. C. Watkins. 1968. Biological control of the bollworm and the tobacco budworm by arthropod predators affected by insecticides. J. Econ. Entomol. 61: 1521-1525.

Lingren, P. D., R. L. Ridgway, and S. L. Jones. 1968. Consumption by several common arthropod predators of eggs and larvae of two *Heliothis* species that attack cotton. Ann. Entomol. Soc. Amer. 61: 613-618.

Lingren, P. D., A. N. Sparks, J. R. Raulston, and W. W. Wolf. 1978. Applications for nocturnal studies of insects. Bull. Entomol. Soc. Amer. 24: 206-212.

Lingren, P. D., W. B. Warner, J. R. Raulston, M. Kehat, T. J. Henneberry, S. D. Pair, A. Zvirgzdins, and J. M. Gillespie. 1988. Observations on the emergence of adults from natural populations of corn earworm, *Heliothis zea* (Boddie) (Lepidoptera: Noctuidae). Environ. Entomol. 17: 254-258.

Lingren, P. D., and W. W. Wolf. 1982. Nocturnal activity of the tobacco budworm and other insects, pp. 491. *In* J. L. Hatfield, and I. J. Thomason (eds.), Biometeorology in integrated pest management. Academic Press, New York.

Lipa, J. J. 1963. Infections caused by Protozoa other than Sporozoa, pp. 335-361. *In* E. A. Steinhaus (ed.), Insect pathology, an advanced treatise, Vol. II. Academic Press, New York.

Lipsey, Richard L. 1970. The hosts of *Neurocolpus nubilus* (Say), the clouded plant bug (Hemiptera: Miridae). Entomol. News 81: 213-219.

Litchfield, M. H. 1985. Toxicity to mammals, pp. 99-162. *In* J. P. Leahey (ed.), The pyrethroid insecticides. Taylor and Francis Ltd., London.

Little, E. J., A. R. McCaffery, C. H. Walker, and T. Perker. 1989. Evidence for an enhanced metabolism of cypermethrin by a monooxygenase in a pyrethroid-resistance strain of the tobacco budworm (*Heliothis virescens* F.). Pestic. Biochem. Physiol. 34: 58-68.

Little, V. A. 1960. A brief history of entomology at the Agricultural and Mechanical College of Texas. College Arch. College Station, Texas.

Little, V. A., and D. F. Martin. 1942. Cotton insects of the United States. Burgess Publishing Company, Minneapolis.

Liu, M. Y., and F. W. Plapp Jr. 1992. Mechanism of formamidine synergism of pyrethroids. Pestic. Biochem. Physiol. 43: 134-140.

Lloyd, E. P. 1972. Progress report on the pilot boll weevil eradication experiment, pp. 46-49. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Lloyd, E. P., W. A. Dickerson, and G. H. McKibben. 1981. Boll weevil eradication trial: research team report 1977-1980. Attachment E of Appendix A, biological evaluation of beltwide boll weevil/cotton insect management programs. USDA, Science and Education Administration,

Lloyd, E. P., M. L. Laster, and M. E. Merkl. 1964. A field study of diapause, diapause control, and population dynamics of the boll weevil. J. Econ. Entomol. 57: 433-436.

Lloyd, E. P., J. L. McMeans, and M. E. Merkl. 1961. Preferred feeding and egg laying sites of the boll weevil and the effect of weevil damage on the cotton plant. J. Econ. Entomol. 54: 979-984.

Lloyd, E. P., and M. E. Merkl. 1966. A field cage study of population dynamics of the boll weevil. J. Econ. Entomol. 59: 85-86.

Lloyd, E. P., F. C. Tingle, and R. T. Gast. 1967. Environmental stimuli inducing diapause in the boll weevil. J. Econ. Entomol. 60: 99-102.

Lloyd, E. P., F. C. Tingle, J. R. McCoy, and T. B. Davich. 1966. The reproduction-diapause approach to population control of the boll weevil. J. Econ. Entomol. 59: 813-816.

Lloyd, E. P., F. C. Tingle, M. E. Merkel, E. C. Burt, D. B. Smith, and T. B. Davich. 1967. Comparison of three rates of application of ultra-low-volume azinphosmethyl in a reproduction-diapause control program against the boll weevil. J. Econ. Entomol. 60: 1691-1699.

Loan, C. C. 1965. Life cycle and development of *Leiophron pallipes* Curtis (Hymenoptera: Braconidae, Euphorinae) in five mirid hosts in the Belleville district. Proc. Entomol. Soc. Ontario 95: 115-121.

Loan, C. C. 1970. Two new parasites of the tarnished plant bug in Ontario: *Leiophron pseudopallipes* and *Euphoriana lygivora* . Proc. Entomol. Soc. Ontario 100: 188-195.

Loan, C. C. 1980. Plant bug hosts (Heteroptera: Miridae) of some parasites (Hymenoptera: Braconidae) near Belleville, Ontario, Canada. Natualiste Can. 107: 87-93.

Loan, C. C., and C. H. Craig. 1976. Euphorine parasitism of *Lygus* spp. in alfalfa in western Canada. Naturaliste Can. 103: 497-500.

Loan, C. C., and S. R. Shaw. 1987. Euphorine parasites of *Lygus* and *Adelphocoris* (Hymenoptera: Braconidae and Heteroptera: Miridae), pp. 69-75. *In* R. C. Hedlund, and H. M. Graham (eds.), Economic importance and biological control of *Lygus* and *Adelphocoris* in North America, ARS-64.

Lockley, T. C., and O. P. Young. 1987. Prey of the striped lynx spider, *Oxyopes salticus* (Araneae: Oxyopidae), on cotton in the delta area of Mississippi. J. Arachnol. 14: 395-397.

Lockwood, J. A., T. C. Sparks, and R. N. Story. 1984. Evolution of insect resistance to insecticides: a reevaluation of the roles of physiology and behavior. Bull. Entomol. Soc. Am. 30: 41-51.

Lockwood, J. A., R. N. Story, R. L. Byford, T. C. Sparks, and S. S. Quisenberry. 1985. Behavioral resistance to the pyrethroids in the horn fly *Haematobia irritans* (L.) (Diptera: Muscidae). Environ. Entomol. 14: 873-880.

Lofgren, C. S. 1986. The economic importance and control of imported fire ants in the United States, pp. 227-256. *In* S. B. Vinson (ed.), Economic impact and control of social insects. Praeger Publishers, New York.

Lofgren, C. S., W. A. Banks, and B. M. Glancey. 1975. Biology and control of imported fire ants. Annu. Rev. Entomol. 20: 1-30.

Logan, J. A. 1988. Toward an expert system for development of pest simulation models. Environ. Entomol. 17: 359-376.

Logan, J. A., R. E. Stinner, R. L. Rabb, and J. S. Bacheler. 1979. A descriptive model for predicting spring emergence of *Heliothis zea* populations in North Carolina. Environ. Entomol. 8: 141-146.

Loh, D. K., M. D. Connor, and P. Janiga. 1991. Jack pine budworm decision support system: A prototype. AI Applications 5: 29-45.

Long, D. W., J. A. Ottea, J. B. Graves, B. R. Leonard, G. E. Church, E. Burris, L. M. Bagwell, R.D. Southwick, and N. P. Tugwell. 1992. Physical incompatibility of insecticides coapplied with foliar urea fertilizer, pp. 850-855. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Lopez Jr., J. D. 1982. Emergence pattern of an overwintering population of *Cardiochiles nigriceps* in central Texas. Environ. Entomol. 11: 838-842.

Lopez Jr., J. D., S. L. Jones, and V. S. House. 1982. Species of *Trichogramma* parasitizing eggs of *Heliothis* spp. and some associated Lepidopterous insects in central Texas. Southwest. Entomol. 7: 87-93.

Lopez Jr., J. D., and R. K. Morrison. 1980. Overwintering of *Trichogramma pretiosum* in Central Texas. Environ. Entomol. 9: 75-78.

Lopez Jr., J. D., and R. K. Morrison. 1985. Parasitization of *Heliothis* spp. eggs after augmentative releases of *Trichogramma pretiosum* Riley. Southwest. Entomol. Suppl. 8: 110-137.

Lopez Jr., J. D., R. L. Ridgway, and R. E. Pinnell. 1976. Comparative efficacy of four insect predators of the bollworm and tobacco budworm. Environ. Entomol. 5: 1160-1164.

Lopez Jr., J. D., T. N. Shaver, and W. A. Dickerson. 1990. Population monitoring of *Heliothis* spp. using pheromones, pp. 473-496. *In* R. L. Ridgway, R. M. Silverstein, and M. N. Inscoe (eds.), Behavior-modifying Chemicals for Insect Management: Applications of Pheromones and Other Attractants. Marcel Dekker, Inc., New York.

Lopez, E. G., and G. L. Teetes. 1976. Selected predators of aphids in grain sorghum and their relation to cotton. J. Econ. Entomol. 69: 198-204.

Lotka, A. J. 1925. Elements of physiological biology. Williams & Wilkins, Baltimore.

Lowry, W. L., and R. S. Berger. 1965. Investigations of pink bollworm resistance to DDT in Mexico and the United States. J. Econ. Entomol. 58: 590-591.

Luckmann, W. H., and R. L. Metcalf. 1982. The pest-management concept, pp. 1-31. *In* R. L. Metcalf, and W. H. Luckmann (eds.), Introduction to Insect Pest Management. Wiley, New York.

Lukefahr, M. J. 1961. Factors related to the induction of diapause in the pink bollworm. Ph.D., Texas A&M, College Station.

Lukefahr, M. J. 1962. Pink bollworm development in relation to age of squares and bolls with notes on biology. J. Econ. Entomol. 55: 158-159.

Lukefahr, M. J. 1970. The tobacco budworm situation in the Lower Rio Grande Valley and northern Mexico, pp. 140-145. *In* Proc. Annu. Texas Conf. on Insects, Plant Diseases, Weed and Brush Control, Texas A&M Univ.

Lukefahr, M. J. 1975. Fleahoppers vs. leafhoppers as pests of glabrous cottons, pp. 93. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Lukefahr, M. J., C. B. Cowan, and J. E. Houghtaling. 1970. Field evaluations of improved cotton strains resistant to the cotton fleahopper. J. Econ. Entomol. 63: 1101-1103.

Lukefahr, M. J., and J. E. Houghtaling. 1969. Resistance of cotton strains with high gossypol content to *Heliothis* spp. J. Econ. Entomol. 62: 588-591.

Lukefahr, M. J., J. E. Houghtaling, and D. G. Crumm. 1975. Suppression of *Heliothis* spp. with cottons containing combinations of resistance characters. J. Econ. Entomol. 68: 743-746.

Lukefahr, M. J., J. E. Houghtaling, and H. M. Graham. 1971. Suppression of *Heliothis* populations with glabrous cotton strains. J. Econ. Entomol. 58: 486-488.

Lukefahr, M. J., J. E. Jones, and J. E. Houghtaling. 1976. Fleahopper and leafhopper populations and agronomic evaluations, pp. 84. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Lukefahr, M. J., and D. F. Martin. 1966. Cotton-plant pigments as a source of resistance to the bollworm and tobacco budworm. J. Econ. Entomol. 59: 176-179.

Lummis, S. C. R., R. D. Pinnock, and D. B. Sattelle. 1987. GABA receptors of the insect central nervous system, pp. 14-24. *In* R. M. Hollingworth, and M. B. Green (eds.), Sites of action for neurotoxic pesticides. American Chemical Society, Washington, D.C.

Lund, A. E. 1985. Insecticide: effects on the nervous system, pp. 9-56. *In* G. A. Kerkut, and L. I. Gilbert (eds.), Comprehensive insect physiology, biochemistry, and pharmacology. Vol. 12. Insect control. Pergamon Press, New York.

Lusby, W. R., J. E. Oliver, G. H. McKibben, and M. J. Thompson. 1987. Free and esterified sterols of cotton buds and anthers. Lipids 22: 80-83.

Luthy, P., J. L. Cprider, and H. M. Fischer. 1982. *Bacillus thuringiensis* as a bacterial insecticide: basic considerations and applications, pp. 35-74. *In* E. Kurstak (ed.), Microbial and viral pesticides. Marcel Dekker, Inc., New York.

Luttrell, R. G. 1985. Efficacy of insecticides applied ultra low volume in vegetable oils in pesticide formulations and application systems. ASTM Spec. Tech. Publ. 875, American Society for testing and materials.

Luttrell, R. G. 1985. Plant bugs: an update, pp. 131-133. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Luttrell, R. G., M. Bell, and R. T. Roush. 1991. Management of pyrethroid resistance in the tobacco budworm: role of insecticide persistence and insecticide mixtures. Southwest. Entomol. Suppl. 15: 93-110.

Luttrell, R. G., M. Crawford, W. C. Yearian, S. Y. Young, and A. J. Mueller. 1980. Aerial release of *Trichogramma pretiosum* for control of *Heliothis* on cotton. Ark. Farm Res. 29: 13.

Luttrell, R. G., J. R. Phillips, and T. R. Pfrimmer. 1986. Cultural control in mid-south U.S. cropping systems, pp. 28-37. *In* Theory and tactics of *Heliothis* population management. I - Cultural and biological control. S. Coop. Ser. Bull. 316.

Luttrell, R. G., and J. Reed. 1986. Insecticide selection and use rates: effects on secondary pests, pp. 144-147. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Luttrell, R. G., R. T. Roush, A. Ali, J. S. Mink, M. R. Reid, and G. L. Snodgrass. 1987. Pyrethroid resistance in field populations of *Heliothis virescens* (Lepidoptera: Noctuidae) in Mississippi in 1986. J. Econ. Entomol. 80: 985-989.

Luttrell, R. G., and D. B. Smith. 1990. Effect of spray deposition characteristics on insecticide efficacy, pp. 56-70. *In* Tenth ASTM Symposium on pesticide formulations and application systems Denver, CO.

Luttrell, R. G., and J. T. Wofford. 1984. Mortality of *Heliothis virescens* larvae treated with permethrin in soybean oil. Proc. Ag. Chem. Uses Soybean Oil 51-52.

Luttrell, R. G., W. C. Yearian, and S. Y. Young. 1983. Effect of spray adjuvants on *Heliothis zea* (Lepidoptera: Noctuidae) nuclear polyhedrosis virus efficacy. J. Econ. Entomol. 76: 162-167.

Luttrell, R. G., W. C. Yearian, and S. Y. Young. 1982a. Mortality of *Heliothis* spp. larvae treated with *Heliothis zea* nuclear polyhedrosis virus spray adjuvant combinations on cotton and soybean. J. Georgia Entomol. Soc. 17: 447-453.

Luttrell, R. G., S. Y. Young, W. C. Yearian, and D. L. Horton. 1982b. Evaluation of *Bacillus thuringiensis* - spray adjuvant - viral insecticide combinations against *Heliothis* spp. (Lepidoptera: Noctuidae). Environ. Entomol. 11: 783-787.

MacDonald, R. S., G. S. Surgoner, K. R. Soloman, and C. R. Harris. 1983. Development of resistance to permethrin and dichlorvos by the house fly (Diptera: Muscidae) following continuous and alternating insecticide use on four farms. Con. Entomol. 115: 1555-1561.

MacQuillan, M. J., V. Sucksoong, and G. H. S. Hopper. 1976. Surfactant quantity and deposit particle size influence direct spray and residual deposit toxicity of chlorpyrifos to *Heliothis punctigera*. J. Econ. Entomol. 69: 492-493.

Maddy, K. T., D. Gibbons, L. O'Connell, C. Cooper, N. Saini, T. Lambert, and V. Quean. 1984. Potential exposure of workers to selected pesticides and defoliants while harvesting cotton. California Dept. of Food and Agric. HS-1203.

Maddy, K. T., D. Richter, and J. Lowe. 1983. The role of pink bollworm infestation in aflatoxin production in cotton plants and the potential exposure to aflatoxin via inhalation by workers harvesting and ginning cotton or handling cotton by-products. California Dept. of Food and Agric. HS-1054.

Maeda, S., T. Kawai, M. Obinata, H. Fugiwari, T. Horiuchi, Y. Saeki, Y. Sato, and M. Furusawa. 1985. Production of human inteferon in silkworm using a baculovirus vector. Nature 315: 592-596.

Magee, P. S. 1982. Structure-activity relationships in phosphoramidates, pp. 101-161. *In* J. R. Coats (ed.), Insecticide mode of action. Academic Press, New York.

Magee, T. A. 1982. Oxime carbamate insecticides, pp. 71-100. *In* J. R. Coats (ed.), Insecticide mode of action. Academic Press, New York.

Mahill, J. F., J. N. Jenkins, W. L. Parrott, and J. C. McCarty Jr. 1984. Registration of four doubled haploid cotton germplasms. Crop Sci. 24: 625.

Makela, M. E., and M. D. Huettel. 1979. Model for genetic control of *Heliothis virescens*. Theor. Appl. Genet. 54: 225-233.

Mallet, J. 1989. The evolution of insecticide resistance: Have the insects won? Trends Ecol. Evol. 4: 336-340.

Mallet, J., A. Korman, D. Heckel, and P. King. 1993. Biochemical genetics of *Heliothis* and *Helicoverpa* (Lepidoptera: Noctuidae) and evidence for a founder event in *Helicoverpa zea*. Ann. Entomol. Soc. Amer. 86: 189-197.

Mallet, J., and R. Luttrell. 1991. A model of insecticidal control failure: the example of *Heliothis virescens* on cotton. Southwest. Entomol. Suppl. 15: 201-212.

Mallis, A. 1971. American entomologists. Rutgers University Press, New Brunswick.

Mally, F. W. 1901. The Mexican cotton boll weevil. USDA Farmers' Bull. 130.

Mally, F. W. 1902. Report on the boll weevil. Von Boeckmann, Schultze and Co., Austin.

Mangel, M., S. E. Stefanou, and J. E. Wilen. 1985. Modeling *Lygus hesperus* injury to cotton yields. J. Econ. Entomol. 78: 1009-1014.

Mangle, M., J. R. Carey, and R. E. Plant. 1986. Pest control: operations and systems analysis in fruit fly management. Springer-Verlag, New York.

Mani, S. S. 1985. Evolution of resistance in the presence of two insecticides. Genetics 109: 761-783.

Mani, S. S. 1990. Evolution of resistance with sequential application of insecticides in time and space, pp. 245-276. *In* Proceedings, R. Soc. London. Ser B.

Mani, S. S., and R. J. Wood. 1984. Persistence and frequency of application of an insecticide in relation to the rate of evolution of resistance. Pestic. Sci. 15: 325-336.

Manley, D. G. 1986. Effects of cropping history on early and late season pink bollworm flight in Arizona. J. Agric. Entomol. 3: 227-232.

Mansour, F. 1987. Spiders in sprayed and unsprayed cotton fields in Israel, their interactions with cotton pests and their importance as predators of the Egyptian cotton leaf worm, *Spodoptera littoralis*. Phytoparasitica 15: 31-41.

Mansour, F., D. Rosen, A. Shulov, and H. N. Plaut. 1980. Evaluation of spiders as biological control agents of *Spodoptera littoralis* larvae on apple in Israel. Acta Oecol. Appl. 1: 225-232.

Maples, R. L., and J. L. Keogh. 1971. Cotton fertilization studies on loessial plains soils of Eastern Arkansas. Ark. Agr. Exp. Sta. Rep. Ser. 194.

Marcano, R. Factors affecting the distribution and abundance of 3 species of *Tetranychus* spider mites on cotton and the effect of their damage on transpiration and photosynthesis. Ph.D. Thesis, Univ. of California, Riverside.

Margolies, D. C., and G. G. Kennedy. 1985. Movement of the two-spotted spider mite *Tetranychus urticae* Koch (Acarina: Tetranychidae), among hosts in a corn-peanut agroecosystem. Entomol. Exp. Appl. 37: 55-61.

Marlatt, C. L. 1933. Report of the chief of the Bureau of Entomology. USDA, Washington, D.C.

Marrone, P. G., and S. C. MacIntosh. 1992. Insect resistance to biotechnology products: An overview of research and possible management strategies, pp. 272-282. *In* I. Denholm, A. L. Devonshire, and D. W. Hollomon (eds.), Resistance 91: Achievements and developments in combating pesticide resistance. Elsevier, London.

Marsh, P. M. 1978. The braconid parasites (Hymenoptera) of *Heliothis* species (Lepidoptera: Noctuidae). Proc. Entomol. Soc. Wash. 80: 15-36.

Marsh, P. M. 1982. Two new species of *Heterospilus* (Hymenoptera: Braconidae) from Mexico being introduced against the cotton boll weevil, *Anthonomus grandis* (Coleoptera: Curculionidae). Proc. Entomol. Soc. Wash. 84: 849-854.

Martignoni, M. E., and P. J. Iwai. 1986. A catalog of viral diseases of insects, mites, and ticks. USDA Forest Serv. General Tech. Report PNW-195.

Martignoni, M. E., and P. J. Iwai. 1981. A catalogue of viral diseases of insects, mites and ticks, pp. 896-911. *In* H. D. Burges (ed.), Microbial control of pests and plant diseases 1970-1980. Academic Press, New York.

Martin Jr., W. R., D. A. Nordlund, and W. C. Nettles Jr. 1989. Influence of host developmental state on host suitability and reproductive biology of the parasitoid *Eucelatoria bryani*. Entomol. Exp. Appl. 50: 141-147.

Martin Jr., W. R., D. A. Nordlund, and W. C. Nettles Jr. 1990. Response of the parasitoid *Eucelatoria bryani* to selected plant material in an olfactometer. J. Chem. Ecol. 16: 499-508.

Martin, D. F., M. L. Laster, F. I. Proshold, P. D. Lingren, S. D. Pair, J. R. Raulston, J. W. Smith, A. N. Sparks, and E. A. Stadelbacher. 1984. Tobacco budworm: behavioral studies of the sterile hybrid backcross in field releases in Puerto Rico. Environ. Entomol. 13: 701-707.

Martin, P. A. W., and D. H. Dean. 1981. Genetics and genetic manipulation of *Bacillus thuringiensis*, pp. 299-311. *In* H. Burges (ed.), Microbial control of pests and plant diseases 1970-1980. Academic Press, New York.

Martin, R. D., W. W. Ballard, and D. M. Simpson. 1923. Growth of fruiting parts in cotton plants. J. Agr. Res. 25: 195-208.

Martin, S. H., G. W. Elzen, J. B. Graves, S. Micinski, B. R. Leonard, and E. Burris. 1992. Toxicological responses of tobacco budworms from Louisiana, Mississippi and Texas to selected insecticides, pp. 735-738. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Martinez-Carrillo, J. L., L. P. Schouest, and T. A. Miller. 1991. Responses of populations of the tobacco budworm (Lepidoptera: Noctuidae) from northwest Mexico to pyrethroids. J. Econ. Entomol. 84: 363-366.

Martinez-Carrillo, J. T., and H. T. Reynolds. 1983. Dosage-mortality studies with pyrethroids and other insecticides on the tobacco budworm (Lepidoptera: Noctuidae) from the Imperial Valley, California. J. Econ. Entomol. 76: 983-986.

Marvel, J. T. 1985. Biotechnology in crop improvement, pp. 477-493. *In* P. A. Hedin (ed.), Bioregulators for pest control. American Chemical Society, Washington, D.C.

Masler, E. P., T. J. Kelley, and J. J. Menn. 1993. Insect neuropeptides: discery and application in insect management. Arch. Insect Biochem. Physiol. 22: 87-111.

Masner, P., M. Angst, and S. Dorn. 1987. Fenoxycarb, an insect growth regulator with juvenile hormone activity: a candidate for *Heliothis virescens* (F.) control on cotton. Pestic. Sci. 18: 89-94.

Mastradone, P. J., and E. A. Woolsen. 1983. Levels of arsenical species in cotton after field application of a cacodylic acid defoliant. Bull. Environ. Toxicol. 31: 216-221.

Masud, S. M., R. D. Lacewell, E. P. Boring III, and T. W. Fuchs. 1985a. Economic implications of a regional uniform planting date cotton production system: Texas Rolling Plains. J. Econ. Entomol. 78: 535-541.

Masud, S., R. Lacewell, J. Stoll, J. Walker, J. Leser, and C. Sellar. 1985b. Impact of a more intensive insect pest infestation level on cotton production: Texas High Plains. So. J. Agr. Eco. 17: 117-125.

Masud, S. M., R. D. Lacewell, E. P. Boring, and T. W. Fuchs. 1984. Economic implications of a delayed uniform planting date for cotton production in the Texas Rolling Plains. Texas Agr. Exp. Sta. Bull. 1489.

Masud, S. M., R. D. Lacewell, C. R. Taylor, J. H. Benedict, and L. A. Lippke. 1980. An economic analysis of integrated pest management strategies for cotton production in the Coastal Bend Region of Texas. Texas Agr. Exp. Sta. MP. 1467.

Matsumura, F. 1985. Toxicology of insecticides. Plenum, New York.

Matsumura, F., K. Tanaka, and Y. Ozoe. 1987. GABA-related systems as targets for insecticides, pp. 44-70. *In* R. M. Hollingworth, and M. B. Green (eds.), Sites of action for neurotoxic pesticides. American Chemical Society, Washington, D.C.

Matthews, G. A. 1994. Chemical control, pp. 535-557. *In* G. A. Matthews, and J. P. Tunstall (eds.), Insect Pests of Cotton. University Press, Cambridge.

Matthews, G. A. 1994. The effects of insect attack on the yield of cotton, pp. 427-430. *In* G. A. Matthews, and J. P. Tunstall (eds.), Insect Pests of Cotton. University Press, Cambridge.

Matthews, G. A. (ed.). 1989. Cotton Insect Pests and Their Management. Longman Singapore Publishers, Singapore.

Matthews, M. 1987. The classification of the Heliothinae. Ph.D. Thesis, University of London, Dept. of Entomol. British Museum (Natl. Hist), King's College London, Campden Hill Rd., London W8.

Matthews, R. E. F. 1982. Classification and nomenclature of viruses. Intervirology 17: 1-199.

Mauney, J. 1988. The power of early insect control. Cotton Grower. May

Mauney, J., and J. M. Stewart (eds.). 1986. Cotton Physiology. Cotton Foundation, Memphis, Tennessee.

Mauney, J. R., and T. J. Henneberry. 1984. Causes of square abscission in cotton. Crop Sci. 24: 1027-1030.

Mauney, J. R., T. J. Henneberry, and T. R. Russell. 1980. Soft rot of cotton squares—another cause of shed., pp. 80. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Maxwell, F. G., J. N. Jenkins, J. C. Keller, and W. L. Parrott. 1963a. An arrestant and feeding stimulant for the boll weevil in water extracts of cotton plant parts. J. Econ. Entomol. 56: 449-454.

Maxwell, F. G., J. N. Jenkins, and J. C. Keller. 1963b. A boll weevil repellent from the volatile substance of cotton. J. Econ. Entomol. 56: 894-895.

Maxwell, F. G., J. N. Jenkins, and W. L. Parrott. 1972. Resistance of plants to insects, pp. 187-265. *In* Advances in agronomy. American Society of Agronomy, Madison, Wisconsin.

Maxwell, F. G., W. L. Parrott, J. N. Jenkins, and H. N. Lafever. 1965. A boll weevil feeding deterrent from the calyx of an alternate host, *Hibiscus syriacus*. J. Econ. Entomol. 58: 985-988.

McBryde, J. B. 1891. A chemical study of the cotton plant. Tennessee Agr. Exp. Sta. Bull. 4: 120-145.

McBryde, J. B. 1891. Cotton experiments with varieties and with fertilizers. South Carolina Agr. Exp. Sta. Bull. 2 (new series).

McCann, I. R., J. D. Lopez, and J. A. Witz. 1989. Emergence model for field populations of overwintering *Heliothis zea* and *H. virescens* (Lepidoptera: Noctuidae). Environ. Entomol. 18: 618-624.

McCartney, H. A., and T. Woodhead. 1983. Electric charge, image-charge forces, and the deposition of pesticide drops. Pestic. Sci. 14: 49-56.

McCarty Jr., J. C. 1974. Evaluation of species and primitive races of cotton for boll weevil resistance and agronomic qualities. Ph.D. Dissertation, Mississippi State University, Mississippi State, Mississippi.

McCarty Jr., J. C., J. N. Jenkins, and W. L. Parrott. 1977. Boll weevil resistance, agronomic characteristics, and fiber quality in progenies of a cotton cultivar crossed with 20 primitive stocks. Crop Sci. 17: 5-7.

McCarty Jr., J. C., J. N. Jenkins, and W. L. Parrott. 1982a. Partial suppression of boll weevil oviposition by a primitive cotton. Crop Sci. 22: 490-492.

McCarty Jr., J. C., J. N. Jenkins, and W. L. Parrott. 1982b. The effect of artificially infesting cotton with tobacco budworm larvae for various times during the fruiting period, pp. 135. *In* Proc. Beltwide Cotton Prod. Res. Conf.

McCarty Jr., J. C., J. N. Jenkins, and W. L. Parrott. 1986a. Yield response of two cotton cultivars to tobacco budworm infestation. Crop Sci. 26: 136-139.

McCarty Jr., J. C., J. N. Jenkins, and W. L. Parrott. 1986b. Registration of two cotton germplasm lines with resistance to boll weevil. Crop Sci. 26: 1088.

McCarty Jr., J. C., J. N. Jenkins, W. L. Parrott, and R. G. Creech. 1979. The conversion of photoperiodic primitive race stocks of cotton to day neutral status. Miss. Agric. For. Exp. Stn. Res. Report.

McCarty Jr., J. C., and J. E. Jones. 1989. Boll weevil (Coleoptera: Curculionidae) nonpreference for primitive cotton. J. Econ. Entomol. 82: 298-300.

McCarty Jr., J. C., and W. L. McGovern. 1987. Oviposition preference in two laboratory colonies of boll weevils (Coleoptera: Curculionidae). J. Econ. Entomol. 80: 366-368.

McCarty Jr., J. C., W. R. Meredith, J. N. Jenkins, W. L. Parrott, and J. C. Bailey. 1983. Genotype X environment interaction of cottons varying in insect resistance. Crop Sci. 23: 970-973.

McClendon, R. W., G. L. Barker, J. W. Jones, and R. F. Colwick. 1981. Simulations of cotton harvesting to maximize returns. Trans. ASAE 24: 1431-1440.

McClendon, R. W., and L. G. Brown. 1983. Using the CIM model to evaluate and improve cotton insect-control strategies in Mississippi, task force-79 and -81. Miss. Agric. For. Exp. Stn. Tech. Bull. 117.

McCutchen, B. F., F. W. Plapp, H. J. Williams, and D. A. Kostroun. 1989. Reproductive deficiences associated with pyrethroid resistance in the tobacco budworm, pp. 364-366. *In* Proc. Beltwide Cotton Prod. Res. Conf.

McDaniel, S. G. 1982. Field evaluation of aircraft spray systems for delivery of reduced volume oil sprays on cotton, pp. 200-202. *In* Proc. Beltwide Cotton Prod. Res. Conf.

McDaniel, S. G., and D. M. Dunbar. 1982. Pounce 3.2 EC plus oil for cotton insect control, pp. 77-79. *In* Proc. Beltwide Cotton Prod. Res. Conf.

McDaniel, S. G., B. M. McKay, R. K. Houston, and L. D. Hatfield. 1983. Aerial drift profile of oil and water sprays. Agri. Avia. 10: 25-29.

McDaniel, S. G., and W. L. Sterling. 1979. Predator determination and efficiency on *Heliothis virescens* eggs in cotton using 32P. Environ. Entomol. 8: 1083-1087.

McDaniel, S. G., and W. L. Sterling. 1982. Predation of *Heliothis virescens* (F.) eggs on cotton in east Texas. Environ. Entomol. 11: 60-66.

McDaniel, S. G., W. L. Sterling, and D. A. Dean. 1981. Predators of tobacco budworm larvae in Texas cotton. Southwest. Entomol. 6: 102-108.

McDonald, R. E., and U. C. Lotfin. 1935. Dispersal of the pink bollworm by flight or wind carriage of the moths. J. Econ. Entomol. 18: 745-755.

McDonough, L. M., D. A. George, and B. J. Landis. 1970. Partial structure of two sex pheromones of the corn earworm, *Heliothis zea*. J. Econ. Entomol. 63: 408-412.

McEnroe, W. D., and K. Dronka. 1971. Photobehavioral classes of the spider mite *Tetranychus urticae* (Acarina: Tetranychidae). Entomol. Exp. Appl. 14: 420-424.

McGarr, R. L. 1968. Field tests with a nuclear polyhedral virus against the bollworm and tobacco budworm, 1964-1966. J. Econ. Entomol. 61: 342.

McGarr, R. L., H. T. Dulmage, and D. A. Wolfenbarger. 1970. The d-endotoxin of *Bacillus thuringiensis*, HD-1, and chemical insecticides for control of the tobacco budworm and the bollworm. J. Econ. Entomol. 63: 1357-1358.

McGough, J. M., and L. W. Noble. 1955. Colonization of imported pink bollworm parasites. J. Econ. Entomol. 48: 626-627.

McGough, J. M., and L. W. Noble. 1957. Summary of work at Brownsville, Texas, with imported pink bollworm parasites and an aphid predator. J. Econ. Entomol. 50: 514.

McGovern, W. L., and W. H. Cross. 1976. Effects of two cotton varieties on levels of boll weevil parasitism (Col.: Curculionidae). Entomophaga. 21: 123-125.

McGovern, W. L., W. H. Cross, J. E. Leggett, D. D. Hardee, G. H. McKibben, and W. L. Johnson. 1974. Mutants of the boll weevil as genetic markers: abnormal field behavior of an ebony pearl strain. J. Econ. Entomol. 67: 701.

McGovern, W. L., E. J. Villavaso, E. B. Mitchell, and T. L. Wagner. 1987. Boll weevil (Coleoptera: Curculionidae) ovipositional behavior: discrimination against damaged squares. Environ. Entomol. 16: 951-955.

McGregor, E. A. 1961. Early cotton insects of the Imperial Valley. Bull. So. Calif. Acad. Sci., Vol. 60, part 1.

McGregor, S. E. 1976. Insect pollination of cultivated crop plants. USDA, Agric. Res. Serv., Agric. Handb. 496.

McHaffey, D. G., and A. B. Borkovec. 1976. Vacuum dipping: a new method of administering chemosterilants to the boll weevil. J. Econ. Entomol. 69: 139-143.

McKee, M. J., Y. B. Ibrahim, and C. O. Knowles. 1987. Relationship between dispersal and fecundity of *Tetranychus urticae* Koch (Acarina: Tetranychidae) exposed to flucythrinate. Exp. Appl. Acar. 3: 1-10.

McKibben, G. H., and W. H. Cross. 1984. Use of pheromone traps to estimate probability of zero populations of boll weevils. Southwest. Entomol. 9: 371-374.

McKibben, G. H., W. L. McGovern, and W. A. Dickerson. 1982. Boll weevil (Coleoptera: Curculionidae) ovipositional behavior: a simulation analysis. J. Econ. Entomol. 75: 928-931.

McKibben, G. H., E. B. Mitchell, W. P. Scott, and P. A. Hedin. 1977. Boll weevils are attracted to volatile oils from cotton plants. Environ. Entomol. 6: 804-806.

McKibben, G. H., J. W. Smith, and W. L. McGovern. 1990. Development of an attract-and-kill device for the boll weevil (Coleoptera: Curculionidae). J. Econ. Entomol. 25: 581-586.

McKibben, G. H., J. W. Smith, and E. J. Villavaso. 1991. Field research results on the boll weevil bait stick, pp. 622-623. *In* Proc. Beltwide Cotton Prod. Res. Conf.

McKibben, G. H., M. J. Thompson, W. L. Parrott, A. C. Thompson, and W. R. Lusby. 1985. Identification of feeding stimulants for boll weevils from cotton buds and anthers. J. Chem. Ecol. 11: 1229-1238.

McKibben, G. H., J. L. Willers, J. W. Smith, and T. L. Wagner. 1991. Stochastic model for studying boll weevil dispersal. Environ. Entomol. 20: 1327-1332.

McKinion, J. M., D. N. Baker, F. D. Whisler, and J. R. Lambert. 1989. Application of the GOSSYM/COMAX system to cotton crop management. Agric. Systems 31: 55-65.

McKinion, J. M., J. W. Jones, and J. D. Hesketh. 1974. Analysis of SIMCOT: photosynthesis and growth, pp. 118-124. *In* Proc. Beltwide Cotton Prod. Res. Conf.

McKinion, J. M., and R. L. Olson. 1991. Interfacing issues for GOSSYM/COMAX/WHIMS. Am. Soc. Agric. Engin., Paper No. 923555

McLaughlin, J. R. 1974. Bionomics of the pink bollworm, *Pectinophora gossypiella* (Saunders) in the southern desert region of California. Ph.D. Thesis, Univ. of California, Riverside.

McLaughlin, R. E. 1962. Infectivity tests with *Beauveria bassiana* (Balsamo) Vuillemin on *Anthonomus grandis* Boheman. J. Insect Pathol. 4: 386-388.

McLaughlin, R. E. 1965a. *Mattesia grandis* n. sp., a sporozoan pathogen of the boll weevil, *Anthonomus grandis* Boheman. J. Protozool 12: 405-413.

McLaughlin, R. E. 1965b. Some relationships between the boll weevil, *Anthonomus grandis* Boheman, and *Mattesia grandis* McLaughlin (Protozoa: Neogregarinida). J. Invertebr. Pathol. 7:(464-473)

McLaughlin, R. E. 1967. Development of the bait principle for boll weevil control. II. Field-cage tests with a feeding stimulant and the protozoan, *Mattesia grandis*. J. Invertebr. Pathol. 9: 70-77.

McLaughlin, R. E. 1969. *Glugea gasti* sp. n., a microsporidian pathogen of the boll weevil *Anthonomus grandis*. J. Protozool 16: 84-92.

McLaughlin, R. E. 1971. Use of protozoans for microbial control of insects, pp. 151-171. *In* H. D. Burges, and N. W. Hussey (eds.), Microbial control of insects and mites. Academic Press Inc., London.

McLaughlin, R. E., M. R. Bell, and S. D. Veal. 1966. Bacteria and fungi associated with dead boll weevils (*Anthonomus grandis*) in a natural population. J. Invertebr. Pathol. 8: 401-408.

McLaughlin, R. E., R. J. Dahm, and M. R. Bell. 1968. Field-cage tests with a feeding stimulant and the protozoans *Mattesia grandis* and a microsporidian. J. Invertebr. Pathol. 12: 168-174.

McLaughlin, R. E., and J. C. Keller. 1964. Antibiotic control of an epizootic caused by *Serratia marcescens* Bizio in the boll weevil, *Anthonomus grandis* Boheman. J. Insect Pathol. 6: 481-485.

McLaughlin, R. E., H. A. Scott, and M. R. Bell. 1972. Infection of the boll weevil by *Chilo* irridescent virus. J. Invertebr. Pathol. 19: 285-290.

McLaughlin, R. E., T. C. Cleveland, R. J. Dahm, and M. R. Bell. 1969. Development of the bait principle for boll weevil control. IV. Field tests with a bait containing a feeding stimulant and the sporozoans *Glugea gasti* and *Mattesia grandis*. J. Invertebr. Pathol. 13: 429-441.

McNamara, H. C., D. R. Hooten, and D. D. Porter. 1940. Differential growth rates in cotton varieties and their response to seasonal conditions at Greenville, TX. USDA Tech. Bull. 710.

McNamara, H. D. 1927. Cotton spacing experiments at Greenville, TX. USDA Bull. 1473.

McPherson, J. C. 1982. The Pentatomidae (Hemiptera) of northeastern North America with emphasis on the fauna of Illinois. So. Ill. Univ. Press.

Medler, J. T. 1961. A new record of parasitism of *Lygus lineolaris* (P. Deb.) (Hemiptera) by Tachinidae (Diptera). Proc. Entomol. Soc. Washington 63: 101-102.

Meinders, D. 1985. Survey of illnesses and injuries due to occupational exposure to pesticides of ground applicators reported to physicians in California in 1984. California Department of Agriculture, Worker Health and Safety Branch. HS-1319.

Meinke, L. J., and J. E. Slosser. 1982. Fall mortality of the boll weevil in fallen cotton squares, with emphasis on parasite-induced mortality. Environ. Entomol. 11: 318-323.

Meister, R. T. (ed.). 1992. Farm chemical handbook. Meister Publishing Co., Willoughby, OH.

Meredith Jr., W. R. 1976. Nectariless cottons, pp. 34-37. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Meredith Jr., W. R. 1991. Varieties for fiber quality and yield, pp. 63-65. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Meredith Jr., W. R., and R. R. Bridge. 1977. Registration of nine germplasm lines of nectariless cotton. Crop Sci. 17: 189.

Meredith Jr., W. R., B. W. Hanny, and J. C. Bailey. 1979a. Genetic variability among glandless cottons for resistance to two insects. Crop Sci. 19: 651-653.

Meredith Jr., W. R., V. Meyer, B. W. Hanny, and J. C. Bailey. 1979b. Influence of five *Gossypium* species cytoplasms on yield components, fiber properties, and insect resistance in upland cotton. Crop Sci. 19: 647-650.

Meredith Jr., W. R., and M. F. Schuster. 1979. Tolerance of glabrous and pubescent cotton to tarnished plant bug. Crop Sci. 19: 484-488.

Meredith Jr., W. R., and R. Wells. 1987. Sub okra leaf influence on cotton yield. Crop Sci. 27: 47-48.

Merkl, M. E., and J. R. McCoy. 1978. Boll weevils: seasonal response over five years to pheromone baited traps. J. Econ. Entomol. 71: 730-731.

Messing, R. H., B. A. Croft, and K. Currans. 1989. Assessing pesticide risk to arthropod natural enemies using expert system technology. AI Appl. Nat. Res. Manage. 3: 1-12.

Metcalf, C. L., and W. P. Flint. 1939. Destructive and useful insects. McGraw-Hill Book Company, Inc., New York.

Metcalf, C. L., W. P. Flint, and R. L. Metcalf. 1962. Destructive and useful insects. McGraw-Hill Book Company, New York.

Metcalf, R. L. 1980. Changing role of insecticides in crop protection. Annu. Rev. Entomol. 25: 219-256.

Metcalf, R. L., and W. H. Luckmann. 1975. Introduction to insect pest management. John Wiley and Sons, New York.

Meyerdirk, D. C., D. L. Coudriet, and N. Prabhaker. 1986. Population dynamics and control strategy for *Bemisia tabaci* in the Imperial Valley, California. Agric. Ecosystems Environ. 17: 61-67.

Micinski, S., and D. Caldwell. 1991. Field performance of cotton genetically-modified to express insecticidal protein from *Bacillus thuringiensis*. IV. Bossier City, LA, pp. 578. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Micinski, S., W. D. Caldwell, B. J. Fitzpatrick, and R. C. Griffin. 1992. First Louisiana field trial of insect-resistant transgenic cotton. Louisiana Agriculture 35: 8-10.

Milam, M. R., J. N. Jenkins, W. L. Parrott, and J. C. McCarty Jr. 1982. Influence of earliness and nectariless traits on reducing the sensitivity to the tarnished plant bug in frego bract cotton, pp. 132-133. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Miles, G. E., E. D. Threadgill, J. F. Thompson, and R. E. Williamson. 1975. Simulation of droplet deposition on bodies with rectangular boundaries. Trans. ASAE 18: 74-78.

Miller, E., R. T. Staten, E. Jones, and J. Pozzi. 1984. Effect of 20 Krad of gamma irradiation on reproduction of pink bollworm (Lepidoptera: Gelechiidae) and their F1 progeny: potential impact of the identification of trap catch. J. Econ. Entomol. 77: 304-307.

Miller, H., and F. Crisfield. 1930. The presence in Georgia of *Bracon mellitor* a parasite of cotton boll weevil. J. Econ. Entomol. 23: 607-608.

Miller, M. C. 1971. Parasitism of the corn earworm, *Heliothis zea*, and the European corn borer, *Ostrinia nubilalis*, on corn in north Georgia. J. Ga. Entomol. Soc. 6: 246-249.

Miller, R. W., B. A. Croft, and R. D. Nelson. 1985. Effects of early season immigration of cyhexatin and formetanate resistance of *Tetranychus urticae* (Acarina: Tetranychidae) on strawberry in Central California. J. Econ. Entomol. 78: 1379-1388.

Miller, T. A. 1976. Distinguishing between carbamate and organophosphate insecticide poisoning in house flies by symptomology. Pestic. Biochem. Physiol. 6: 307-319.

Miller, T. A. 1985. International status of pyrethroid resistance, pp. 123-125. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Miller, T. A. 1987. Resistance monitoring of pink bollworm, pp. 218-219. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Miller, T. A., and M. E. Adams. 1982. Mode of action of pyrethroids, pp. 3-27. *In* J. R. Coats (ed.), Insecticide mode of action. Academic Press, New York.

Miller, T. A., and A. E. Chambers. 1987. Actions of GABA agonists and antagonists on invertebrate nerves and muscles, pp. 2-13. *In* R. M. Hollingworth, and M. B. Green (eds.), Sites of action for neurotoxic pesticides. American Chemical Society, Washington, D.C.

Miller, T. A., J. M. Kennedy, and C. Collins. 1979. CNS insensitivity to pyrethroids in the resistant kdr strain of house flies. Pestic. Biochem. Physiol. 12: 224-230.

Minsky, M. 1975. A framework for representing knowledge, pp. 211-277. *In* P. H. Winston (ed.), The psychology of computer vision. McGraw-Hill, New York.

Misch, A. 1993. Chemical reaction. World Watch 6: 10-17.

Mistric, W. J. 1968. Effects of nitrogen fertilization on cotton under boll weevil attack in North Carolina. J. Econ. Entomol. 61: 282-283.

Mitchell, E. B., and D. D. Hardee. 1974. In-field traps: a new concept in survey and suppression of low populations of boll weevils. J. Econ. Entomol. 67: 506-508.

Mitchell, E. B., D. D. Hardee, W. H. Cross, P. M. Huddleston, and H. C. Mitchell. 1972. Influence of rainfall, sex ratio, and physiological condition of boll weevils on their response to pheromone traps. Environ. Entomol. 1: 438-440.

Mitchell, E. B., P. M. Huddleston, N. M. Wilson, and D. D. Hardee. 1973. Boll weevils: relationship between time of entry into diapause and time of emergence from overwintering. J. Econ. Entomol. 66: 1230-1231.

Mitchell, E. B., E. P. Lloyd, D. D. Hardee, W. H. Cross, and T. B. Davich. 1976. In-field traps and insecticides for suppression and elimination of populations of boll weevils. J. Econ. Entomol. 69: 83-88.

Mitchell, E. B., M. E. Merkl, T. B. Davich, and M. A. Brown. 1983. Field performance of boll weevils (Coleoptera: Curculionidae) sterilized with diflubenzuron and gamma irradiation. J. Econ. Entomol. 76: 294-297.

Mitchell, E. R. 1981. Management of insect pests with semiochemicals. Plenum Press, New York.

Mitchell, E. R., and W. J. Mistric. 1965. Concepts of population dynamics and estimation of boll weevil populations. J. Econ. Entomol. 58: 757-763.

Mitchell, H. C. 1967. Natural boll weevil behavior: inter-relationships of field movements, matings, and oviposition. M.S. Thesis, Mississippi State Univ., Mississippi State.

Mitchell, H. C., and W. H. Cross. 1969. Oviposition by the boll weevil in the field. J. Econ. Entomol. 62: 604-605.

Mitchell, H. C., W. H. Cross, W. L. McGovern, and E. M. Dawson. 1973. Behavior of the boll weevil on frego bract cotton. J. Econ. Entomol. 66: 677-680.

Mitchell, R. 1973. Growth and population dynamics of a spider mite (*Tetranychus urticae* K., Acarina: Tetranychidae). Ecol. 54: 1349-1355.

Mitchell, W. C., and R. F. L. Mau. 1971. Response of the female southern green stink bug and its parasite, *Trichopoda pennipes* to male stink bug pheromones. J. Econ. Entomol. 64: 856-859.

Miyamoto, J., M. Hirano, Y. Takimoto, and M. Hatakoshi. 1993. Insect growth regulators for pest control, with emphasis on juvenile hormone analogs: present status and future prospects, pp. 144-168. *In* S. O. Duke, J. J. Menn, and J. R. Plimmer (eds.), Pest control with enhanced environmental safety. American Chemical Society, Washington, D.C.

Moffat, A. S. 1993. New chemicals seek to outwit insect pests. Science 261: 550-551.

Molnar, D. R. 1975. Comparison of three methods of treatment on fruiting characteristic, physiological shet, and insect damage yield and quality of cotton. Ph.D. Thesis, Oklahoma State University, Stillwater, OK.

Moore, J. H. 1956. Cotton breeding in the old South. Agric. His. 50: 95-101.

Moore, L. 1972. The pest management system in cotton, implementing practical pest management strategies. Proc. of a Natl. Ext. Insect-Pest Mgmt. Workshop, Purdue Univ.

Moore, L. 1985. Status of boll weevil in western U.S., pp. 129-130. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Moore, L., and T. F. Watson. 1990. Trap crop effectiveness in community boll weevil (Coleoptera: Curculionidae) control programs. J. Entomol. Sci. 25: 519-525.

Moore, L., T. F. Watson, M. Lame, M. Rethwisch, and G. Dick. 1988. Insect pest management for cotton. Ariz. Coop. Ext. Pub. 8820.

Moore, L. H. 1950. Surveys wil speed control of most cotton pests. N.M. Ext. News 30: 6.

Moore, R. F. 1980. Boll weevils: effect of insect growth regulators and juvenile hormone analogues on adult development. J. Ga. Entomol. Soc. 15: 227-231.

Moore, R. F. 1987. Adaptation of the boll weevil to laboratory rearing on a soybean-pharmamedia based diet. J. Agric. Entomol. 4: 29-32.

Moore, R. F., R. A. Leopold, and H. M. Taft. 1978. Boll weevils: mechanism of transfer of diflubenzuron from male to female. J. Econ. Entomol. 71: 587-590.

Moore, R. F., T. M. Odell, and C. O. Calkins. 1985. Quality assessment in laboratory-reared insects, pp. 107-135. *In* P. Singh, and R. F. Moore (eds.), Handbook of Insect Rearing, Vol. 1 Elsevier, New York.

Moore, R. F., and H. M. Taft. 1975. Boll weevil: chemosterilization of both sexes with busulfan plus Thompson-Hayward TH-6040. J. Econ. Entomol. 68: 96-98.

Moore, R. F., and F. F. Whisnant. 1985. *Anthonomus grandis*, pp. 217-225. *In* P. Singh, and R. F. Moore (eds.), Handbook of Insect Rearing, Vol. 1 Elsevier, New York.

Moore, W. J. 1972. Physical chemistry. Prentice-Hall, Inc., Englewood Cliffs.

Moosberg, C. A., and B. A. Waddle. 1958. Rex Cotton...a progress report. Ark. Farm. Res. 7: 9.

Morales-Ramos, J. A., and J. R. Cate. 1992. Laboratory determination of age-dependent fecundity, development, and rate of increase of *Catolaccus grandis* (Burks) (Hymenoptera: Pteromalidae). Ann. Entomol. Soc. Am. 85: 469-476.

Morales-Ramos, J. A., and J. R. Cate. 1993. Temperature-dependent developmental rates of *Catolaccus grandis* (Burks) (Hymenoptera: Pteromalidae). Environ. Entomol. 22: 226-233.

Morales-Ramos, J. A., E. G. King, and K. R. Summy. 1993. Magnitude and timing of *Catolaccus* *grandis* releases against the cotton boll weevil aided by a simulation model, pp. 915-921. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Morales-Ramos, J. A., M. G. Rojas, J. L. Roberson, R. G. Jones, E. G. King, K. R. Summy, and J. R. Brazzel. 1994. Suppression of the boll weevil first generation by augmentative releases of *Catolaccus grandis* in Aliceville, Alabama, pp. 958-964. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Morales-Ramos, J. A., K. R. Summy, J. L. Roberson, J. R. Cate, and E. G. King. 1992. Feasibility of mass rearing *Catolaccus grandis*, a parasitoid of the boll weevil, pp. 723-726. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Moritz, R. J. 1979. West Texas diapause boll weevil control program, pp. 35-36. *In* Proc. Summary Western Cotton Prod. Conf., El Paso, Texas.

Morrill, A. W. 1910. Plant bugs injurious to cotton bolls. USDA Bur. of Entomol. Bull. 86: 110.

Morrill, A. W. 1918. Insect pests of interest to Arizona cotton growers. Ariz. Agric. Exp. Sta. Bull. No. 87.

Morris, R. F. 1965. Contemporaneous mortality factors in population dynamics. Can. Entomol. 97: 1173-1184.

Morrison, R. K. 1985a. Effective mass production of eggs of the Angoumois grain moth, *Sitroga ceralella* (Olivier). Southwest. Entomol. Suppl. 8: 28-35.

Morrison, R. K. 1985b. Mass production of *Trichogramma pretiosum* Riley. Southwest. Entomol. Suppl. 8: 21-27.

Morrison, R. K., S. L. Jones, and J. D. Lopez. 1978. A unified system for the production and preparation of *Trichogramma pretiosum* for field release. Southwest. Entomol. 3: 62-68.

Motoba, K., T. Suzuki, and M. Uchida. 1992. Effect of a new acaricide, fenpyroximate, on energy metabolism and mitochondrial morphology in adult female *Tetranychus urticae* (Two-spotted spider mite). Pestic. Biochem. Physiol. 43: 37-44.

Mound, L. A. 1962. Studies on the olfaction and color sensitivity of *Bemisia tabaci* Genn. (Homoptera: Aleyrodidae). Entomol. Exp. Appl. 5: 99-104.

Mound, L. A., and S. H. Halsey. 1978. Whitefly of the world. British Museum (Natural History). John Wiley & Son, New York.

Mueller, A. J., and V. M. Stern. 1974. Timing pesticide treatments on safflower to prevent *Lygus* from dispersing to cotton. J. Econ. Entomol. 67: 77-80.

Mueller, T. F. 1983. The effect of plants on the host relations of a specialist parasitoid of *Heliothis* larvae. Entomol. Exp. Appl. 34: 78-84.

Mueller, T. F., and J. R. Phillips. 1983. Population dynamics of *Heliothis* spp. in spring weed hosts in southeastern Arkansas: survivorship and stage-specific parasitism. Environ. Entomol. 12: 1846-1850.

Muesebeck, C. F., K. V. Krombein, and H. Townes. 1951. Hymenoptera of America north of Mexico, Synoptic catalog. USDA Monog. 2.

Muggleton, J. 1984. The evolution of insecticide resistance and its relevance to control strategy, pp. 585-592. *In* Brit. Crop Protection Conference,

Mullins, J. W. 1992. Imidacloprid: A new nitroguanidine insecticide, pp. 183-198. *In* S. O. Duke, J. J. Menn, and J. R. Plimmer (eds.), Pest control with enhanced environmental safety. American Chemical Society, Washington, D.C.

Mullins, J. W., S. L. Riley, C. S. Staetz, R. J. Marrese, R. Robers, and B. J. Monke. 1991. Status of *Heliothis* resistance to pyrethroids in U.S. cotton: a report from PEG-US, pp. 634-637. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Mullins, W., and E. P. Pieters. 1981. Dosage-mortality studies of permethrin on the cotton bollworm and the tobacco budworm in Mississippi, 1977-1979. J. Ga. Entomol. Soc. 16: 197-202.

Muma, M. H. 1955. Factors contributing to the natural control of citrus insects and mites in Florida. J. Econ. Entomol. 48: 432-438.

Mumford, J. D./Norton, G.A. 1994. Pest management systems, pp. 559-576. *In* G. A. Matthews, and J. P. Tunstall (eds.), Insect Pests of Cotton. University Press, Cambridge.

Muniappan, R., and H. L. Chada. 1970a. Biological control of the greenbug by the spider *Phidippus audax*. J. Econ. Entomol. 63: 1712.

Muniappan, R., and H. L. Chada. 1970b. Biology of the crab spider, *Misumenops celer*. Ann. Entomol. Soc. Amer. 63: 1718-1722.

Murdoch, W. W. 1969. Switching in general predators: experiments on predator specificity and stability of prey populations. Ecol. Monogr. 39: 335-354.

Murphey, S. M. 1980. Use of simulation to evaluate alternative cotton insect pest control strategies. M.S. Thesis, Mississippi State Univ., Mississippi State.

Murphy, H. F., and C. E. Sanburn. 1929. Growing cotton under boll weevil conditions. Okla. State Coop. Ext. Circ. 256.

Mussett, K. S., J. H. Young, R. G. Price, and R. D. Morrison. 1979. Predatory arthropods and their relationship to fleahoppers on *Heliothis* resistant cotton varieties in Southwestern Oklahoma. Southwest. Entomol. 4: 35-39.

Naegele, J. A., R. N. Coulson, N. D. Stone, and R. E. Frisbie. 1985. The use of expert systems to integrate and deliver IPM technology, pp. 692-711. *In* R. E. Frisbie and P. L. Adkisson (eds.), CIPM: Integrated Pest Management on Major Agricultural Systems. Texas Agric. Exp. Stn. MP-1616.

Nagarkatti, S., and H. Nagaraja. 1971. Redescriptions of some known species of *Trichogramma* (Hym.: Trichogrammatidae showing the importance of the male genitalia as a diagnostic character. Bull. Entomol. Res. 61: 13-31.

Nagarkatti, S., and H. Nagaraja. 1977. Biosystematics of *Trichogramma* and *Trichogrammatoidae* species. Annu. Rev. Entomol. 22: 157-176.

Nakatsugawa, T., and M. A. Morelli. 1976. Microsomal oxidation and insecticide metabolism, pp. 61-114. *In* C. F. Wilkinson (ed.), Insecticide biochemistry and physiology. Plenum Press, New York.

Namken, L. N., and M. D. Heilman. 1973. Determinate cotton cultivars for more efficient cotton production in the Lower Rio Grande Valley. Agron. J. 65: 953.

Namken, L. N., M. D. Heilman, J. N. Jenkins, and P. A. Miller. 1983. Plant resistance and modified cotton culture, pp. 73-101. *In* R. L. Ridgway, E. P. Lloyd, and W. H. Cross (eds.), Cotton Insect Management with Special Reference to the Boll Weevil. USDA Agr. Handb. No. 589.

Narahashi, T. 1987. Neuronal target sites of insecticides pesticides, pp. 226-250. *In* R. M. Hollingworth, and M. B. Green (eds.), Sites of action for neurotoxic. American Chemical Society, Washinton, D.C.

Nathans, J., J. P. Piantanida, B. L. Eddy, T. B. Shows, and D. S. Hogness. 1986. Molecular genetics of inherited variation in human color vision. Science 232: 203-210.

National Academy of Sciences. 1969. Principles of plant and animal pest control. Vol. 3. Insect-pest management and control. Publ. 1695.

National Academy of Sciences. 1975. Cotton pest control, *In* Pest control: an assessment of present and alternative technologies, vol. III Washington, DC.

National Academy of Sciences. 1981. Cotton boll weevil: An evaluation of USDA programs. NAS Press, Washington, DC.

National Cotton Council of America. 1989. Boll weevil eradication: a cooperative federal, state, and producer program. National Cotton Council of America, Memphis, TN.

National Research Council. 1981. Cotton boll weevil: an evaluation of USDA programs. National Academy Press, Washington, DC.

National Research Council. 1986. Pesticide resistance: strategies and tactics for management. National Academy Press, Washington, D.C.

Natwick, E. T. 1987. Pink bollworm control using a high rate gossyplure formulation, pp. 262-267. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Natwick, E. T., and R. T. Staten. 1986. PBW Rope - does it work? Imperial Agricultural Briefs, Sept.-Oct. Cooperative Extension, Court House, El Centro, California.

Natwick, E. T., and F. G. Zalom. 1984. Surveying sweetpotato whitefly in the Imperial Valley. Calif. Agr. 38: 11.

Navon, A. 1985. *Spodoptera littoralis*, pp. 469-475. *In* P. Singh, and R. F. Moore (eds.), Handbook of Insect Rearing, Vol. 2 Elsevier, New York.

Neeb, C. W., J. F. Leser, E. P. Boring III, and T. W. Fuchs. 1983. Management of cotton insects in the High Plains, Rolling Plains and Trans-Pecos areas of Texas. Tex. Agric. Ext. Serv. B-209.

Nelson, G. S., and C. Lincoln. 1968. Performance of airplane sprayers for insecticide application. Univ. of Ark. Agric. Exp. Sta. Bull. 730.

Nelson, M., and J. O. Ware. 1932. The relation of nitrogen, phosphorus and potassium to the fruiting of cotton. Ark. Agr. Exp. Sta. Bull. 273.

Nemec, S. J., and P. L. Adkisson. 1969. Laboratory tests of insecticides for bollworm, tobacco budworm, and boll weevil control. Texas Agr. Exp. Stn. PR. 2676.

Nentwig, W. 1986. Non-web building spiders: prey specialists or generalists? Oecologia 69: 571-576.

Nettles Jr., W. C. 1980. Adult *Eucelatoria* sp.: response to volatiles from cotton and okra plants and from larvae of *Heliothis virescens*, *Spodoptera eridania*, and *Estigmene acrea*. Environ. Entomol. 9: 759-763.

Nettles Jr., W. C. 1982. Contact stimulants from *Heliothis virescens* that influence the behavior of females of the tachinid, *Eucelatoria bryani*. J. Chem. Ecol. 8: 1183-1191.

Nettles Jr., W. C., and M. L. Burks. 1975. A substance form *Heliothis virscens* larvae stimulating larviposition by females of the tachinid, *Archytas marmoratus*. J. Insect Physiol. 21: 965-978.

Neumann, R., and H. H. Peter. 1987. Insecticidal organophosphates: Nature made them first. Experientia 43: 1235-1237.

Neunzig, H. H. 1963. Wild host plants of the corn earworm and the tobacco budworm in eastern North Carolina. J. Econ. Entomol. 56: 135-139.

Neunzig, H. H. 1964. The eggs and early instar larvae of *Heliothis zea* and *Heliothis virescens* (Lepidoptera: Noctuidae). Ann. Entomol. Soc. Amer. 57: 98-102.

Neunzig, H. H. 1969. The biology of the tobacco budworm and the corn earworm in North Carolina, with particular reference to tobacco as a host. N. C. Agric. Exp. Sta. Tech. Bull. 196.

New Mexico A&M. 1951. Cotton insect control guide for New Mexico-1951. NM A&M Col. Agric. Ext. Ser. Circ. 227.

New Mexico A&M. 1954. Cotton insect control guide for New Mexico-1954. NM A&M Col. Agric. Ext. Ser. Circ. 227.

New Mexico A&M. 1957. Sixty-eight years of progress and research. NM A&M Col. Agric. Exp. Sta.

New Mexico A&M. 1958. Sixty-ninth annual report-research serves New Mexico agriculture. NM A&M Col. Agric. Exp. Sta.

New Mexico A&M. 1959. Seventieth annual report-New Mexico agriculture advances with research. NM A&M Col. Agric. Exp. Sta.

New Mexico Department of Agriculture. 1962. New Mexico agricultural statistics. New Mexico Department of Agriculture.

New Mexico Department of Agriculture. 1968. Regulatory order No. 2 (Amended) plant protection act effective February 29, 1968. New Mexico Department of Agriculture.

New Mexico Department of Agriculture. 1989. New Mexico agricultural statistics. New Mexico Department of Agriculture.

New, T. R. 1975. The biology of Chrysopidae and Hemerobiidae (Neuroptera), with reference to their usage as biocontrol agents: a review. Trans. R. Entomol. Soc. Lond. 127: 115-145.

Newby, L. C., and C. G. Rock. 1986. Industry perspective on legislation, pp. 478-487. *In* W. Y. Garner, R. C. Honeycutt, and H. N. Nigg (eds.), Evaluation of pesticides in ground water. Symposium Series 315. American Chemical Society, Washington, D.C.

Newell, W. 1908. The early cotton and the boll weevil: how to reduce the number of weevils during June and July. State Crop Pest Commission of Louisiana C. 22.

Newell, W. 1909a. Destroying the boll weevils before they enter hibernation, pp. 41-48. *In* Third biennial report of the secretary, 1908-1909.

Newell, W. 1909b. Special boll weevil bulletin No. 1 of the Louisiana State Board of Agriculture and Immigration. State Crop Pest Commission of Louisiana. C. 25.

Newell, W., and M. S. Dougherty. 1909. The "V" cotton stalk cutter. How to make it and how to use it, pp. 151-158. *In* Third Biennial report of the secretary, 1908-1909. State Crop Pest Commission of Louisiana. C. 30.

Newell, W., and Rosenfeld. 1909. Report upon variety and fertilizer experiments with cotton in the boll weevil infested sections of Louisiana. State Crop Pest Commission of Louisiana. C. 26.

Newman, J. S. 1890. Field experiments in 1889. Alabama Agr. Exp. Sta. Bull. 16 (new series).

Newman, J. S., and J. Clayton. 1891. Cotton. Alabama Agr. Exp. Sta. Bull. 33 (new series).

Newman, J. S., and J. Clayton. 1891. Experiments with cotton. Alabama Agr. Exp. Sta. Bull. 22. (new series).

Newsom, L. D. 1970. The end of an era and future prospects for insect control, pp. 117-136. *In* Proceedings, Tall Timbers Conf. Ecol. Anim. Contr. Habitat Manage., February 26-28, Tallahassee, Florida.

Newsom, L. D. 1974. Pest management: history, current status and future progress, pp. 1-18. *In* F. G. Maxwell and F. A. Harris (eds.), Proc. Summer Instit. Biol. Contrl. Plant Insects and Diseases. Univ. Press Miss., Jackson, Mississippi.

Newsom, L. D. 1975. Pest management: Concept to practice, pp. 257-277. *In* D. Pimentel (ed.), Insects, Sciency, and Society. Academic Press, New York.

Newsom, L. D. 1978. Eradication of plant pests. Conn. Bull. Entomol. Soc. Amer. 24: 35-40.

Newsom, L. D. 1980. The next rung up the integrated pest management ladder. Bull. Entomol. Soc. Amer. 26: 369-374.

Newsom, L. D., and D. J. Boethel. 1985. Interpreting multiple pest interactions in soybean, pp. 232-255. *In* R. E. Frisbie and P. L. Adkisson (eds.), Integrated Pest Management on Major Agricultural Systems. Texas Agric. Expt. Sta. MP-1616.

Newsom, L. D., and J. R. Brazzel. 1968. Pests and their control, pp. 367-405. *In* F. C. Elliot, M. Hoover, and W. K. Porter Jr. (eds.), Advances in production and utilization of quality cotton: principles and practices. Iowa State University Press, Ames.

Newsom, L. D., J. S. Roussel, and C. E. Smith. 1953. The tobacco thrips: its seasonal history and status as a cotton pest. Louisiana Ag. Exp. Sta. Tech. Bull. 474.

Newsom, L. D., and C. E. Smith. 1949. Destruction of certain insect predators by applications of insecticides to control cotton pests. J. Econ. Entomol. 42: 904-908.

Nicholson Jr., W. F. 1975. Feeding of *Heliothis virescens* (F.) and *H. zea* (Boddie) on cotton with emphasis and development of a simulation model of larval feeding. Ph.D. Thesis, Mississippi State Univ., Mississippi State.

Nicholson Jr., W. F., J. R. Phillips, and D. R. Johnson. 1984. Bollworm management communities in Arkansas. University of Arkansas, Cooperative Extension Service. Pub. EL 663.

Nicholson, A. J., and V. A. Bailey. 1935. The balance of animal populations. Proc. Zool. Soc. Lond. 1: 551-598.

Nicholson, R. A., and T. A. Miller. 1985. Multifactorial resistance to *trans*-permethrin in field collected strains of the tobacco budworm *Heliothis virescens* (F.). Pestic. Sci. 16: 561-570.

Nickel, J. L. 1960. Temperature and humidity relationships of *Tetranychus desertorum* Banks with special reference to distribution. Hilgardia 30: 41-100.

Nickle, W. R. 1974. Nematode infections, pp. 327-376. *In* G. E. Cantwell (ed.), Insect diseases Vol. II. Marcel Dekker, Inc., New York.

Nickle, W. R. 1978. On the biology and life history of some terrestrial mermithids parasitic on agricultural pest insects. J. Nematol. 10: 295.

Nielsson, R. J., A. P. Bhatkar, and H. A. Denmark. 1971. A preliminary list of ants associated with aphids in Florida. Fla. Entomol. 54: 245-248.

Niles, G. A. 1970. Development of plant types with special adaptation to narrow row culture, pp. 63-64. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Niles, G. A. 1980. Breeding cotton for resistance to insect pests, pp. 337-369. *In* F. G. Maxwell, and P. R. Jennings (eds.), Breeding plants resistant to insects. John Wiley and Sons, New York.

Niles, G. A., L. H. Harvey, and J. K. Walker. 1978. Cultural control of the boll weevil, pp. 23-38. *In* The boll weevil: management and strategies. S. Coop. Series. Bull. 228.

Noble, L. W. 1936. The biological possibility of infestation by flight of the pink bollworm moth. J. Econ. Entomol. 29: 78-79.

Noble, L. W. 1969. Fifty years of research on the pink bollworm in the United States. USDA Agric. Res. Serv. Agric. Hdbk. 357.

Noble, L. W., A. J. Chapman, L. C. Fife, and O. T. Robertson. 1962. Winter survival of the pink bollworm, *In* A summary of recent research basic to the cultural control of the pink bollworm. Tex. Agr. Exp. Sta. MP. 579.

Noble, L. W., and W. T. Hunt. 1937. Imported parasites of pink bollworm at Presidio, Texas, 1932-36. J. Econ. Entomol. 30: 842-844.

Noldus, L. P. J. 1988. Response of the egg parasitoid *Trichogramma pretiosum* to the sex pheromone of its host *Heliothis zea*. Entomol. Exp. Appl. 48: 293-300.

Nordh, M. B., L. R. Zavaleta, and W. G. Ruesink. 1988. Estimating multidimensional economic injury levels with simulation models. Agric. Systems 26: 19-33.

Nordlund, D. A., R. B. Chalfant, and W. J. Lewis. 1984. Arthropod populations, yield and damage in monocultures and polycultures of corn, beans and tomatoes. Agric. Ecosystems Environ. 11: 353-367.

Nordlund, D. A., R. B. Chalfant, and W. J. Lewis. 1985a. Response of *Trichogramma pretiosum* females to extracts of two plants attacked by *Heliothis zea*. Agric. Ecosystems Environ. 12: 127-133.

Nordlund, D. A., R. B. Chalfant, and W. J. Lewis. 1985b. Response of *Trichogramma pretiosum* females to volatile synomones from tomato plants. J. Entomol. Sci. 20: 372-376.

Nordlund, D. A., and W. J. Lewis. 1976. Terminology of chemical releasing stimuli in intraspecific and interspecific interactions. J. Chem. Ecol. 2: 211-220.

Nordlund, D. A., and W. J. Lewis. 1985. Response of the braconid parasitoid *Microplitis demolitor* to frass of larvae of the noctuids, *Heliothis zea* and *Trichoplusia ni* and to 13-methylhentriacontane. Entomol. Exp. Appl. 38: 109-112.

Nordlund, D. A., W. J. Lewis, and M. A. Altieri. 1987. Influences of plant produced allelochemicals on the host and prey selection behavior of entomophagous insects, pp. 65-90. *In* P. Barbosa, and D. K. Letourneau (eds.), Novel aspects of insect-plant interactions. Wiley, New York.

Nordlund, D. A., W. J. Lewis, R. L. Jones, and H. R. Gross Jr. 1976. Kairomones and their use for management of entomophagous insects. IV. Effect of kairomones on productivity and longevity of *Trichogramma pretiosum* Riley (Hymenoptera: Trichogrammatidae). J. Chem. Ecol. 2: 67-72.

Nordlund, D. A., W. J. Lewis, R. L. Jones, H. R. Gross Jr., and K. S. Hagen. 1977. Kairomones and their use for management of entomophagous insects. VI. an examination of the kairomones for the predator *Chrysopa carnea* Stephens at the ovipositon sites of *Heliothis zea* (Boddie). J. Chem. Ecol. 3: 507-511.

Nordlund, D. A., W. J. Lewis, and J. H. Tumlinson. 1989. Habitat and host location behavior of *Microplitis croceipes*, pp. 39-48. *In* J. E. Powell, D. L. Bull, and E. G. King (Eds.), Biological control of *Heliothis* spp. by *Microplitis croceipes*. Southwest. Entomol. Suppl. 12.

Nordlund, D. A., W. J. Lewis, S. B. Vinson, and H. R. Gross Jr. 1986. Behavioral manipulation of entomophagous insects, pp. 104-115. *In* S. J. Johnson, E. G. King, and J. R. Bradley Jr. (Eds.), Theory and tactics of Heliothis population management: I. Cultural and biological control. S. Coop. Ser. Bull. No. 316.

Nordlund, D. A., and C. E. Sauls. 1981. Kairomones and their use for management of entomophagous insects. XI. Effect of host plants on kairomonal activity of frass from *Heliothis zea* larvae for the parasitoid *Microplitis croceipes*. J. Chem. Ecol. 7: 1057-1061.

Nordlund, D. A., M. R. Strand, W. J. Lewis, and S. B. Vinson. 1987. Role of kairomones from host accessory gland secretion in host recognition by *Telenomus remus* and *Trichogramma pretiosum*, with partial characterization. Entomol. Exp. Appl. 44: 37-43.

Norgaard, R. B. 1976. The economics of improving pesticide use. Annu. Rev. Entomol. 21: 45-60.

Norman Jr., J. W., D. G. Riley, A. N. Sparks Jr., and J. F. Leser. 1993. Texas suggestions for managing sweetpotato whitefly and aphids in cotton, 1993, pp. 36-37. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Norman Jr., J. W., A. N. Sparks Jr., and D. Riley. 1992. Sweetpotato whitflies in Lower Rio Grande Valley cotton, pp. 687-690. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Norman, J. W. 1988. Management of cotton insects in the Lower Rio Grande Valley. Tex. Agric. Ext. Serv. B-1210.

Norman, J. W. 1989. Suggested insecticides for management of cotton insects in the Lower Rio Grande Valley. Tex. Agric. Ext. Serv. B-1210.

Norman, J. W., and T. J. Henneberry. 1987. Insect management requirements and benefits with short season production systems, pp. 85-87. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Norman, J. W., K. R. Summy, and J. R. Cate. 1984. Boll weevil management through cotton stalk destruction, pp. 216-218. *In* Proc. Beltwide Cotton Prod. Res. Conf.

North, D. T. 1975. Inherited sterility in Lepidoptera. Annu. Rev. Entomol. 20: 167-182.

North, D. T., and G. G. Holt. 1968. Inherited sterility in progeny of irradiated male cabbage loopers. J. Econ. Entomol. 61: 928-931.

North, D. T., and G. G. Holt. 1970. Population control of Lepidoptera: the genetic and physiological basis. Manitoba Entomol. 4: 53-69.

North, D. T., and G. G. Holt. 1971. Inherited sterility and its use in population suppression of Lepidoptera, pp. 99-111. *In* Application of Induced Sterility for Control of Lepidopterous Populations. Int. Atomic Energy Agency Proc. Ser. 210 Vienna, Austria.

North, D. T., J. W. Snow, D. Haile, and F. I. Proshold. 1975. Corn earworms: quality of sperm in sterile males released for population suppression on St. Croix Island. J. Econ. Entomol. 68: 595-598.

Nosky, J. B., J. A. Harding, and D. A. Wolfenbarger. 1980. Activity of certain *O*-ethyl *S*-propyl phosphorothioates, phosphorodithioates and oxime carbamates against organophosphorus resistant and susceptible strains of the tobacco budworm. Southwest. Entomol. 5: 245-249.

Nye, D. E. 1986. Aerial applicator and mixer-loader exposure to cypermethrin during ULV application to cotton, pp. 198-200. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Nyffeler, M. 1982. Field studies of the ecological role of the spiders as predators of insects in agroecosystems. Ph.D. Thesis, Swiss Fed. Inst. Technology. Zurich, Switzerland.

Nyffeler, M., and G. Benz. 1987. Spiders in natural pest control: a review. Zeit. Ang. Entomol. 103: 321-339.

Nyffeler, M., D. A. Dean, and W. L. Sterling. 1986. Feeding habits of the spiders *Cyclosa turbinata* (Walckenaer) and *Lycosa rabida* Walckenaer. Southwest. Entomol. 11: 195-201.

Nyffeler, M., D. A. Dean, and W. L. Sterling. 1987a. Predation by green lynx spider, *Peucetia viridans* (Araneae: Oxyopidae), inhabiting cotton and woolly cotton plants in east Texas. Environ. Entomol. 16: 355-359.

Nyffeler, M., D. A. Dean, and W. L. Sterling. 1987b. Evaluation of the importance of the striped lynx spider, *Oxyopes salticus* (Araneae: Oxyopidae), as a predator in Texas cotton. Environ. Entomol. 16: 1114-1123.

Nyffeler, M., D. A. Dean, and W. L. Sterling. 1987c. Feeding ecology of the orb-weaving spider *Argiope aurantia* (Araneae: Araneidae) in a cotton agroecosystem. Entomophaga 32: 367-375.

Nyffeler, M., D. A. Dean, and W. L. Sterling. 1988. The southern black widow spider, *Latrodectus mactans* (Araneae, Theridiidae), as a predator of the red imported fire ant, *Solenopsis invicta* (Hymenoptera, Formicidae), in Texas cotton fields. J. Appl. Entomol. 106: 52-57.

Nyffeler, M., D. A. Dean, and W. L. Sterling. 1989. Prey selection and predatory importance of orb-weaving spiders (Araneae: Araneidae and Uloboridae) in Texas cotton. Environ. Entomol. 18: 373-380.

Optner, S. L. 1965. Systems analysis for business and industrial problem solutions. Prentiss Hall, Englewood Cliff, N.J.

Orchard, I., and A. B. Lange. 1987. Octopamine in insects: control of hemolymph lipid and visceral muscle in locusts, pp. 136-153. *In* R. M. Hollingworth, and M. B. Green (eds.), Sites of action for neurotoxic pesticides. American Chemical Society, Washington, D.C.

Orphanides, G. M., and D. Gonzalez. 1971. Fertility and life table studies with *Trichogramma pretiosum* and *T. retorridum* (Hymenoptera: Trichogrammatidae). Ann. Entomol. Soc. Amer. 64: 824-834.

Orphanides, G. M., D. Gonzalez, and B. R. Bartlett. 1971. Identification and evaluation of pink bollworm predators in southern California. J. Econ. Entomol. 64: 421-424.

Orr Jr., C. 1966. Particulate technology. The Macmillan Co., New York.

Osborne, M. P. 1985. DDT, HCH the cyclodienes, pp. 131-182. *In* G. A. Kerkut, and L. I. Gilbert (eds.), Comprehensive insect physiology, biochemistry and pharmacology. Vol. 12. Insect control. Pergamon Press, New York.

Osman, A. A., T. F. Watson, and S. Sivasupramaniam. 1991. Reversion of permethrin resistance in field strains and selection for azinphosmethyl and permethrin resistance in pink bollworm (Lepidoptera: Gelechiidae). J. Econ. Entomol. 84: 353-357.

Osman, A. A., T. F. Watson, and S. Sivasupramaniam. 1991. Susceptibility of field populations of pink bollworm (Lepidoptera: Gelechiidae) to azinphosmethyl and permethrin and synergism of prermethrin. J. Econ. Entomol. 84: 358-362.

Osman, A. A., T. F. Watson, and S. Sivasupramaniam. 1992. Inheritance of permethrin resistance in the pink bollworm (Lepidoptera: Gelechiidae). J. Econ. Entomol. 85: 335-339.

Ota, K., and B. D. Hammock. 1980. Differential properties of cytosolic and microsomal epoxide hydrolases in mammalian liver. Science 207: 1479-1481.

Ouye, M. T., R. S. Garcia, and D. F. Martin. 1964. Determination of the optimum sterilizing dosage for pink bollworms treated as pupae with gamma radiation. J. Econ. Entomol. 57: 387-390.

Ouye, M. T., H. M. Graham, R. D. Garcia, and D. F. Martin. 1964. Comparative mating competitiveness of metepa-sterilized and normal pink bollworm males in laboratory and field cages. J. Econ. Entomol. 58: 927-929.

Owen, W. L., and S. L. Calhoun. 1932. Biology of the pink bollworm at Presidio, Texas. J. Econ. Entomol. 25: 741-751.

Pack, T. M., and N. P. Tugwell. 1976. Clouded and tarnished plant bugs on cotton: a comparison of injury symptoms and damage on fruit parts. Univ. of Arkansas Ag. Exp. Stn. Report Series 226.

Paddock, F. B. 1919. The cotton or melon louse. Texas Ag. Exp. Sta. Bull. 257.

Painter, R. H. 1930. The tarnished plant bug, *Lygus pratensis* L.: progress report. Annu. Rep. Entomol. Soc. Ont. (1929) 60: 102-107.

Painter, R. H. 1951. Insect resistance in crop plants. MacMillan Co., New York.

Pair, S. D., M. L. Laster, and D. F. Martin. 1982. Parasitoids of *Heliothis* spp. (Lepidoptera: Noctuidae) larvae in Mississippi associated with sesame interplantings in cotton, 1971-1974: implications of host habitat interaction. Environ. Entomol. 11: 509-512.

Pair, S. D., J. R. Raulston, A. N. Sparks, and P. B. Martin. 1986. Fall armyworm (Lepidoptera: Noctuidae) parasitoids: differential spring distribution and incidence on corn and sorghum in the southern United States and northeastern Mexico. Environ. Entomol. 15: 342-348.

Pair, S. D., M. L. Laster, and D. F. Martin. 1977. Hybrid sterility of the tobacco budworm: effects of alternate sterile and normal matings on fecundity and fertility. Ann. Entomol. Soc. Amer. 70: 952-954.

Palm, C. E., W. W. Dykstra, G. R. Ferguson, R. Hansberry, W. J. Hayes Jr., L. W. Hazleton, J. G. Horsfall, E. F. Knipling, L. D. Leach, R. L. Lovvorn, and G. A. Swanson. 1969. Insect-pest management and control. National Academy of Sciences, Publ. No. 1965, Washington, D.C.

Palumbo, J. C. 1985. The effects of *Sphaeralcea* spp. on overwinter survival and reproductivity of boll weevils, *Anthonomus grandis* Boheman. M.S. Thesis, Univ. of AR.

Optner, S. L. 1965. Systems analysis for business and industrial problem solutions. Prentiss Hall, Englewood Cliff, N.J.

Orchard, I., and A. B. Lange. 1987. Octopamine in insects: control of hemolymph lipid and visceral muscle in locusts, pp. 136-153. *In* R. M. Hollingworth, and M. B. Green (eds.), Sites of action for neurotoxic pesticides. American Chemical Society, Washington, D.C.

Orphanides, G. M., and D. Gonzalez. 1971. Fertility and life table studies with *Trichogramma pretiosum* and *T. retorridum* (Hymenoptera: Trichogrammatidae). Ann. Entomol. Soc. Amer. 64: 824-834.

Orphanides, G. M., D. Gonzalez, and B. R. Bartlett. 1971. Identification and evaluation of pink bollworm predators in southern California. J. Econ. Entomol. 64: 421-424.

Orr Jr., C. 1966. Particulate technology. The Macmillan Co., New York.

Osborne, M. P. 1985. DDT, HCH the cyclodienes, pp. 131-182. *In* G. A. Kerkut, and L. I. Gilbert (eds.), Comprehensive insect physiology, biochemistry and pharmacology. Vol. 12. Insect control. Pergamon Press, New York.

Osman, A. A., T. F. Watson, and S. Sivasupramaniam. 1991. Reversion of permethrin resistance in field strains and selection for azinphosmethyl and permethrin resistance in pink bollworm (Lepidoptera: Gelechiidae). J. Econ. Entomol. 84: 353-357.

Osman, A. A., T. F. Watson, and S. Sivasupramaniam. 1991. Susceptibility of field populations of pink bollworm (Lepidoptera: Gelechiidae) to azinphosmethyl and permethrin and synergism of permethrin. J. Econ. Entomol. 84: 358-362.

Osman, A. A., T. F. Watson, and S. Sivasupramaniam. 1992. Inheritance of permethrin resistance in the pink bollworm (Lepidoptera: Gelechiidae). J. Econ. Entomol. 85: 335-339.

Ota, K., and B. D. Hammock. 1980. Differential properties of cytosolic and microsomal epoxide hydrolases in mammalian liver. Science 207: 1479-1481.

Ouye, M. T., R. S. Garcia, and D. F. Martin. 1964. Determination of the optimum sterilizing dosage for pink bollworms treated as pupae with gamma radiation. J. Econ. Entomol. 57: 387-390.

Ouye, M. T., H. M. Graham, R. D. Garcia, and D. F. Martin. 1964. Comparative mating competitiveness of metepa-sterilized and normal pink bollworm males in laboratory and field cages. J. Econ. Entomol. 58: 927-929.

Owen, W. L., and S. L. Calhoun. 1932. Biology of the pink bollworm at Presidio, Texas. J. Econ. Entomol. 25: 741-751.

Pack, T. M., and N. P. Tugwell. 1976. Clouded and tarnished plant bugs on cotton: a comparison of injury symptoms and damage on fruit parts. Univ. of Arkansas Ag. Exp. Stn. Report Series 226.

Paddock, F. B. 1919. The cotton or melon louse. Texas Ag. Exp. Sta. Bull. 257.

Painter, R. H. 1930. The tarnished plant bug, *Lygus pratensis* L.: progress report. Annu. Rep. Entomol. Soc. Ont. (1929) 60: 102-107.

Painter, R. H. 1951. Insect resistance in crop plants. MacMillan Co., New York.

Pair, S. D., M. L. Laster, and D. F. Martin. 1982. Parasitoids of *Heliothis* spp. (Lepidoptera: Noctuidae) larvae in Mississippi associated with sesame interplantings in cotton, 1971-1974: implications of host habitat interaction. Environ. Entomol. 11: 509-512.

Pair, S. D., J. R. Raulston, A. N. Sparks, and P. B. Martin. 1986. Fall armyworm (Lepidoptera: Noctuidae) parasitoids: differential spring distribution and incidence on corn and sorghum in the southern United States and northeastern Mexico. Environ. Entomol. 15: 342-348.

Pair, S. D., M. L. Laster, and D. F. Martin. 1977. Hybrid sterility of the tobacco budworm: effects of alternate sterile and normal matings on fecundity and fertility. Ann. Entomol. Soc. Amer. 70: 952-954.

Palm, C. E., W. W. Dykstra, G. R. Ferguson, R. Hansberry, W. J. Hayes Jr., L. W. Hazleton, J. G. Horsfall, E. F. Knipling, L. D. Leach, R. L. Lovvorn, and G. A. Swanson. 1969. Insect-pest management and control. National Academy of Sciences, Publ. No. 1965, Washington, D.C.

Palumbo, J. C. 1985. The effects of *Sphaeralcea* spp. on overwinter survival and reproductivity of boll weevils, *Anthonomus grandis* Boheman. M.S. Thesis, Univ. of AR.

Parencia Jr., C. R. 1976. Events leading to the pilot boll weevil eradication experiment, pp. 59-61. *In* Proc. Conf. on Boll Weevil Suppression, Management and Elimination Technology. USDA, ARS-S-71.

Parencia Jr., C. R. 1978. One hundred twenty years of research on cotton insects in the United States. USDA Agr. Handb. No. 515.

Parencia Jr., C. R., W. P. Scott, and J. W. Smith. 1980. Comparative populations of beneficial arthropods and *Heliothis* spp. larvae in selected fields in Panola and Pantotoc counties, Mississippi in 1977 and 1978. Southwest. Entomol. 5: 22-31.

Parencia Jr., C. R., W. P. Scott, J. W. Smith, and T. C. Lockley. 1981. A report of biological data developed in 1977-1980 for the optimum pest management trial, Panola and Pontotoc Counties, Mississippi. Attachment D of Appendix A, biological evaluation of beltwide boll weevil/cotton insect management programs. USDA, Science and Education Administration,

Park, E. C., and H. R. Horvitz. 1986. Mutations with dominant effects on the behavior and morphology of the nematode *Caenorhabditis elegans*. Genetics 113: 821-852.

Parker, R. D., and J. H. Benedict. 1982. Management of cotton insects in South & East Texas counties. Tex. Agric. Ext. Serv. B-1204.

Parker, R. D., and J. A. Swart. 1989. Suggested insecticides for management of cotton insects in the Blacklands, South & East Texas, counties. Tex. Agric. Ext. Serv. B-1204.

Parker, R. D., J. K. Walker, G. A. Niles, and J. R. Mulkey. 1980. The short-season effect in cotton and escape from the boll weevil. Texas Agr. Exp. Sta. Bull. 1315.

Parker, R. D., and R. L. Zrubek. 1989. Management of cotton insects in the Southern, Eastern and Blackland areas of Texas. Texas Agric. Ext. Serv. B-1204.

Parnell, F. R. 1925. The breeding of jassid resistant cottons: report for season. Empire Cotton Grow. Rev. 2: 330-336.

Parrott, W. L., J. N. Jenkins, and W. T. Buford. 1970. Instars and duration of stadia of boll weevil larvae. Ann. Entomol. Soc. Amer. 63: 1265-1267.

Parrott, W. L., J. N. Jenkins, and J. C. McCarty Jr. 1983. Feeding behavior of first-stage tobacco budworm (Lepidoptera: Noctuidae) on three cotton cultivars. Ann. Entomol. Soc. Amer. 76: 167-170.

Parrott, W. L., J. N. Jenkins, J. C. McCarty Jr., and L. Lambert. 1978. A procedure to evaluate for antibiosis in cotton to the tobacco budworm. J. Econ. Entomol. 71: 310-312.

Parrott, W. L., W. R. Meredith Jr., J. N. Jenkins, and J. C. McCarty Jr. 1982. Effects of cotton genotype and early or no insecticide treatment on abundance of selected insects in the Mississippi Delta. USDA-ARS Agricultural Research Results; Southern Series No. 2 (ARS-S-12).

Parrott, W. L., J. E. Mulrooney, J. N. Jenkins, and J. C. McCarty Jr. 1986. Improved techniques for production of tobacco budworm (Lepidoptera: Noctuidae) eggs. J. Econ. Entomol. 79: 277-280.

Parvin, D. W. 1990a. The weight loss associated with defoliated cotton and its implications, pp. 469-471. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Parvin, D. W. 1990b. The importance of harvest initiation date, pp. 471-474. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Parvin, D. W. 1990c. The cost of delay dominates the value of earliness in Australia. Australian Cotton Grower. Aug.-Oct.

Parvin, D. W. 1990d. The weight loss associated with defoliated cotton under Mississippi conditions. Staff Paper No. 92, Dept. Agric. Econ., Mississippi State University

Parvin, D. W. 1990e. The economic value of earliness in Australia. Rhone-Poulenc Rural Australia. PTY LTD. Moree, NSW.

Parvin, D. W. 1991. The economics of earliness: Stoneville, MS, and Moree, New South Wales, pp. 392-394. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Parvin, D. W., M. Cochran, W. F. Nicholson, and J. R. Phillips. 1984. An economic evaluation of community pest management programs on cotton in Arkansas. Staff Paper SP2484. Department of Agricultural Economics and Rural Sociology, University of Arkansas.

Parvin, D. W., and F. T. Cooke Jr. 1990. The mathematics of cotton harvest, pp. 119-121. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Parvin, D. W., and F. A. Harris. 1986. Preventive and corrective strategies within an integrated pest management system in Mississippi. Delta Farm Press 44:(24) 7.

Parvin, D. W., and T. Miller. 1986. The role of the consulting entomologist within a preventive cotton insect management system in Mississippi. Delta Farm Press 44:(23) 27.

Parvin, D. W., and J. W. Smith. 1985. The economics of cotton harvesting in the Mid South with emphasis on early season insect control. Staff Paper No. 74, Dept. Agric. Econ., Mississippi State University.

Parvin, D. W., and F. H. Tyner. 1974. The systems approach - research or research management. S. J. Agric. Econ.

Patana, R. 1982. Disposable diet packet for feeding and oviposition of *Lygus hesperus* (Hemiptera: Miridae). J. Econ. Entomol. 75: 668-669.

Patana, R. 1985. *Heliothis zea/Heliothis virescens*, pp. 329-334. *In* P. Singh, and R. F. Moore (eds.), Handbook of Insect Rearing Vol. II Elsevier, New York.

Patana, R. 1985. *Spodoptera exigua*, pp. 465-468. *In* P. Singh, and R. F. Moore (eds.), Handbook of Insect Rearing Vol. II Elsevier, New York.

Pate, T. L., and J. R. Brazzel. 1964. Cotton pests exhibit resistance to DDT. Agri. Chem. 19: 34-36.

Pate, T. L., and J. R. Brazzel. 1964. Resistance of bollworms to poison tested. Miss. Farm Res. 27: 1-3.

Patti, J. H., and G. R. Carner. 1974. *Bacillus thuringiensis* investigations for control of *Heliothis* spp. on cotton. J. Econ. Entomol. 67: 415-418.

Patton, C. N. 1958. A catalogue of larvaevoridae in Florida. Fla. Entomol. 41: 29-39, 77-89.

Payne, G. T. 1987. Inheritance and mechanisms of permethrin resistance in the tobacco budworm, *Heliothis virescens* (Lepidoptera: Noctuidae). Ph.D., Clemson Universtiy.

Pearl, J. 1988. Probabalistic reasoning in intelligent systems: networks of plausible inference. Morgan Kaufmann, San Mateo.

Pearson, E. O. 1958. The insect pests of cotton in tropical Africa. Commonwealth Inst. Entomol., London.

Peck, W. B., and W. H. Whitcomb. 1970. Studies on the biology of a spider, *Chiracanthium inclususm* (Hentz). Ark. Agr. Exp. Stn. Bull. 753.

Pedigo, L. P. 1993. Introduction to sampling arthropod populations, pp. 1-11. *In* L. P. Pedigo, and G. D. Buntin (eds.), Handbook of Sampling Methods for Arthropods in Agriculture. CRC Press, Ann Arbor.

Pedigo, L. P., S. H. Hutchins, and L. G. Higley. 1986. Economic injury levels in theory and practice. Annu. Rev. Entomol. 31: 341-368.

Pencoe, N. L., and J. R. Phillips. 1987. The cotton boll weevil: legend, myth, and reality. J. Entomol. Sci. Suppl. 1: 30-51.

Penman, D. R., and R. B. Chapman. 1983. Fenvalerate-induced distributional imbalances of two-spotted spider mite on bean plants. Entomol. Exp. Appl. 33: 71-78.

Penman, D. R., R. B. Chapman, and M. H. Bowie. 1986. Direct toxicity and repellent activity of pyrethroids against *Tetranychus urticae* (Acrina: Tetranychidae). J. Econ. Entomol. 79: 1183-1187.

Penman, D. R., and W. W. Cone. 1972. Behavior of two-spotted spider mites in response to quiescent female deutonymph and to web. Ann. Entomol. Soc. Amer. 65: 1289-1293.

Penman, D. R., and W. W. Cone. 1974. Role of web, tactile stimuli, and female sex pheromone in attraction of male twospotted spider mites to quiescent female deutonymphs. Ann. Entomol. Soc. Amer. 67: 179-182.

Pepper, B. H. 1943. The relationship between cropping practices and injury by *Heliothis armigera* with special reference to lima beans and tomatoes. J. Econ. Entomol. 36: 329-330.

Periak, F. J., and D. A. Fischhoff. 1993. Insect-resistant cotton: from the laboratory to the marketplace, pp. 199-221. *In* L. Kim (eds.), Advanced engineered pesticides. Macel Dekker, New York.

Perkins, J. H. 1982. Insects, experts, and the insecticide crisis. The quest for new pest management strategies. Plenum Press, New York.

Perlak, F. J., R. W. Deaton, T. A. Armstrong, R. L. Fuchs, S. R. Sims, J. T. Greenplate, and D. A. Fischoff. 1990. Insect resistant cotton plants. Biotechnology 8: 939-943.

Perring, T. M., A. D. Cooper, R. J. Rodriguez, C. A. Farrar, and T. S. Bellows Jr. 1993. Identification of a whitefly species by genomic and behavioral studies. Science 259: 74-77.

Peterson, J. J. 1982. Current status of nematodes for biological control of insects. Parasitology 84: 177-184.

Pfadt, R. E. 1971. Insect pests of cotton, pp. 343-373. *In* R. E. Pfadt (ed.), Fundamentals of applied entomology. 2nd ed.. Macmillan Publishing Co., Inc., New York.

Pfrimmer, T. R. 1964. Populations of certain insects and spiders on cotton plants following insecticide applications. J. Econ. Entomol. 57: 640-643.

Pfrimmer, T. R. 1979. *Heliothis* spp. control on cotton with pyrethroids, carbamates, organophosphates, and biological insecticides. J. Econ. Entomol. 72: 593-598.

Pfrimmer, T. R. 1986. *Heliothis* spp.: seasonal species changes on cotton from 1980 to 1985 at Stoneville, MS, pp. 226-227. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Pfrimmer, T. R., R. E. Furr, and E. A. Stadelbacher. 1971. Material for control of boll weevils, bollworms, and tobacco budworms on cotton at Stoneville, Mississippi. J. Econ. Entomol. 64: 475-478.

Phillips, J. R. 1971. Bollworm control with chlorphenamidine. Ark. Farm Res. 4: 9.

Phillips, J. R. 1978. Integrated insect management systems: an area-wide insect mangement program, pp. 114. *In* Symposium on development of optimum crop production systems for the Mid-South. Ark. Agric. Exp. Stn. Spec. Rep. 67.

Phillips, J. R. 1990. 10-Point program for managing *Heliothis* resistance. Cotton Grower. June.

Phillips, J. R., J. B. Graves, and R. G. Luttrell. 1989. Insecticide resistance management: Relationship to integrated pest management. Pestic. Sci. 27: 459-464.

Phillips, J. R., A. P. Gutierrez, and P. L. Adkisson. 1980. General accomplishments toward better insect control in cotton, pp. 123-153. *In* C. B. Huffaker (ed.), New technology of pest control. John Wiley & Sons, New York.

Phillips, J. R., and W. F. Nicholson. 1979. Coping with the tobacco budworm/bollworm problem: community-wide mangement, pp. 39-41. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Phillips, J. R., W. F. Nicholson, T. Teague, J. Bernhardt, and T. F. Mueller. 1981. Community wide bollworm management, pp. 48-50. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Pierce, W. D. 1908. Studies of parasites of the cotton boll weevil. USDA Bur. Entomol. Bull. 73.

Pierce, W. D. 1913. The occurrence of a cotton boll weevil in Arizona. J. Agric. Res. 1: 89-99.

Pierce, W. D. 1922. How insects affect the cotton plant and means of combating them. USDA Farmers' Bull. No. 890.

Pierce, W. D., R. A. Cushman, C. E. Hood, and W. D. Hunter. 1912. The insect enemies of the cotton boll weevil. USDA Bur. Entomol. Bull. 100.

Pieters, E. P., K. S. Akbay, L. G. Brown, and R. W. McClendon. 1981. Use of computer game COTGAME in teaching entomology. Environ. Entomol. 10: 256-261.

Pieters, E. P., and W. L. Sterling. 1974. Aggregation indices of cotton arthropods in Texas. Environ. Entomol. 3: 598-600.

Pieters, E. P., and T. C. Urban. 1977. Dispersal of the boll weevil in the coastal bend area of Texas. Southwest. Entomol. 2: 4-7.

Pimentel, D. Insecticide resistance management in agriculture, pp. 10. *In* R. Whalon, and R. Wollingworth (Eds.), Resistance Pest Management Newsletter. Spring, 5(1). Pesticide Research Center, Michigan State University, East Lancing, Michigan.

Pimentel, D., D. Chant, A. Kelman, R. L. Metcalf, L. D. Newsom, and J. C. Smith. 1965. Improved pest control practices in restoring the quality of our environment, pp. 227-291. *In* Rpt. of Environ. Pollution Panel. President's Science Advisory Committee.

Pimentel, D., J. Krummel, D. Gallahan, J. Hough, A. Merrill, I. Schreiner, P. Vittum, F. Koziol, E. Back, D. Yen, and S. Fiance. 1981. A cost-benefit analysis of pesticide use in U.S. food production, pp. 27-54. *In* D. Pimentel (ed.), Handbook of pest management in agriculture. Vol. II. CRC Press, Boca Raton.

Pimentel, D. C., C. Shoemaker, E. LaDue, R. Rovinsky, and N. Russell. 1976. Alternatives for reducing insecticides on cotton and corn: economic and environmental impact. Environmental Protection Agency Report.

Pimm, S. C., and D. P. Bartell. 1980. Statistical model for predicting range expansion of the red imported fire ant, *Solenopsis invicta*, in Texas. Environ. Entomol. 9: 653-658.

Pinkas, L. H. 1972. Modification of flowering in Pima cotton with ethephon. Crop Sci. 12: 465-466.

Pinto, J. D., and E. R. Oatman. 1985. Additions to nearctic *Trichogramma* (Hymenoptera: Trichogrammatidae). Proc. Entomol. Soc. Wash. 87: 176-186.

Pinto, J. D., G. R. Platner, and E. R. Oatman. 1978. Clarification of the identity of several common species of North American *Trichogramma* (Hymenoptera: Trichogramma). Ann. Entomol. Soc. Am. 72: 170-180.

Pintureau, B., and J. Voegele. 1980. Une nouvelle espece proche de *Trichogramma evanescens*: *T. maidis* (Hym.: Trichogrammatidae). Entomophaga 25: 431-440.

Pitre, H. N., T. L. Hillhouse, M. C. Donahue, and H. C. Kinard. 1978. Beneficial arthropods on soybeans and cotton in different ecosystems in Mississippi. Miss. Agric. For. Exp. Stn. Tech. Bull. 90.

Pitre, H. N., J. E. Mulrooney, and D. B. Hogg. 1983. Fall armyworm (Lepidoptera: Noctuidae) oviposition: crop preferences and egg distribution on plants. J. Econ. Entomol. 76: 463-466.

Pitts, D. L., and E. P. Pieters. 1980. Ovicidal activity of insecticides against tobacco budworm eggs on cotton. J. Econ. Entomol. 73: 570-572.

Pittuck, B. C. 1897. Cotton and corn experiments. Tex. Agr. Exp. Sta. Bull. 45.

Pittuck, B. C., and S. A. McHenry. 1899. Cotton experiments. Tex. Agr. Exp. Sta. Bull. 50.

Planer, F. R. 1988. Southeast boll weevil eradiction program, pp. 239-240. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Plant, R. E. 1989a. An integrated decision support system for agricultural management. Agric. Systems 29: 49-66.

Plant, R. E. 1989b. An artificial intelligence based method for scheduling crop management actions. Agric. Systems 31: 127-155.

Plant, R. E., and L. T. Wilson. 1986. A computer based pest management system for San Joaquin Valley cotton, pp. 69-172. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Plant, R. E., L. T. Wilson, L. Zelinski, P. B. Goodell, and T. A. Kerby. 1987. CALEX:/Cotton: an expert system-based management aid for California cotton growers, pp. 203-206. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Plant, R. E., F. G. Zalom, J. A. Young, and R. N. Rice. 1989. An expert system for the diagnosis of peach and nectarine disorders. Hort. Sci. 24: 700.

Plapp Jr., F. W. 1972. Laboratory tests of alternate insecticides for control of methyl parathion resistant tobacco budworms. J. Econ. Entomol. 65: 903-904.

Plapp Jr., F. W. 1973. Comparison of insecticide absorption and detoxification in larvae of the bollworm, *Heliothis zea*, and the tobacco budworm, *H. virescens*. Pestic. Biochem. Physiol. 2: 447-455.

Plapp Jr., F. W. 1976. Biochemical genetics of insecticide resistance. Annu. Rev. Entomol. 21: 179-197.

Plapp Jr., F. W. 1976. Chlordimeform as a synergist for insecticides against the tobacco budworm. J. Econ. Entomol. 69: 91-92.

Plapp Jr., F. W. 1979. Synergism of pyrethroid insecticides by formamidines against *Heliothis* pests of cotton. J. Econ. Entomol. 72: 667-670.

Plapp Jr., F. W. 1987. Managing resistance to synthetic pyrethroids in the tobacco budworm, pp. 224-226. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Plapp Jr., F. W. 1991. Pyrethroid resistance in the tobacco budworm: five years later. Southwest. Entomol. Suppl. 15: 69-74.

Plapp Jr., F. W. 1993. Alternate strategies for insect control and resistance management: possibilities and future prospects, pp. 698-701. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Plapp Jr., F. W., and D. L. Bull. 1978. Toxicity and selectivity of some insecticides to *Chrysopa carnea*, a predator of the tobacco budworm. J. Econ. Entomol. 7: 431-434.

Plapp Jr., F. W., and D. L. Bull. 1980. Effects of pyrethroid insecticides on the common green lacewing. J. Econ. Entomol. 73: 306-309.

Plapp Jr., F. W., and C. Campanhola. 1986. Synergism of pyrethroids by chlordimeform against susceptible and resistant *Heliothis*, pp. 167-169. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Plapp Jr., F. W., C. Campanhola, R. D. Bagwell, and B. F. McCutchen. 1990. Management of pyrethroid-resistant tobacco budworms on cotton in the United States, pp. 237-260. *In* R. T. Roush, and B. E. Tabashnik (eds.), Pesticide resistance and arthropods. Chapman & Hall, New York.

Plapp Jr., F. W., R. E. Frisbie, and J. A. Jackman. 1988. Monitoring for pyrethroid resistance in the tobacco budworm - 1987, pp. 237-239. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Plapp Jr., F. W., J. A. Jackman, C. Campanhola, R. E. Frisbie, J. B. Graves, R. G. Luttrell, W. F. Kitten, and M. Wall. 1990. Monitoring and management of pyrethroid resistance in tobacco budworm (Lepidoptera: Noctuidae) in Texas, Mississippi, Louisiana, Arkansas, and Oklahoma. J. Econ. Entomol. 83: 335-341.

Plapp Jr., F. W., G. N. McWhorter, and W. H. Vance. 1987. Monitoring for pyrethroid resistancein the tobacco budworm in Texas — 1986, pp. 324-326. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Plapp Jr., F. W., and S. B. Vinson. 1977. Comparative toxicities of some insecticides to the tobacco budworm and its ichneumonid parasite, *Campoletis sonorensis*. Environ. Entomol. 6: 381-384.

Plummer, E. L. 1984. Biphenylmethyl pyrethroids. A structure-activity relationship approach to pesticide design, pp. 297-320. *In* P. S. Magee, G. K. Kohn, and J. J. Menn (eds.), Pesticide synthesis through rational approaches. American Chemical Society, Washington, D.C.

Poinar Jr., G. O. 1975. Description and biology of a new insect parasitic rhabditoid, *Heterorhabditis bacteriophora* n. gen., n. sp. (Rhabditida; Heterorhabditidae n. fam.). Nematologica 21: 463-470.

Poinar Jr., G. O. 1990. Taxonomy and biology of Steinernematidae and Heterorhabditidae, pp. 23-61. *In* R. Gaugler, and H. K. Kaya (eds.), Entomopathogenic nematodes in biological control. CRC Press, Inc., Boca Raton.

Poinar, J. J. 1983. The natural history of nematodes. Prentice-Hall, Inc., Englewood Cliffs.

Polazzo, R. J. 1978. Comparison of the responses of adults and larvae of five lepidopteran species to seven insecticides. M.S. Thesis, Louisiana State University.

Polles, S. G. 1968. The effect of various droplet sizes on U/V insecticide concentrate on residual action and toxicity. M.S. Thesis, Mississippi State Univ., Miss. State.

Polles, S. G., and S. B. Vinson. 1972. Penetration, distribution and metabolism of `14`C-endrin in resistant and susceptible tobacco budworm larvae. J. Agric. Food Chem. 20: 38-41.

Poole, R. W. 1989a. A general synopis of the systematics of *Heliothis*, pp. 161-171. *In* E. G. King and R. D. Jackson (eds.), Proc. Workshop on Biological Control of *Heliothis*: Increasing the Effectiveness of Natural Enemies. FERRO, USDA.

Poole, R. W. 1989b. Fascicle 118, Noctuidae, part I, Lepidopterorum catalogue. E. J. Brille, Flora & Fauna Publications, Leiden, New York.

Poston, F. L., L. P. Pedigo, and S. M. Welch. 1983. Economic injury levels: reality and practicality. Bull. Entomol. Soc. Amer. 29: 49-53.

Potter, H. S. 1983. Results of plant canopy spray penetration studies with fixed-wing aircraft. ASAE and NAAA Paper No. AA 83-004.

Potter, M. F., and T. F. Watson. 1980. Induction of diapause in the tobacco budworm in Arizona. J. Econ. Entomol. 73: 820-823.

Powell, J. E. 1989. Importation and establishment of predators and parasitoids of *Heliothis* into the USA, pp. 387-395. *In* E. G. King and R. D. Jackson (eds.), Proc. Workshop on Biological Control of *Heliothis*: Increasing the Effectiveness of Natural Enemies. FERRO, USDA.

Powell, J. E., D. L. Bull, and E. G. King (eds.). 1989. Biological control of *Heliothis* spp. by *Microplitis croceipes*. Southwest. Entomol. Suppl. 12.

Powell, J. E., and G. W. Elzen. 1989. Biological and host relationships of *Microplitis croceipes*. Southwest. Entomol. Suppl. 12: 11-16.

Powell, J. E., E. G. King Jr., and C. S. Jany. 1986. Toxicity of insecticides to adult *Microplitis croceipes* (Hymenoptera: Braconidae). J. Econ. Entomol. 79: 1343-1346.

Powell, J. E., and E. G. King. 1984. Behavior of adult *Microplitis croceipes* (Hymenoptera: Braconidae) and parasitism of *Heliothis* spp. (Lepidoptea: Noctuidae) host larvae in cotton. Environ. Entomol. 13: 272-277.

Powell, J. E., and J. L. Roberson. 1989. Technology transfer: boll weevil production for sterile release, pp. 242-248. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Powell, J. E., J. L. Roberson, and E. G. King Jr. 1988. Advances in boll weevil production technology: Alabama sterile release program, 1987, pp. 274-275. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Powell, J. E., and W. P. Scott. 1991. Survival of *Microplitis croceipes* (Hymenoptera: Braconidae) in contact with residues of insecticides on cotton. Environ. Entomol. 20: 346-348.

Powers, D. A., T. Lauerman, D. Crawford, and L. DiMichele. 1991. Genetic mechanisms for adapting to a changing environment. Ann. Rev. Genetics 25: 629-659.

Powles, R. J., and P. L. Rogers. 1989. *Bacillus* toxins for insect control - a review. Australian J. Biotechnol. 3: 223-228.

Prabhaker, N., D. L. Coudriet, and N. C. Toscano. 1988. Effect of synergists on organophosphate and permethrin resistance in sweetpotato whitefly (Homoptera: Aleyrodidae). J. Econ. Entomol. 81: 34-39.

Pree, D. J., D. E. Archibald, and R. K. Morrison. 1989. Resistance to insecticides in the common green lacewing, *Chrysoperla carnea* (Neuroptera: Chrysopidae) in southern Ontario. J. Econ. Entomol. 82: 29-34.

Price, P. W. 1981. Relevance of ecological concepts to practical biological control, pp. 3-19. *In* G. C. Papavizas (ed.), Biochemical control in Crop Production. Allenheld, Osmum and Company,.

Proshold, F. I., and J. A. Bartell. 1970. Inherited sterility in progeny of irradiated male tobacco budworms: effects on reproductions, development time, and sex ratio. J. Econ. Entomol. 63: 280-285.

Proshold, F. I., and J. A. Bartell. 1972. Inherited sterility and post embryonic survival of two generations of tobacco budworms, *Heliothis virescens* (Lepidoptera: Noctuidae), from partially sterile males. Can. Entomol. 104: 221-230.

Proshold, F. I., M. L. Laster, D. F. Martin, and E. G. King. 1982. The potential for hybrid sterility in *Heliothis* management, pp. 329-339. *In* W. Reed and V. Kumble (eds.), Proc. Internl. Workshop on *Heliothis* Management. ICRISAT, Patancheru, A.P., India.

Proshold, F. I., and J. W. Smith. 1982. The potential for hybrid sterility in *Heliothis virescens* management, pp. 182-184. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Proverbs. M. D., and J. R. Newton. 1962a. Some effects of gamma radiation on the reproductive potential of the codling moth, *Carpocapsa pomonella* (L.) (Lepidopera: Olethreutidae). Can. Entomol. 94: 1162-1170.

Proverbs, M. D., and J. R. Newton. 1962b. Suppression of the reproductive potential of the codling moth by gamma irradiated males in caged orchard trees. J. Econ. Entomol. 55: 934-936.

Proverbs, M. D., J. R. Newton, and D. M. Logan. 1969. Codling moth control by release of radiation-sterilized moths in a commercial apple orchard. J. Econ. Entomol. 62: 1331-1334.

Putman, W. L. 1937. Biological notes on the Chrysopidae. Can. J. Res. 15: 29-37.

Puttler, B., R. E. Sechriest, and D. M. Daughtery Jr. 1973. *Hexamermis arvalis* parasitising *Agrotis ipsilon* in corn and the origin of the pest infestation. Environ. Entomol. 2: 963-964.

Quaintance, A. L. 1905. Some present-day features of applied entomology in America. USDA Bur. Entomol. Bull. No. 52.

Quaintance, A. L., and C. T. Brues. 1905. The cotton bollworm. USDA Bur. Entomol. Bull. No. 50.

Quesenberry, G. R. 1936. Summary of extension work in New Mexico. Ext. Circ. 145.

Quistad, G. B., D. C. Cerf, S. J. Kramer, B. J. Bergot, and D. A. Schooley. 1985. Design of novel insect anti juvenile hormones: allylic alcohol derivatives. J. Agric. Food Chem. 33: 47-50.

Rabb, R. L. 1972. Principles and concepts of pest management, *In* Implementing practical pest management strategies. Proc. Nat. Ext. Insect-Pest Management Workshop, March 14-16, 1972. Purdue Univ., Lafayette, IN.

Rabb, R. L. 1978. A sharp focus on insect populations and pest management from a wide-area view. Bull. Entomol. Soc. Amer. 24: 55-61.

Rabb, R. L. 1978. Eradication of plant pests. Conn. Bull. Entomol. Soc. Amer. 24: 40-44.

Rabb, R. L. 1985. Conceptual bases to develop and use information on the movement and dispersal of biotic agents in agriculture, pp. 5-34. *In* D. R. MacKenzie, C. S. Barfield, G. G. Kennedy, and R. D. Berger (eds.), The Movement and Dispersal of Agriculturally Important Biotic Agents. Claitor's Publishing, Baton Rouge.

Rabb, R. L., G. K. DeFoliart, and G. G. Kennedy. 1984. An ecological approach to manging insect populations, pp. 697-728. *In* C. B. Huffaker, and R. L. Rabb (eds.), Ecological Entomology. Wiley, New York.

Rabb, R. L., and F. E. Guthrie. 1970. Concepts of pest management. Proc. Conf. N.C. State Univ., Raleigh, NC., March 25-27.

Rabb, R. L., R. E. Stinner, and G. A. Carlson. 1974. Ecological principles as a basis for pest management in the agroecosystem, pp. 19-45. *In* F. G. Maxwell and F. A. Harris (eds.), Proc. Summer Instit. Biol. Contrl. Plant Insects and Diseases. Univ. Press Miss., Jackson, Mississippi.

Rabb, R. L., R. E. Stinner, and R. van den Bosch. 1976. Conservation and augmentation of natural enemies, pp. 233-254. *In* C. B. Huffaker, and P. S. Messenger (eds.), Theory and Practice of Biological Control. Academic, New York.

Race, S. R. 1960. A comparison of two sampling techniques for lygus bugs and stink bugs on cotton. J. Econ. Entomol. 53: 689-690.

Race, S. R. 1965. Importance and control of Western flower thrips *Frankliniella occidentalis*, on seedling cotton. New Mexico Ag. Exp. Sta. Bull. 497.

Raina, A. K. 1988. Selected factors influencing neurohormonal regulation of sex pheromone production in *Heliothis* species. J. Agric. Food Chem. 14: 2063-2069.

Raina, A. K., R. A. Bell, and W. Klassen. 1981. Diapause in the pink bollworm: preliminary genetic analysis. Insect Sci. Appl. 1: 231-235.

Raina, A. K., H. Jafe, T. G. Kempe, P. Keim, R. W. Blacher, H. M. Fales, C. T. Riley, J. A. Klun, R. L. Ridgway, and D. K. Hayes. 1989a. Identification of a neuropeptide hormone that regulates sex pheromone production in female moths. Science 244: 796-798.

Raina, A. K., E. A. Stadelbacher, and R. L. Ridgway. 1989b. Comparison of sex pheromone composition and pheromone-mediated male behavior of laboratory-reared and wild *Heliothis zea* (Lepidoptera: Noctuidae). J. Agric. Food Chem. 15: 1259-1265.

Ramalho, F. S., J. C. McCarty Jr., J. N. Jenkins, and W. L. Parrott. 1984. Distribution of tobacco budworm (Lepidoptera: Noctuidae) larvae within cotton plants. J. Econ. Entomol. 77: 591-594.

Ramaswamy, S. B., S. A. Randle, and W. K. Ma. 1985. Field evaluation of the sex pheromone components of *Heliothis virescens* (Lepidoptera: Noctuidae) in cone traps. Environ. Entomol. 14: 293-296.

Ramaswamy, S. B., and R. T. Roush. 1986. Sex pheromone titers in females of *Heliothis virscens* from three geographical locations (Lepidoptera: Noctuidae). Entomol. Gen. 12: 19-23.

Ratchford, K. J., A. M. Pavloff, J. B. Graves, and E. Burns. 1987. Evaluation of insecticides for control of early season cotton pests in the loessial hill section of Northeast Louisiana, pp. 231-233. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Rathman, R. J. 1981. The role of host plants and parasitoids on the abundance of spring populations of *Heliothis* spp. in Arizona. M.S. Thesis, University of Arizona.

Rathman, R. J., and T. F. Watson. 1985. A survey of early-season host plants and parasites of *Heliothis* spp. in Arizona. J. Ag. Entomol. 2: 388-394.

Raulston, J. R. 1979. *Heliothis virescens* migration, pp. 412-419. *In* R. L. Rabb, and G. G. Kennedy (eds.), Movement of highly mobile insects: concepts and methodology in research. University Graphics, North Carolina State University, Raleigh.

Raulston, J. R., H. M. Graham, P. D. Lingren, and J. W. Snow. 1976. Mating interaction of native and laboratory-reared tobacco budworms released in the field. Environ. Entomol. 5: 195-198.

Raulston, J. R., and P. D. Lingren. 1969. A technique for rearing larvae of the bollworm and tobacco budworm in large numbers. J. Econ. Entomol. 62: 959-961.

Raulston, J. R., and P. D. Lingren. 1972. Methods for large scale rearing of the tobacco budworm. U.S. Dept. of Agric. Prod. Res. Rep.

Raulston, J. R., S. D. Pair, J. Loera, and H. E. Cabanillas. 1992. Prepupal and pupal parasitism of *Helicoverpa zea* and *Spodoptera frugiperda* (Lepidoptera: Noctuidae) by *Steinernema* sp. in cornfields in the Lower Rio Grande Valley. J. Econ. Entomol. 85: 1666-1670.

Raulston, J. R., S. D. Pair, F. A. Pedraza-Martinez, J. K. Westbrook, A. N. Sparks, and V. M. Sanchez Valdez. 1986a. Ecological studies indicating the migration of *Heliothis zea*, *Spodoptera frugiperda*, and *Heliothis virescens* from northeastern Mexico and Texas, pp. 204-220. *In* W. Danthanarayana (ed.), Insect flight dispersal and migration. Springer-Verlag, Berlin.

Raulston, J. R., S. D. Pair, A. N. Sparks, J. K. Westbrook, J. Loera, K. R. Summy, and D. R. Rummel. 1986b. Production of *Heliothis zea* on corn in northeastern Mexico and the Lower Rio Grande Valley of Texas: a potential source for corn and cotton infestation on the High Plains, pp. 222-225. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Raulston, J. R., J. W. Snow, H. M. Graham, and P. D. Lingren. 1975. Tobacco budworm: effect of prior mating and sperm content on the mating behavior of females. Ann. Entomol. Soc. Amer. 68: 701-704.

Raulston, J. R., W. W. Wolf, P. D. Lingren, and A. N. Sparks. 1982. Migration as a factor in *Heliothis* management, pp. 61-74. *In* W. Reed and V. Kumble (eds.), Proc. Internl. Workshop on *Heliothis* Management. ICRISAT, Patancheru, A.P., India.

Raulston, J. R., D. A. Wolfenbarger, and A. C. Bartlett. 1985. Tobacco budworm: response to gossypol and selection in a field-collected strain under laboratory conditions. J. Econ. Entomol. 78: 158-162.

Ray, L. L. 1970. Breeding cotton varieties for narrow-row production, pp. 57. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Ray, L. L., and T. R. Richmond. 1966. Morphological measures of earliness of crop maturity in cotton. Crop Sci. 6: 527-531.

Raymond, M. 1985. Presentation d'un programme basic d'analyse log-probit pour micro-ordinnateur. ORSTOM, Ser. Ent. Med. et Parasitol 22: 117-121.

Readio, J., and M. H. Sweet. 1982. A review of the Geocorinae of the United States East of the 100th Meridian (Hemiptera: Lygaeidae). Entomol. Soc. Amer. Misc. Publ. 12: 1-91.

Reagan, T. E. 1981. A pest management system for sugarcane insects. La. Agr. 24: 12-14.

Rebeiz, C. A. 1988. Porphyric insecticides. Pest. Biochem. 30: 11-27.

Redding, R. J., and J. M. Kimbrough. 1906. Cotton culture. Georgia Agr. Exp. Sta. Bull. 75.

Reed, W., and V. Kumble (eds.) 1982. Proceedings International Workshop on *Heliothis* Management, Nov. 15-20, 1981, . ICRISAT, Patancheru, A.P., India.

Regev, S., and W. W. Cone. 1975. Evidence of farnesol as a male sex attractant of the twospotted spider mite, *Tetranychus urticae* Koch (Acarina: Tetranychidae). Environ. Entomol. 4: 307-311.

Regev, S., and W. W. Cone. 1976. Analyses of pharate female twospotted spider mites for nerolidol and geraniol: evaluation for sex attraction of males. Environ. Entomol. 5: 133-138.

Regev, S., and W. W. Cone. 1980. The monoterpene citronellol as a male sex attractant of the two-spotted spider mite *Tetranychus urticae* (Acarina: Tetranychidae). Environ. Entomol. 9: 50-52.

Reichelderfer, K. 1982. Data needs and analytical approaches for large-scale regional and national IPM evaluation. Paper presented at the 1982 annual meeting of the Entomological Society of America

Reid, P. E., N. S. Thompson, P. K. Lawrence, D. J. Luckett, G. T. McIntyre, and E. R. William. 1989. Regional evaluation of cotton cultivars in eastern Australia, 1974-1985. Australian Journal of Experimental Agriculture 29: 679-689.

Reinecke, J. P., J. L. Roberson, E. J. Villavaso, and E. P. Lloyd. 1986. Rearing, sterilizing, containerizing and quality assessing of sterile boll weevils released in a large-scale field experiment in South Carolina, 1985, pp. 238-241. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Reinhard, H. J. 1928. Hibernation of the cotton fleahopper. Tex. Ag. Exp. Sta. Bull. 377.

Rejesus, R. S. 1968. Bio-ecological studies on the cotton leafperforator, *Bucculatrix thurberiella* Busck (Lepidoptera: Lyonetiidae). MS thesis, Univ. Calif.,Riverside.

Remaudiere, G., and S. Keller. 1980. Revision systematique des genres d Entomophthoraceae a potentialite entomophathogene. Mycotaxon 11: 323-338.

Rester, D. G. 1982. Calibrate your agricultural spray plane. La. Coop. Ext. Ser., Baton Rouge.

Retnakaran, A., J. Granett, and T. Ennis. 1985. Insect growth regulators. pp. 529-601. *In* G. A. Kerkut, and L. I. Gilbert (eds.), Comprehensive insect physiology, biochemistry and pharmacology. Vol. 12. Insect control. Pergamon Press, New York.

Reynolds, E. B. 1926. The effect of spacing on the yield of cotton. Tex. Agr. Exp. Sta. Bull. 340.

Reynolds, H. T. 1971. A world review of the problem of insect population upsets and resurgences caused by pesticide chemicals, pp. 108-112. *In* J. E. Swift (ed.), Agricultural chemicals - harmony or discord for food, people, environment. Proc. Symp. Univ. Calif. Div. Agric. Sci., Sacramento, Calif.

Reynolds, H. T. 1972. Practical application of suppression in pest management, *In* Implementing practical pest management strategies. Proc. National Pest Management Workshop. Purdue University, Lafayette, IN.

Reynolds, H. T. 1980. Insecticides for control of pink bollworm populations, pp. 35-39. *In* H. Graham (ed.), Pink bollworm control in the Western United States. USDA, Science and Education Administration ARM-W-16.

Reynolds, H. T., P. L. Adkisson, and R. F. Smith. 1975. Cotton insect pest management, pp. 379-343. *In* R. L. Metcalf, and W. H. Luckmann (eds.), Introduction to pest management. John Wiley & Sons, Inc., New York.

Reynolds, H. T., P. L. Adkisson, R. F. Smith, and R. E. Frisbie. 1982. Cotton insect pest management, pp. 375-441. *In* R. L. Metcalf, and W. H. Luckmann (eds.), Introduction to insect pest management. John Wiley and Sons, New York.

Rice, R. E., and H. T. Reynolds. 1971. Seasonal emergence and population development of the pink bollworm in California. J. Econ. Entomol. 64: 1429-1432.

Richmond, C. A., and C. Ignoffo. 1964. Mass rearing pink bollworms. J. Econ. Entomol. 57: 503-505.

Ridgway, R. L. 1986. Cultural and biological control of *Heliothis*: status and opportunities, pp. 155-161. *In* Theory and tactics of *Heliothis* management: I-Cultural and biological control. S. Coop. Ser. Bull. 316.

Ridgway, R. L., J. R. Ables, C. Goodpasture, and Hartstack. 1981. *Trichogramma* and its utilization for crop protection in the U.S.A., pp. 41-48. *In* J. R. Coulson (ed.), Proc. Joint American-Soviet Conf. on the Use of Beneficial Organisms in the Control of Crop Pests. Entomol. Soc. Am., College Park, MD.

Ridgway, R. L., L. A. Bariola, and D. D. Hardee. 1971. Seasonal movement of boll weevils near the High Plains of Texas. J. Econ. Entomol. 64: 14-019.

Ridgway, R. L., W. A. Dickerson, J. R. Brazzel, J. F. Leggett, E. P. Lloyd, and F. R. Planer. 1985. Boll weevil pheromone trap captures for treatment thresholds and population assessments, pp. 138-141. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Ridgway, R. L., R. M. Silverstein, and M. N. Inscoe (eds.). 1990a. Behavior-modifying Chemicals for Insect Management: Applications of Pheromones and Other Attractants. Marcel Dekker, Inc., New York.

Ridgway, R. L., M. N. Inscoe, and W. A. Dickerson. 1990b. Role of the boll weevil pheromone in pest management, pp. 437-471. *In* R. L. Ridgway, R. M. Silverstein, and M. N. Inscoe (eds.), Behavior-modifying Chemicals for Insect Management: Applications of Pheromones and Other Attractants. Marcel Dekker, Inc., New York.

Ridgway, R. L., M. N. Inscoe, K. W. Thorpe, A. K. Raina, and J. C. Davis. 1990c. Potential for disrupting biological processes in *Heliocverpa* and *Heliothis* spp. neuropeptides and recombinant baculoviruses, pp. 314-318. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Ridgway, R. L., and S. L. Jones. 1968. Plant feeding by *Geocoris pallens* and Nabis *americoferus*. Ann. Entomol. Soc. Amer. 61: 232-233.

Ridgway, R. L., and S. L. Jones. 1969. Innundative releases of *Chrysopa carnea* for control of *Heliothis* on cotton. J. Econ. Entomol. 62: 117-118.

Ridgway, R. L., E. G. King, and J. L. Carillo. 1977. Augmentation of natural enemies for control of plant pests in the western hemisphere, pp. 379-428. *In* R. L. Ridgway, and S. B. Vinson (eds.), Biological control by augmentation of natural enemies. Plenum Press, New York.

Ridgway, R. L., and R. E. Kinzer. 1974. Chrysopids as predators of crop pests. Entomophaga Mem. H. S., 7: 45-51.

Ridgway, R. L., and P. D. Lingren. 1972. Predaceous and parasitic arthropods as regulators of *Heliothis* populations, pp. 48-56. *In* Distribution, abundance and control of *Heliothis* species in cotton and other host plants, South. Coop. Ser. Bull. 169.

Ridgway, R. L., P. D. Lingren, C. B. Cowan, and J. W. Davis. 1967. Populations of arthropod predators and *Heliothis* spp. after applications of systemic insecticides to cotton. J. Econ. Entomol. 60: 1012-1016.

Ridgway, R. L., and E. P. Lloyd. 1983. Evaluation of cotton insect management in the United States, pp. 3-28. *In* R. L. Ridgway, E. P. Lloyd, and W. H. Cross (eds.), Cotton Insect Management with Special Reference to the Boll Weevil. USDA Agr. Handb. No. 589.

Ridgway, R. L., E. P. Lloyd, and W. H. Cross (eds.). 1983. Cotton insect management with special reference to the boll weevil. USDA Agr. Handb. No. 589. Washington, D.C.

Ridgway, R. L., and R. K. Morrison. 1985. Worldwide perspective on practical utilization of *Trichogramma* with special reference to control of *Heliothis* on cotton. Southwest. Entomol. Suppl. 8: 190-198.

Ridgway, R. L., and S. B. Vinson (eds.). 1977. Biological control by augmentation of natural enemies. Plenum Press, New York.

Riechert, S. E., and T. Lockley. 1984. Spiders as biological control agents. Annu. Rev. Entomol. 29: 299-320.

Riley, D. G., and D. Wolfenbarger. 1993. Cultivated hosts and population dynamics of sweetpotato whitefly in the Lower Rio Grande Valley of Texas, pp. 667-670. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Riley, S. L. 1989. Pyrethroid resistance in *Heliothis virescens*: current U.S. management programs. Pestic. Sci. 411-421.

Ring, D. R., J. H. Benedict, J. A. Landivar, and B. R. Eddleman. 1993. Economic injury levels and development and application of response surfaces relating insect injury, normalized yield, and plant physiological age. Environ. Entomol. 22: 273-282.

Ring, D. R., J. H. Benedict, S. M. Masud, R. D. Lacewell, G. R. Zummo, and M. F. Treacy. 1989. Economic decision-aid for management of bollworm and fleahopper on cotton in the lower gulf coast of Texas, pp. 222-226. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Roach, S. H. 1973. Developmental changes in the boll weevil, *Anthonomus grandis* studied with time-lapse photography. Ann. Entomol. Soc. Amer. 66: 24-27.

Roach, S. H. 1975. *Heliothis* spp.: Larvae and associated parasites and diseases on wild host plants in the Pee Dee area of South Carolina. Environ. Entomol. 4: 725-28.

Roach, S. H. 1975. *Heliothis zea* and *H. virescens*: Moth activity as measured by blacklight and pheromone traps. J. Econ. Entomol. 68: 17-21.

Roach, S. H. 1979. Boll weevil: reproductive potential, feeding,and longevity of overwintering adults with some effects of photoperiod on fecundity. J. Ga. Entomol. Soc. 14: 346-350.

Roach, S. H. 1980. Arthropod predators on cotton, corn, tobacco, and soybeans in South Carolina. J. Ga. Entomol. Soc. 15: 131-138.

Roach, S. H., and A. R. Hopkins. 1981. Reduction in arthropod predator populations in cotton fields treated with insecticides for *Heliothis* spp. control. J. Econ. Entomol. 74: 454-457.

Roach, S. H., and L. Ray. 1972. Boll weevils captured at Socastee, South Carolina, in 1970, in wing traps placed around fields with and without growing cotton. J. Econ. Entomol. 65: 559-560.

Roach, S. H., L. Ray, H. M. Taft, and A. R. Hopkins. 1971. Wing traps baited with male boll weevils for determining spring emergence of overwintered weevils and subsequent infestations in cotton. J. Econ. Entomol. 64: 107-110.

Roach, S. H., H. M. Taft, L. Ray, and A. R. Hopkins. 1971. Population dynamics of the boll weevil in an isolated cotton field in South Carolina. Ann. Entomol. Soc. Amer. 64: 394-399.

Roberson, J. 1984. Laboratory rearing, pp. 85-113. *In* P. P. Sikorowski, J. G. Griffin, J. Roberson, and O. H. Lindig (eds.), Boll weevil mass rearing technology. Univ. Press of Mississippi, Jackson.

Roberson, J. L., and D. K. Harsh. 1993. Mechanized production processes to encapsulate boll weevil larvae (*Anthonomus grandis*) for mass production of *Catolaccus grandis* (Burks), pp. 922-923. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Roberson, J. L., S. Malone, D. K. Harsh, and O. L. Malone. 1989. Automated *Heliothis* spp. production system, *In* Proc. Mississippi Insect Control Conference.

Roberson, J. L., and L. W. Noble. 1968. Rearing of tobacco budworm in honeycomb-like cells. J. Econ. Entomol. 61: 331-331.

Roberson, J. L., and E. J. Villavasso. 1986. Improvements in boll weevil rearing, release, and field competition, 1983-1985, pp. 19-20. *In* Proceedings Mississippi Insect Control Conference, November, 1985.

Roberson, J. L., and J. E. Wright. 1984. Production of boll weevils, *Anthonomus grandis grandis*, pp. 188-192. *In* E. G. King, and N. C. Leppla (eds.), Advances and Challenges in Insect Rearing. USDA, ARS, New Orleans, La.

Roberts, P., and G. L. Lentz. 1993. Cotton insect and mite control. University of Tennessee Cooperative Extension Service. Publication 387.

Robinson, J. R. C., J. E. Slosser, J. K. Walker, and J. R. Price. 1986. CDA/ULV-OIL technology versus conventional spray technology for ground application of sprays for bollworm control in the Texas Rolling Plains. Southwest. Entomol. 11: 25-37.

Robinson, J. V., and J. W. Stewart. 1987. Management of cotton insects in Blacklands, South & East Texas, counties. Tex. Agric. Ext. Serv. B-1204.

Robinson, R. 1971. Lepidoptera genetics. Pergamon Press, New York.

Robinson, R. R., J. R. Young, and R. D. Morrison. 1972a. Strip-cropping effects on abundance of *Heliothis* damaged cotton squares, boll placement, total bolls, and yield in Oklahoma. Environ. Entomol. 1: 140-145.

Robinson, R. R., J. H. Young, and R. D. Morrison. 1972b. Strip-cropping effects on the abundance of predatory and harmful cotton insects in Oklahoma. Environ. Entomol. 1: 145-149.

Roe, R. M., P. Y. K. Cheung, B. D. Hammock, D. Buster, and A. R. Alford. 1985. Endotoxin of *Bacillus thuringiensis* var. *israelensis*. Broad-spectrum toxicity and neural response elicited in mice and insects, pp. 279-292. *In* P. A. Hedin (ed.), Bioregulators for pest control. American Chemical Society, Washington, D.C.

Roelofs, W. L., A. S. Hill, R. T. Carde, and T. C. Baker. 1974. Two sex pheromone components of the tobacco budworm moth, *Heliothis virescens*. Life Sciences 14: 1555-1562.

Rogers, B., L. Boykin, R. Blenk, and D. Clower. 1991. *Heliothis* resistance monitoring in the cotton belt: the next steps, pp. 660-662. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Rolston, L. H., and R. L. Kendirck. 1961. Biology of the brown stink bug, *Euschistus servus* Say. J. Kan. Entomol. 34: 151-157.

Romney, V. E., and T. P. Cassidy. 1945. *Anaphes ovijentatus* and egg-parasite of *Lygus hesperus*. J. Econ. Entomol. 38: 497-498.

Ronis, M. J. J., and E. Hodgson. 1989. Cytochrome P-450 monooxygenases in insects. Xenobiotica 19: 1077-1092.

Roof, M. 1988. Insect control for earliness: strategy and basis, pp. 28-30. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Roof, M. E. 1988. Cotton insect management, information card 97. Clemson University Cooperative Extension Service.

Rook, S. P., and G. A. Carlson. 1985. Participation in pest management groups. Am. J. Agri. Econ. 67: 563-566.

Room, P. M. 1979. A prototype 'on-line' system for management of cotton pests in the Namoi Valley, New South Wales. Prot. Ecol. 1: 245-264.

Roome, R. E. 1975. Field trial, with a nuclear polyhedrosis virus and *Bacillus thuringiensis* against *Heliothis armigera* larvae on sorghum and cotton. Botswana Bull. Int. Res. 65.

Rose, R. L., and T. C. Sparks. 1984. Acephate toxicity, metabolism, and anticholinesterase activity in *Heliothis virescens* (F.) and *Anthonomus grandis grandis* (Boheman). Pestic. Biochem. Physiol. 22: 69-77.

Ross, D. C., J. W. Crim, M. R. Brown, G. A. Herzog, and A. O. Lea. 1986a. Toxic and antifeeding actions of melittin in the corn earworm, *Heliothis zea* (Boddie): comparisons to bee venom and the insecticides chlorpyriphos and cyromazine. Toxicol 25: 307-313.

Ross, D. C., G. A. Herzog, and J. W. Crim. 1986b. Peptide toxins from arthropod venoms disrupt feeding and utilization of diet in the cotton bollworm. Insect Neurochem. Neurophys. 86: 401-404.

Ross, D. C., G. A. Herzog, and J. W. Crim. 1987. Toxicity of the venoms of two scorpions (*Androctonus australis* and *Centruroides sculpturatus*) and a sea anemone (*Condylactis gigantea*): acute and antifeeding actions in the cotton bollworm (*Heliothis zea*). Comp. Biochem. Physiol. 89: 229-232.

Roth, V. D. 1993. Spider genera of North America. American Arachnological Society, Gainesville, FL, 3rd ed.

Rothschild, G. H. L., B. F. Nesbitt, P. S. Beevor, A. Cork, D. R. Hall, and R. A. Vickers. 1982. Studies of the female sex pheromone of the native budworm, *Heliothis punctiger*. Entomol. Exp. Appl. 31: 395-401.

Roush, R. T. 1986. Inbreeding depression and laboratory adaptation in *Heliothis virescens* (Lepidoptera: Noctuidae). Ann. Entomol. Soc. Amer. 79: 583-587.

Roush, R. T., and J. C. Daly. 1990. The role of population genetics in resistance research and management, pp. 97-152. *In* R. T. Roush, and B. E. Tabashnik (eds.), Pesticide resistance in arthropods. Chapman & Hall. New York.

Roush, R. T., and R. G. Luttrell. 1987. The phenotypic expression of pyrethroid resistance in *Heliothis* and implications for resistance management, pp. 220-224. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Roush, R. T., and R. G. Luttrell. 1989. Expression of resistance to pyrethroid insecticide in adults and larvae of tobacco budworm (Lepidoptera: Noctuidae): implications for resistance monitoring. J. Econ. Entomol. 82: 1305-1310.

Roush, R. T., and J. A. McKenzie. 1987. Ecological genetics of insecticide and acaricide resistance. Annu. Rev. Entomol. 32: 361-380.

Roush, R. T., and G. L. Miller. 1986. Considerations for design of resistance monitoring programs. J. Econ. Entomol. 79: 293-298.

Roush, R. T., and J. C. Schneider. 1985. An analytical model for genetic control of *Heliothis virescens* incorporating the effects of sterile males. Theor. Appl. Genet. 71: 472-477.

Roush, R. T., and J. E. Wright. 1986. Abamectin: toxicity to house flies (Diptera: Muscidae) resistant to synthetic organic insecticides. J. Econ. Entomol. 79: 562-564.

Roussel, J. S., and D. F. Clower. 1955. Resistance to the chlorinated hydrocarbon insecticides in the boll weevil (*Anthonomus grandis* Boh.). Louisiana Agr. Exp. Sta. Circ. 41.

Roussel, J. S., and D. F. Clower. 1957. Resistance to the chlorinated hydrocarbon insecticides in the boll weevil. J. Econ. Entomol. 50: 462-468.

Royama, T. 1981. Evaluation of mortality factors in insect life table analysis. Ecol. Monographs 51: 495-505.

Ru, N., W. H. Whitcomb, and M. Murphey. 1976. Culturing of *Chrysopa rufilabris* (Neuroptera: Chrysopidae). Fla. Entomol. 59: 21-26.

Ruigt, G. S. F. 1985. Pyrethroids, pp. 183-262. *In* G. A. Kerkut, and L. I. Gilbert (eds.), Comprehensive insect physiology, biochemistry and pharmacology. Vol. 12., Insect control. Pergamon Press, New York.

Rummel, D. R. 1965. Boll weevil control—Rolling Plains of Texas, pp. 3. *In* Focus on Entomology. Tex. Agric. Ext. Serv.,

Rummel, D. R. 1975. Focus on entomology. Tex. Agric. Ext. Serv. 14:(16) 7.

Rummel, D. R., and P. L. Adkisson. 1970. Distribution of boll weevil-infested cotton fields in relation to overwintering habitats in the High and Rolling Plains of Texas. J. Econ. Entomol. 63: 1906-1909.

Rummel, D. R., and D. G. Bottrell. 1976. Seasonally related decline in response of boll weevils to pheromone traps during mid-season. Environ. Entomol. 5: 783-787.

Rummel, D. R., D. G. Bottrell, P. L. Adkisson, and R. C. McIntyre. 1975. An appraisal of a 10-year effort to prevent the westward spread of the boll weevil. Bull. Entomol. Soc. Amer. 21: 6-11.

Rummel, D. R., and S. C. Carrol. 1985. Longevity of overwintered boll weevils (Coleoptera: Curculionidae) following emergence in spring and early summer. Environ. Entomol. 14: 127-130.

Rummel, D. R., and S. C. Carroll. 1983. Winter survival and effective emergence of boll weevil cohorts entering winter habitat at different times. Southwest. Entomol. 8: 101-106.

Rummel, D. R., and R. E. Frisbie. 1978. Suppression of potentially overwintering boll weevils as a pest management practice, pp. 39-49. *In* The boll weevil: management strategies. S. Coop. Ser. Bull. No. 228.

Rummel, D. R., L. B. Jordan, J. R. White, and L. J. Wade. 1977. Seasonal variation in the height of boll weevil flight. Environ. Entomol. 6: 674-678.

Rummel, D. R., J. F. Leser, J. E. Slosser, G. J. Puterka, C. W. Neeb, J. K. Walker, J. H. Benedict, M. D. Heilman, L. N. Namken, J. W. Norman, and J. H. Young. 1986. Cultural control of *Heliothis* spp. in southwestern U.S. cropping systems, pp. 38-53. *In* Theory and tactics of *Heliothis* population management. I - cultural and biological control. S. Coop. Ser. Bull. 316.

Rummel, D. R., and J. E. Quisenberry. 1979. Influence of thrips injury on leaf development and yield of various cotton genotypes. J. Econ. Entomol. 72: 706-709.

Rummel, D. R., and R. E. Reeves. 1971. Response of bollworm and predacious arthropod populations to aldicarb treatments in cotton. J. Econ. Entomol. 64: 907-911.

Rummel, D. R., J. R. White, S. C. Carroll, and G. R. Pruitt. 1980. Pheromone trap index system for predicting need for overwintered boll weevil control. J. Econ. Entomol. 73: 806-810.

Russell, L. M. 1975. Collection records of *Bemisia tabaci* (Gennadius) in the United States. USDA Coop. Econ. Insect Rep. 25: 229-230.

Russell, T. E., T. F. Watson, and G. F. Ryan. 1976. Field accumulation of aflatoxin in cottonseed as influenced by irrigation, termination dates and pink bollworm infestation. Appl. Environ. Microbial. 31: 711-713.

Rykiel, E. J., M. C. Saunders, T. L. Wagner, D. K. Loh, R. H. Turnbow, L. C. Hu, P. E. Pulley, and R. N. Coulson. 1984. Computer-aided decision making and information accessing in pest management system, with emphasis on the southern pine beetle. J. Econ. Entomol. 77: 1073-1082.

Saba, F. 1971. *Tetranychus yusti*, a spider mite of potential economic importance. J. Econ. Entomol. 64: 141-144.

Sabelis, M. W., and M. Dicke. 1985. Long-range dispersal and searching behaviour. pp. 141-160. *In* W. Helle, and M. W. Sabelis (eds.), Spider mites: their biology, natural enemies and control. Elsevier, Amsterdam.

Sabrosky, C. W. 1955. The taxonomic status of the armyworm parasite known as *Archytas piliventris* (van der Wulp) (Diptera: Larvaevoridae). Fla. Entomol. 38: 77-83.

Sabrosky, C. W. 1981. A partial revision of the genus *Eucelatoria* (Diptera, Tachinidae), including important parasites of *Heliothis*. U.S. Dept. of Agric., Tech. Bull. No. 1635, Washington, D.C.

Sabrosky, C. W., and P. H. Arnaud. 1965. Family Tachinidae, *In* A. Stone, C. W. Sabrosky, W. W. Wirth, R. H. Foote, and J. R. Coulson (eds.), A catalogue of the diptera of America North of Mexico. U.S. Dept. of Aric. Handbook No. 276, 1696 pp. Washington, D.C.

Salama, M. S., L. P. Schouest, and T. Miller. 1992. Effect of diet on the esterase patterns in the hemolymph of the corn earworm and the tobacco budworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 85: 1079-1087.

Salas-Aguilar, J., and L. E. Ehler. 1977. Feeding habits of *Orius tristicolor*. Ann. Entomol. Soc. Am. 70: 60-62.

Salgado, V. L. 1992. The neurotoxic insecticial mechanism of the non-steroidal ecdysone agonist RH-5849: K+ channel block in nerve and muscle. Pestic. Biochem. Physiol. 43: 1-13.

Salgado, V. L., S. N. Irving, and T. Miller. 1983a. Depolarization of motor nerve terminals by pyrethroids in susceptible and kdr-resistant house flies. Pestic. Biochem. Physiol. 20: 100-114.

Salgado, V. L., S. N. Irving, and T. Miller. 1983b. The importance of nerve terminal depolarization in pyrethroid poisoning of insects. Pestic. Biochem. Physiol. 20: 169-182.

Salt, G. 1937. Experimental studies in insect parasitism. V. The sense used by *Trichogramma* to distinguish between parasitized and unparasitized hosts. Proc. Roy. Soc. London, Ser. B 122: 57-75.

Samson, R. A. 1974. *Paecilomyces* and some allied hyphomycetes. Stud. Mycol. No. 6.

Samson, R. A. 1981. Identification: entomopathogenic deuteromycetes, pp. 93-106. *In* H. D. Burges (ed.), Microbial control of pests and plant diseases 1970-1980. Academic Press, New York.

Samuelson, P. A. 1961. Economics - An Introductory Analysis. McGraw-Hill, New York.

Sanborne, C. E., H. C. Young, E. Hixson, H. C. Young, E. E. Scholl, and C. F. Stiles. 1935. History and control of the boll weevil in Oklahoma. Bull. No. 318 General Series 93. Oklahoma Agric. Exp. Sta.

Sanderson, E. D. 1905. The boll weevil and cotton crop of Texas. Texas Dept. of Agric.

Sanderson, R., E. W. Huddleston, J. B. Ross, J. A. Henderson, and E. W. Ferguson. 1986. Deposition and drift of Pydrin in cottonseed oil and water under arid conditions applied with a dual spray system aircraft. Trans. ASAE 29: 378-381.

Sappenfield, W. P. 1981. Registration of HYC76-59 cotton germplasm. Crop Sci. 21: 991-992.

Sappenfield, W. P. 1985. Registration of 'Delcot 390'cotton. Crop Sci. 25: 198.

Sapturo, S., D. B. Smith, and D. R. Shaw. 1991. Expert system for agricultural aerial spray drift. Trans. ASAE 34: 764-772.

Sattelle, D. B., S. Buckingham, K. Wafford, S. Sherby, N. Bakry, A. Eldefrawi, M. Eldefrawi, and T. May. 1989. Action of the insecticide 2-(nitromethylene) tetranhydro-1,3-thiazine in insect and vertebrate nicotinic acetylcholine receptors, pp. 501-514. *In* Proceedings, R. Soc. London.

Sauls, C. E., D. A. Nordlund, and W. J. Lewis. 1979. Kairomones and their use for managment of entomophagous insects. VIII.Efffects of diet on the kairomonal activity of frass from *Heliothis zea* (Boddie) larvae for *Microplitis croceipes* (Cresson). J. Chem. Ecol. 5: 363-369.

Saunders, M. C., C. W. Haeseler, J. W. Travis, B. J. Miller, K. D. Loh Coulson, and N. D. Stone. 1987. GRAPES: an expert system for viticulture in Pennsylvania. AI Appl. Nat. Res. Manage. 1: 13-20.

Savinelli, C. E. 1984. Ovipositional responses, larval feeding behavior and injury assessment of the European corn borer, *Ostrinia nubilalis* (Hubner), and cotton in North Carolina. Ph.D. dissertation, North Carolina State Univ. Raleigh.

Savinelli, C. E., J. C. Bacheler, and J. R. Bradley Jr. 1986. Nature and distribution of European corn borer (Lepidoptera: Pyralidae) larval feeding change to cotton in North Carolina. Environ. Entomol. 15: 399-402.

Savinelli, C. E., J. S. Bacheler, and J. R. Bradley Jr. 1988. Ovipositional preferences of the European corn borer (Lepidoptera: Pyralidae) for field corn and cotton under field cage conditions in North Carolina. Environ. Entomol. 17: 688-690.

Sawicki, R. M. 1985. Insecticide resistance in *Heliothis armigera*. Report on a visit to Australia, January-February 1985, to investigate insecticide resistance in *Heliothis armigera*. Rothamsted Experimental Station, Harpenden, United Kingdom.

Sawicki, R. M. 1985. Resistance to pyrethroid insecticides in arthropods, pp. 143-192. *In* D. H. Hutson, and T. R. Roberts (eds.), Progress in pesticide biochemistry and toxicology Vol. 5. John Wiley & Sons, New York.

Sawicki, R. M. 1987. Definition, detection and documentation of insecticide resistance, pp. 105-117. *In* M. G. Ford, D. M. Holloman, B. P. S. Khambay, and R. M. Sawicki (eds.). Combating resistance to xenobiotics Horwood, Chichester.

Sawicki, R. M. 1989. Current insecticide management practices in cotton around the world—short term successes as a template for the future. Pestic. Sci. 26: 411-421.

Sawicki, R. M., and I. Denholm. 1987. Management of resistance to pesticides in cotton pests. Tropical Pest Management 33: 262-272.

Sawicki, R. M., and D. Lord. 1970. Some properties of a mechanism delaying penetration of insecticides into house flies. Pestic. Sci. 1: 213-225.

Scales, A. L. 1968. Female tarnished plant bugs attract males. J. Econ. Entomol. 61: 1466-1467.

Scales, A. L. 1973. Parasites of the tarnished plant bug in the Mississippi Delta. Environ. Entomol. 2: 304-305.

Scaramuzza, L. C. 1946. Capitulo XII. Los insectos y otros animales que atacan a la cana de azucar en Cuba, pp. 529-563. *In* F. Agete y Pinero (ed.), La cana asucar en Cuba, Vol. 2 Havana.

Schaunak, R. K., R. D. Lacewell, and J. Norman. 1982. Economic implication of alternative cotton production strategies in the Lower Rio Grande Valley of Texas, 1973-78. Tex. Agr. Exp. Sta. Bull. 1420.

Schmidt, C. D., and J. L. Robertson. 1986. Effects of treatment technique on response of horn flies (Diptera: Muscidae) to permethrin at different temperatures. J. Chem. Ecol. 79: 684-687.

Schmoldt, D. L. 1991. Simulation of plant physiological processes using fuzzy variables. AI Applications 5: 3-16.

Schmutterer, H. 1977. Other injurious Lepidoptera, pp. 666. *In* J. Kranz, H. Schmutterer, and W. Koch (eds.), Diseases, pests and weeds in Tropical Crops Verlag Paul Parey, Berlin.

Schneider, F. 1962. Dispersal and migration. Annu. Rev. Entomol. 7: 223-242.

Schneider, J. C., J. H. Benedict, F. Gould, W. R. Meredith Jr., M. F. Schuster, and G. R. Zummo. 1986. Interaction of *Heliothis* with its host plants, pp. 3-21. *In* Theory and tactics of *Heliothis* population management I - cultural and biological control. S. Coop. Ser. Bull. 316.

Schoene, W. T., and G. W. Underhill. 1933. Economic status of the green stink bug with reference to the succession of its wild hosts. J. Agric. Res. 46: 863-866.

Schoolfield, R. M. 1983. A PDE formulation and numerical solution for a boll weevil cotton crop model with soil and light penetration. Ph.D. Dissertation, Texas A&M University, College Station.

Schouest, L. P., and T. A. Miller. 1988. Factors influencing pyrethroid toxicity in pink bollworm (Lepidptera: Gelechiidae): implications for resistance management. J. Econ. Entomol. 81: 431-436.

Schouest, L. P., and T. A. Miller. 1991. Field incubation of insects for insecticide toxicity assays in resistance monitoring programs. Environ. Entomol. 20: 1526-1530.

Schouest, L. P., N. Umetsu, and T. Miller. 1983. Solvent-modified deposition of insecticides on house fly (Diptera: Muscidae) cuticle. J. Econ. Entomol. 76: 973-982.

Schowalter, T. D., and J. D. Stein. 1987. Influence of Douglas fir seedling provenance and proximity to insect population sources on susceptibility to *Lygus hesperus* (Heteroptera: Miridae) in a forest nursery in western Oregon. Environ. Entomol. 16: 984-988.

Schreiber, A., and C. O. Knowles. 1991. Comparison of topical and vial bioassays on bollworm: implications for resistance monitoring, pp. 654-656. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Schuster, M. F. 1977. Plant bugs - key pests on cotton, pp. 156-157. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Schuster, M. F. 1980. Cotton ecosystem diversification and plant bug trapping with interplanted alfalfa in the delta of Mississippi. Miss. Agric. For. Exp. Stn. Tech. Bull. 98.

Schuster, M. F., and J. C. Boling. 1974. Phenology of early and mid season predatory and phytophagous insects in cotton in the Lower Rio Grande Valley of Texas. Tex. Agric. Exp. Stn. MP-1133.

Schuster, M. F., and E. T. Cherry. 1975. Cross resistance in twospotted spider mite-resistant cotton to the desert spider mite. J. Econ. Entomol. 68: 131-132.

Schuster, M. F., and J. L. Frazier. 1977. Mechanisms of resistance to *Lygus* spp. in *Gossypium hirsutum*. Bull. Symp. Inter. Organ. Biol. Control Nox. Anim. Plants West Palearctic Rep. Sec. 3: 129-135.

Schuster, M. F., M. J. Lukefahr, and F. G. Maxwell. 1976. Impact of nectariless cotton on plant bugs and natural enemies. J. Econ. Entomol. 69: 400-403.

Schuster, M. F., and F. G. Maxwell. 1976. Resistance to two-spotted spider mites in cotton. Miss. Agric. For. Exp. Stn. Bull. 821.

Schuster, M. F., F. G. Maxwell, J. N. Jenkins, E. T. Cherry, W. L. Parrott, and D. G. Holder. 1973. Resistance to twospotted spider mite in cotton. Miss. Agric. For. Exp. Stn. Bull. 802.

Schuster, M. F., F. G. Maxwell, J. N. Jenkins, and W. L. Parrott. 1972a. Mass screening seedlings of *Gossypium* sp. for resistance to the twospotted spider mite. J. Econ. Entomol. 65: 1105-1107.

Schuster, M. F., F. G. Maxwell, and J. N. Jenkins. 1972b. Resistance to the twospotted spider mite in certain *Gossypium hirsutum* races, *Gossypium* species, and glandled-glandless counterpart cottons. J. Econ. Entomol. 65: 1108-1110.

Schwartz, P. H. 1983. Losses in yield of cotton due to insects, pp. 329-358. *In* R. L. Ridgway, E. P. Lloyd, and W. H. Cross (eds.), Cotton Insect Management with Special Reference to the Boll Weevil. USDA Agr. Handb. No. 589.

Schwartz, P. H., and W. Klassen. 1981. Estimates of losses caused by insects and mites to agricultural crops, pp. 15-77. *In* D. Pimentel (ed.), CRC handbook of pest management in agriculture, Vol. 1. CRC Press, Inc., Boca Raton.

Scott, D. R. 1977. Annotated listing of host plants of *Lygus hesperus* Knight. Bull. Entomol. Soc. Amer. 23: 19-22.

Scott, J. G. 1989. Cross-resistance to the biological insecticide abamectin in pyrethroid-resistant house flies. Pestic. Biochem. Physiol 34: 27-31.

Scott, R. D., M. Cochran, and W. F. Nicholson Jr. 1983. Evaluation of farm level benefits of bollworm management communities. Ark. Farm Res. November-December.

Scott, W. P., D. B. Smith, and E. P. Lloyd. 1974. Direct and residual kill of the boll weevil with ULV sprays and azinphosmethyl. J. Econ. Entomol. 67: 408-410.

Scott, W. P., J. W. Smith, and G. L. Snodgrass. 1985. Response of cotton arthropod populations in cotton to various dosages of aldicarb in-furrow at planting. J. Econ. Entomol. 78: 249-257.

Scott, W. P., J. W. Smith, and G. L. Snodgrass. 1985. The tarnished plant bug (Hemiptera: Miridae): a key pest of cotton in the Mississippi Delta, pp. 164-167. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Seiber, J. N., J. E. Woodrow, B. W. Herman, and P. L. Sanders. 1983. Determination of airborne residues from four harvest aid chemicals (DEF, Folex, cacodylates and paraquat) at treated San Joaquin Valley cotton field sites, as a measure of potential human exposure. California Dept. of Food and Agric. HS-1326.

Sequeira, R. A., P. J. H. Sharpe, N. D. Stone, K. M. El-Zik, and M. E. Makela. 1991. Object-oriented simulation: plant growth and discrete organ to organ interactions. Ecol. Modelling 58: 55-89.

Sequeira, R. L., and R. L. Olson. 1993. Theoretical background and validation of CPM, a new cotton simulation model, pp. 544-549. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Serebrovsky, A. S. 1940. On the possibility of a new method for the control of insect pests. Zoologicheskii Zhurnal 19: 618-630.

Sevacherian, V., and V. M. Stern. 1975. Movements of lygus bugs between alfalfa and cotton. Environ. Entomol. 4: 163-165.

Shahjahan, M. 1970. Food plants as factors influencing host selection by *Leiophron pallipes* (Hymenoptera: Braconidae), a parasitoid of *Lygus lineolaris* (Hemiptera: Miridae). PhD. dissertation, Univ. of Conn.

Shahjahan, M., and F. A. Streams. 1973. Plant effects on host-finding by *Leiophron pseudopallipes* (Hymenoptera: Braconidae), a parasitoid of the tarnished plant bug. Environ. Entomol. 2: 921-925.

Shankland, D. L., and J. L. Frazier. 1985. Nervous system: electrical events, pp. 253-286. *In* M. S. Blum (eds.), Fundamentals of insect physiology. John Wiley and Sons, New York.

Shanklin, D. L., and J. Tucker. 1980. Aerial application of pesticide sprays. Miss. Agric. For. Exp. Sta., Tech. Bull. 103.

Shapiro, M. 1982. In vivo mass production of insect viruses for use as pesticides, pp. 463-492. *In* E. Kurstak (ed.), Microbial and viral pesticides. Marcel Dekker, Inc., New York.

Sharma, R. K., R. E. Rice, H. R. Reynolds, and H. H. Shorey. 1971. Seasonal influence and effect of trap location on catches of pink bollworm males in sticky traps baited with hexalure. Ann. Entomol. Soc. Amer. 64: 102-105.

Sharpe, P. J. H., G. L. Curry, D. W. DeMichele, and C. L. Cole. 1977. Distribution model of organism development times. J. Theor. Biol. 66: 21-38.

Sharpe, P. J. H., and D. W. DeMichele. 1977. Reaction kinetics of poikilotherm development. J. Theor. Biol 64: 649-670.

Sharpe, P. J. H., and L. Hu. 1980. Reaction kinetics of nutrient dependent poikilotherm development. J. Theor. Biol. 82: 317-333.

Sharpe, P. J. H., R. M. Schoolfield, and G. D. Butler Jr. 1981. Distribution model of *Heliothis zea* (Lepidoptera: Noctuidae) development times. Can. Entomol. 113: 845-856.

Shaunak, R. K., R. D. Lacewell, and J. Norman. 1982. Economic implications of alternative cotton production strategies in the Lower Rio Grande Valley of Texas, 1973-1978. Tex. Agri. Exp. Stn. Bull. B-1420.

Shaver, T. N., D. E. Hendricks, and J. D. Lopez. 1987. Enhancement of field performance of *Heliothis virescens* pheromone components by (Z)-11-hexadecen-1-ol in PVC dispenser, pp. 307-309. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Sheih, T. R., and G. T. Bohmfalk. 1980. Production and efficacy of baculoviruses. Biotech. and Bioeng. 22: 1357-1375.

Shen, S. K., and P. F. Dowd. 1991. 1-naphthyl acetate esterase activity from cultures of the symbiont yeast of the cigarette beetle (Coleoptera: Anobiidae). J. Econ. Entomol. 84: 402-407.

Shepard, M., and W. L. Sterling. 1972a. Incidence of parastism of *Heliothis* spp. (Lepidoptera: Noctuidae) in some cotton fields of Texas. Ann. Entomol. Soc. Amer. 65: 759-760.

Shepard, M., and W. L. Sterling. 1972b. Effects of early season applications of insecticides on beneficial insects and spiders in cotton. Tex. Agric. Exp. Stn. Misc. Publ. 1045.

Shepard, M., W. L. Sterling, and J. K. Walker Jr. 1972. Abundance of beneficial arthropods on cotton genotypes. Environ. Entomol. 1: 117-121.

Shepherd, R. L. 1982a. Registration of three germplasm lines of cotton. Crop Sci. 22: 692.

Shepherd, R. L. 1982b. Registration of eight germplasm lines of frego-bract cotton. Crop Sci. 22: 696-693.

Shepherd, R. L. 1982c. Registration of eight germplasm lines of nectariless cotton. Crop Sci. 22: 693.

Shepherd, R. L. 1982d. Registration of eight gemplasm lines of smooth-leaf cotton. Crop Sci. 22: 899.

Shepherd, R. L., W. L. Parrott, J. C. McCarty, and J. N. Jenkins. 1986a. Registration of eight okra leaf-frego bract cotton germplasm lines. Crop Sci. 26: 1259-1260.

Shepherd, R. L., J. N. Jenkins, W. L. Parrott, and J. C. McCarty Jr. 1986b. Registration of eight nectariless-frego bract cotton germplasm lines. Crop Sci. 26: 1260.

Shepherd, R. L., and A. J. Kappelman Jr. 1982. Registration of eight germplasm lines of okra-leaf cotton. Crop Sci. 22: 900.

Sherman, F. 1930. Results of airplane dusting in the control of the cotton bollworm (*Heliothis obsoleta* Fabr.). J. Econ. Entomol. 23: 810-813.

Shimke, R. T. 1986. Methotrexate resistance and gene amplification. Cancer 57: 1912-1917.

Shorey, H. H., L. K. Gaston, and R. S. Kaae. 1976. Air-permeation with gossyplure for control of the pink bollworm, pp. 67-74. *In* M. Beroza (ed.), Pest management with insect sex attractants. ACS Symposium Series 23. American Chemical Society, Washington, DC.

Shorey, H. H., and R. L. Hale. 1965. Mass rearing of the larvae of nine noctuid species on a single artificial medium. J. Econ. Entomol. 58: 522-524.

Shour, M. H., and L. A. Crowder. 1980. Effects of pyrethroid insecticides on the common green lacewing. J. Econ. Entomol. 73: 306-309.

Shull, H., and A. S. Dylla. 1976. Wind effects on water application patterns from a large, single nozzle sprinkler. Trans. ASAE 19: 501-523.

Siddall, C., and J. C. Gaines. 1942. Guide for controlling cotton insects. Tex. Agric. Ext. Serv. C-182.

Sieburth, S. McN, S. Y. Lin, J. F. Engle, J. A. Greenblat, S. E. Burkart, and D. W. Gammon. 1990.

Silane analogs of MIT-800: biology and chemistry, pp. 142-150. *In* L. Crombie (ed.), Recent advances in the chemistry of insect control II. Royal Society of Chemistry, Cambridge, U.K.

Sikorowski, P. P. 1984. Pathogens and microbial contaminants: their occurrence and control, pp. 115-169. *In* P. P. Sikorowski, J. G. Griffin, J. L. Roberson, and O. H. Lindig (eds.), Boll weevil mass rearing technology. University Press of Mississippi, Jackson.

Sikorowski, P. P., G. L. Andrews, and J. R. Broome. 1973. Transovum transmission of a cytoplasmic polyhedrosis virus of *Heliothis virescens* (Lepidoptera: Noctuidae). J. Invertebr. Pathol. 21: 41-45.

Sikorowski, P. P., J. M. Wyatt, and O. H. Lindig. 1977. Method of surface sterilization of boll weevil eggs. Southwest. Entomol. 2: 32-36.

Sillings, J. O., and D. B. Broersma. 1974. The parasites of the tarnished plant bug *Lygus lineolaris* in Indiana. Proc. North Cent. Branch Entomol. Soc. Amer. 29: 120-125.

Simmonds, M. S. J., H. C. Evans, and W. M. Blaney. 1992. Pesticides for the year 2000: mycochemicals and botanicals, pp. 127-143. *In* A. A. Kadir, and H. S. Barlow (eds.), Pest management and the environment in 2000. CAB International,.

Simmons, C. L., and P. P. Sikorowski. 1973. A laboratory study of the effects of cytoplasmic polyhedrosis virus on *Heliothis virescens* (Lepidoptera: Noctuidae). J. Invertebr. Pathol. 22: 369-371.

Singh, J., and A. S. Sidhu. 1984. Comparative study of resistance in two American cotton varieties against pink bollworm. J. Res. Punjab Agric. Univ. 21: 211-219.

Singh, P., and R. F. Moore. 1985a. Handbook of insect rearing, Vol. 1. Elsevier, New York.

Singh, P., and R. F. Moore. 1985b. Handbook of insect rearing, Vol. 2. Elsevier, New York.

Skinner, R. B. 1974. The relative and seasonal abundance of spiders from the herb-shrub stratum of cotton fields and the influence of peripheral habitat on spider populations. M.S. Thesis, Auburn Univ.

Slama, K., M. Romanuk, and F. Sorm. 1974. Insect hormones and bioanalogues. Springer-Verlag, New York.

Slater, J. A., and R. M. Baranowski. 1978. How to know the true bugs. William C. Brown Co.,

Slaymaker, P. H., and N. P. Tugwell. 1982. Low-labor method for rearing the tarnished plant bug (Hemiptera: Miridae). J. Econ. Entomol. 75: 487-488.

Slaymaker, P. H., and N. P. Tugwell. 1984. Inexpensive female-baited trap for the tarnished plant bug (Hemiptera: Miridae). J. Econ. Entomol. 77: 1062-1063.

Slosser, J. E. 1978. The influence of planting date on boll weevil management. Southwest. Entomol. 3: 241-349.

Slosser, J. E. 1980. Irrigation timing for bollworm management in cotton. J. Econ. Entomol. 73: 346-349.

Slosser, J. E., and E. P. Boring III. 1980. Shelter belts and boll weevils: a control strategy based on management of overwintering habitat. Environ. Entomol. 9: 1-6.

Slosser, J. E., J. R. Price, and G. L. Puterka. 1989. Evaluation of furrow-diking and early-season insecticide applications on boll weevils (Coleoptera: Curculionidae), bollworms (Lepidoptera: Noctuidae) and cotton yield in the Texas Rolling Plains. J. Econ. Entomol. 82: 599-607.

Slosser, J. E., and T. F. Watson. 1972a. Population growth of the pink bollworm. Ariz. Ag. Exp. Sta. Tech. Bull. 195.

Slosser, J. E., and T. F. Watson. 1972b. Influence of irrigation on overwinter survival of the pink bollworm. Environ. Entomol. 1: 572-576.

Sluss, T. P., and H. M. Graham. 1979. Allozyme variation in natural populations of *Heliothis virescens*. Ann. Entomol. Soc. Amer. 72: 317-322.

Smart, J. R. 1993. Reduced herbicide rates with narrow row cotton, pp. 1514-1516. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Smith, C. W. 1983. Registration of UARK-1 and UARK-2 early maturing cotton germplasms. Crop Sci. 23: 1226-1227.

Smith, C. W. 1984. Combining ability for earliness traits among five diverse cotton genotypes, pp. 98. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Smith, C. W. 1988. Registration of 'Arkot 518' upland cotton. Crop Sci. 28: 190.

Smith, D. B. 1983. Evaluation of broadcast spray deposits. ASAE, St. Joseph, MI, Paper No. 83-1512.

Smith, D. B. 1978. What's new in pesticide application research. *In* Proceedings, Oklahoma Pesticide Applicator's Conference, January 24-25, Oklahoma.

Smith, D. B. 1989. Drift and swath evaluations for three roadside sprayers. Trans. ASAE 32: 1512-1518.

Smith, D. B. 1992. Uniformity and recovery of broadcast sprays using fan nozzles. Trans. ASAE 35: 39-44.

Smith, D. B., and L. F. Bouse. 1981. Machinery and factors that affect the application of pathogens, pp. 635-53. *In* H. D. Burges (ed.), Microbial control of pests and plant diseases 1970-1980. Academic Press, New York.

Smith, D. B., E. C. Burt, and E. P. Lloyd. 1975. Selection of optimum spray-droplet sizes for boll weevil and drift control. J. Econ. Entomol. 68: 415-417.

Smith, D. B., F. D. Harris, and C. E. Goering. 1982a. Variables affecting drift from ground boom sprayers. Trans. ASAE 25: 1499-1503.

Smith, D. B., D. L. Hostetter, R. E. Pinnell, and C. M. Ignoffo. 1982b. Laboratory studies of viral adjuvants: formulation development. J. Econ. Entomol. 75: 16-20.

Smith, D. B., and D. L. Hostetter. 1982. Laboratory and field evaluations of pathogen-adjuvant treatments. J. Econ. Entomol. 75: 472-476.

Smith, D. B., D. L. Hostetter, and C. M. Ignoffo. 1977a. Laboratory performance specifications for a bacterial (*Bacillus thuringensis*) and a viral (*Baculovirus heliothis*) insecticide. J. Econ. Entomol. 70: 437-441.

Smith, D. B., D. L. Hostetter, and C. M. Ignoffo. 1977b. Ground spray equipment for applying *Bacillus thuringiensis* suspension on soybeans. J. Econ. Entomol. 70: 633-637.

Smith, D. B., D. L. Hostetter, and C. M. Ignoffo. 1978. Formulation and equipment effects on application of a viral (*Baculovirus heliothis*) insecticide. J. Econ. Entomol. 71: 814-817.

Smith, D. B., D. L. Hostetter, and C. M. Ignoffo. 1981. Development of a soybean adjuvant for microbial insecticides. ASAE 81-1008.

Smith, D. B., and R. G. Luttrell. 1987. Performance specifications for tobacco budworm (Lepidoptera: Noctuidae) larvae treated with vegetable oil and water sprays containing fluvalinate. J. Econ. Entomol. 80: 1314-1318.

Smith, D. B., W. P. Scott, and E. P. Lloyd. 1973. Selected spray droplet sizes and cotton varieties for bollworm control. J. Econ. Entomol. 66: 260-261.

Smith, D. B., M. H. Willcutt, and T. T. Spencer. 1992. Spreadsheet for aerial atomization and calibration decisions. NAAA-ASAE AA92-003:

Smith, D. B., M. H. Willcutt, D. L. Valcore, J. W. Barry, and M. E. Teske. 1993. Guidelines for aerial atomization and spray drift reduction for Mississippi applicators. MAFES Information Bulletin 251.

Smith, E. H. 1978. Integrated pest management needs-teaching, research and extension, pp. 309-328. *In* E. H. Smith, and D. Pimentel (eds.), Pest Control Strategies. Academic Press, New York.

Smith, G. D. 1921. Studies on the biology of the Mexican cotton boll weevil in short staple upland, long staple upland, and sea island cotton. USDA Bull. 926.

Smith, G. D. 1922. Preliminary report upon an improved method of controlling the boll weevil. Florida State Plant Board. Q. Bull. 7: 1-64.

Smith, G. D. 1924. Further experiments with the Florida method of boll weevil control. Florida State Plant Board. Q. Bull. 8: 27-72.

Smith, G. L. 1936. Percentage and causes of mortality of boll weevil stages within the squares. J. Econ. Entomol. 29: 99-105.

Smith, G. L. 1942. California cotton insects. University of Calif. Agric. Exp. Stn. Bull. 660.

Smith, G. L., and D. E. Bryan. 1949. Recommendations for the control of California cotton insects. University of California, Div. of Entomol. and Parisitology Mimeo.

Smith, G. L., and J. A. Fontenot. 1942. Notes on the effect of arsenicals upon the cotton aphid, predators, and other insects. J. Econ. Entomol. 34: 587.

Smith, H. P. 1964. Transmission of power, pp. 35. *In* Farm machinery and equipment. McGraw-Hill Book Co., New York.

Smith, H. P., and D. L. Jones. 1948. Mechanized production of cotton in Texas. Tex. Agr. Exp. Sta. Bull. 304.

Smith, J. M. 1986. Reproductive and developmental toxicity risk assessment, pp. 414-422. *In* W. Y. Garner, R. C. Honeycutt, and H. N. Nigg (eds.), Evaluation of pesticides in ground water. Symposium Series 315. American Chemical Society, Washington, D.C.

Smith, J. W., and F. A. Harris. 1994. *Anthonomus* (Coleoptera: Curculionidae), pp. 223-258. *In* G. A. Matthews, and J. P. Tunstall (eds.), Insect Pests of Cotton. University Press, Cambridge.

Smith, J. W., and E. A. Stadelbacher. 1978. Predatory arthropods: Seasonal rise and decline of populations in cotton fields in the Mississippi Delta. Environ. Entomol. 7: 367-371.

Smith, J. W., E. A. Stadelbacher, and G. W. Gantt. 1976a. A comparison of techniques for sampling beneficial arthropod populations associated with cotton. Environ. Entomol. 5: 435-444.

Smith, J. W., E. G. King, and J. V. Bell. 1976b. Parasites and pathogens among *Heliothis* species in the central Mississippi delta. Environ. Entomol. 5: 224-226.

Smith, J. W., E. J. Villavaso, and W. L. McGovern. 1989. A large area sterile boll weevil release experiment in western Alabama, pp. 256-258. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Smith, J. W., E. J. Villavaso, W. L. McGovern, and J. R. Brazzel. 1988. Sterile boll weevil releases as part of a boll weevil eradication program, pp. 286-288. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Smith, J. W., G. Wiygul, G. D. Carpenter, and J. R. McCarty. 1993. Mississippi boll weevil management program 1992 - Update, pp. 930-931. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Smith, K. M. 1976. Virus insect relationships. Longman, New York.

Smith, R. C. 1922. The biology of the Chrysopidae. Cornell Univ. Agric. Exp. Stn. Mem. 58: 1287-1372.

Smith, R. F. 1971. Economic aspect of pest control, pp. 21-23. *In* Proc. Tall Timbers Conference on Ecological Animal Control by Habitat Management, No. 3. Tallahassee, Florida.

Smith, R. F. 1978. History and complexity of integrated pest management, pp. 41-53. *In* E. H. Smith, and D. Pimentel (eds.), Pest control strategies. Academic, New York.

Smith, R. F., and H. T. Reynolds. 1965. Principles, definitions and scope of integrated pest control. Proc. of the FAO Symp. on Integrated Pest Control 1: 11-17.

Smith, R. F., and R. van den Bosch. 1967. Integrated control, pp. 295-340. *In* W. W. Kilgore, and R. L. Doutt (eds.), Pest control - biological, physical, and selected chemical methods. Academic Press, New York.

Smith, R. H. 1980. Potential for short-season cotton in the Mid-South, pp. 155-157. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Smith, R. H. 1983. Economic impact of IPM, pp. 231-234. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Smith, R. H. 1990. Fall armyworm control considered - prevention preferred method. Southern Farm Press, Sept.

Smith, R. H., J. D. Harper, and M. J. Gaylor. 1989. Diseases, parasites help control beet armyworms in cotton. Highlights of Agricultural Research 36:(2) 12.

Smith, R. L., and H. M. Flint. 1977. A bibliography of the cotton leaf-perforator and a related species, *Bucculatrix thurberiella* that also feeds on cotton. Entomol. Soc. Amer. Bull. 23: 195-198.

Smith, W. C., and G. A. Niles. 1988. Registration of fourteen cotton germplasms. Crop Sci. 28: 578-579.

Smitley, D. R., and G. G. Kennedy. 1985. Photo-oriented aerial-dispersal behavior of *Tetranychus urticae* (Acarina: Tetranychidae) enhances escape from the leaf surface. Ann. Entomol. Soc. Amer. 78: 609-614.

Smyth Jr., T. 1985. Muscle systems, pp. 227-252. *In* M. S. Blum (ed.), Fundamentals of insect physiology. John Wiley and Sons, New York.

Snipes, L. E., and M. Hammer. 1984. Field crops: acreages, yield, production and value, Georgia, 1978-1983. Georgia Agricultural Facts - 1984 edition. Ga. Crop Reporting Serv., Athens.

Snodgrass, G. L., and J. M. McWilliams. 1992. Rearing the tarnished plant bug (Heteroptera: Miridae) using a tissue paper oviposition site. J. Econ. Entomol. 85: 1162-1166.

Snodgrass, G. L., W. P. Scott, and J. W. Smith. 1984. An annotated list of the host plants of *Lygus lineolaris* (Hemiptera: Miridae) in the Arkansas, Louisiana, and Mississippi Delta. J. Ga. Entomol. Soc. 19: 93-101.

Snodgrass, G. L., W. P. Scott, and J. W. Smith. 1984. Host plants and seasonal distribution of the tarnished plant bug (Hemiptera: Miridae) in the Delta of Arkansas, Louisana, and Mississippi. Environ. Entomol. 13: 110-116.

Snow, J. W. 1964. Seasonal occurrence of *Heliothis virescens* (F.) on cotton in Georgia. J. Econ. Entomol. 57: 787-788.

Snow, J. W. 1965. Bollworm and budworm resistance to DDT. Ga. Agr. Res. 6: 12-13.

Snow, J. W., and J. R. Brazzel. 1965. Investigations of possibility of host specific strains of the bollworm and tobacco budworm in Mississippi. J. Econ. Entomol. 58: 525-526.

Snow, J. W., and J. R. Brazzel. 1965. Seasonal host activity of the bollworm and tobacco budworm during 1963 in northeast Mississippi. Miss. Agric. Exp. Stn. Bull. 712.

Snow, J. W., R. L. Burton, A. N. Sparks, and W. W. Cantelo. 1971. Attempted eradication of the corn earworm from St. Croix, U.S. Virgin Islands. USDA Prod. Res. Rep. 125.

Snow, J. W., W. W. Cantelo, and M. C. Bowman. 1969. Distribution of the corn earworm on St. Croix, U.S. Virgin Islands and its relation to suppression programs. J. Econ. Entomol. 62: 606-611.

Snow, J. W., and W. W. Copeland. 1971. Distribution and abundance of the corn earworm in the United States. USDA Cooperative Economic Insect Report 21: 71-76.

Snow, J. W., J. J. Hamm, and J. R. Brazzel. 1966. *Geranium carolinianum* as an early host for *Heliothis zea* and *H. virescens* (Lepidoptera: Noctuidae) in the southeastern United States, with notes on associated parasites. Ann. Entomol. Soc. Amer. 59: 506-509.

Snow, J. W., R. L. Jones, D. T. North, and G. G. Holt. 1972. Effects of irradiation on ability of adult male corn earworms to transfer sperm, and field attractiveness of females mated to irradiated males. J. Econ. Entomol. 65: 906-908.

Soderlund, D. A., and J. R. Bloomquist. 1988. Neurotoxic actions of pyrethroid insecticides. Annu. Rev. Entomol. 34: 77-96.

Soderlund, D. A., C. W. Hessney, and M. Jiang. 1987. Metabolism of fenvalerate by resistant Colorado potato beetles. J. Agric. Food Chem. 35: 100-105.

Soderlund, D. A., J. R. Sanborn, and P. W. Lee. 1983. Metabolism of pyrethrins and pyrethroids in insects, pp. 401-435. *In* D. H. Hutson, and T. R. Roberts (eds.), Progress in pesticide biochemistry and toxicology, vol. 3. John Wiley and Sons, New York.

Solomon, M. E. 1949. The natural control of animal populations. J. Anim. Ecol. 18: 1-35.

Solway, S. B., A. C. Henry, W. D. Kollmeyer, W. M. Padgatt, J. E. Powell, S. A. Roman, C. H. Tieman, R. A. Corey, and C. A. Horne. 1979. Nitromethylene insecticides, pp. 206-217. *In* H. Geissbuhler (ed.), Advances in pesticide science, Part 2, Fourth International Congress of Pesticide Chemistry, Zurich, 1978. Pergamon, New York.

Southwick, L. M., D. J. Boethel, G. H. Willis, D. C. Rester, J. Yanes Jr., N. N. Troxclair Jr., and A. N. Sparks Jr. 1986. Deposits and persistence of permethrin ulv and ec applications on soybean leaves. J. Econ. Entomol. 79: 202-207.

Southwood, T. R. E. 1962. Migration of terrestrial arthropods in relation to habitat. Biol. Rev. 37: 171-214.

Southwood, T. R. E. 1978. Ecological methods: with particular reference to the study of insect populations. John Wiley, New York.

Southwood, T. R. E., and G. A. Norton. 1973. Economic aspects of pest management strategies and decisions, pp. 168-184. *In* P. W. Geier, L. R. Clark, D. J. Anderson, and H. A. Nix (eds.), Insects: studies in population management. Ecol. Soc. Australia, Mem., Canberra.

Sparks, A. N. 1972. *Heliothis* migration, pp. 15-17. *In* Distribution abundance and control of *Heliothis* species in cotton and other host plants. S. Coop. Ser. Bull. 169.

Sparks, A. N. 1979. A review of the biology of the fall armyworm. Fla. Entomol. 62: 82-87.

Sparks, A. N., J. E. Carpenter, J. A. Klun, and B. G. Mullinix. 1979a. Field responses of male *Heliothis zea* (Boddie) to pheromonal stimuli and trap design. J. Ga. Entomol. Soc. 14: 318-325.

Sparks, A. N., J. R. Raulston, P. D. Lingren, J. E. Carpenter, J. A. Klun, and B. G. Mullinix. 1979b. Field response of male *Heliothis virescens* to pheromonal stimuli and traps. Bull. Entomol. Soc. Amer. 25: 268-274.

Sparks, A. N., and E. A. Harrell. 1976. Corn earworm mechanization. USDA, Tech. Bulletin 1554.

Sparks, A. N., R. D. Jackson, and C. L. Allen. 1975. Corn earworms: capture of adults in light traps on unmanned oil platforms in the Gulf of Mexico. J. Econ. Entomol. 68: 431-432.

Sparks, A. N., J. A. Klun, J. R. Raulston, P. E. A. Teal, and J. E. Carpenter. 1988. *Heliothis* pheromones: chemistry and potential for use as mating disruptors/attracticides, pp. 50-65. *In* G. A. Herzog, S. Ramaswamy, G. Lentz, J. L. Goodenough, and J. J. Hamm (eds.), Theory and tactics of *Heliothis* population management. III - emerging control tactics and techniques. Southern Coop. Ser. Bull. 337

Sparks, T. C. 1981. Development of insecticide resistance in *Heliothis zea* and *Heliothis virescens* in North America. Bull. Entomol. Soc. Amer. 27: 186-192.

Sparks, T. C. 1990. Endocrine based insecticides, pp. 103-154. *In* E. Hodgson, and R. J. Kuhr (eds.), Safer insecticides: Development and use. Marcel Dekker, Inc., New York.

Sparks, T. C., J. B. Graves, and B. R. Leonard. 1993a. Insecticide resistance and the tobacco budworm: Past present and future, pp. 149-183. *In* R. M. Roe, and R. J. Kuhr (eds.), Reviews in pesticide toxicology, vol. 2.. Toxicology Communications, Inc., Raleigh, NC.

Sparks, T. C., B. R. Leonard, F. Schneider, and J. B. Graves. 1993b. Ovicidal activity and alteration of octopamine titers: the effects of selected insecticides on eggs of the tobacco budworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 86: 294-300.

Sparks, T. C., and B. B. Hammock. 1983. Insect growth regulators: resistance and the future, pp. 615-668. *In* G. P. Georghiou, and T. Saito (eds.), Pest resistance to pesticides. Plenum Press, New York.

Sparks, T. C., B. R. Leonard, and J. B. Graves. 1988. Pyrethroid resistance and the tobacco budworm: interactions with chlordimeform and mechanisms of resistance, pp. 366-370. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Sparks, T. C., B. R. Leonard, and J. B. Graves. 1991. Pyrethroid-formamidine interactions and behavioral effects in pyrethroid susceptible and resistant tobacco budworms. Southwest. Entomol. Suppl. No. 15 111-119.

Sparks, T. C., J. A. Lockwood, R. L. Byford, J. B. Graves, and B. R. Leonard. 1989. The role of behavior in insecticide resistance. Pestic. Sci. 26: 383-399.

Sparks, T. C., A. M. Pavloff, R. L. Rose, and D. F. Clower. 1983. Temperature -toxicity relationships of pyrethroids on *Heliothis virescens* (F.) and *Anthonomus grandis grandis* Boheman. J. Econ. Entomol. 76: 243-246.

Sparks, T. C., S. S. Quisenberry, J. A. Lockwood, R. L. Byford, and R. T. Roush. 1985. Insecticide resistance in the horn fly, *Haematobia irritans*. J. Agric. Entomol. 2: 217-233.

Sparks, T. C., M. H. Shour, and E. G. Wellemeyer. 1982. Temperature-toxicity relationships of pyrethroids on three Lepidopterans. J. Econ. Entomol. 75: 643-646.

Spears, T. F. 1968. The westward movement of the pink bollworm. Bull. Entomol. Soc. Amer. 14: 118-119.

Spencer, C. B. 1953. Cooperative program for pink bollworm control in Texas 1952, pp. 54-56. *In* Proc. Seventh Beltwide Cotton Prod. and Cotton Insect Control Conf.

Splinter, W. E. 1968. Electrostatic charging of agricultural sprays. Trans. ASAE 11: 491-495.

Sprenkel, R. K., and W. M. Brooks. 1977. Winter survival of the entomogenous fungus *Nomuraea rileyi* in North Carolina. J. Invertebr. Pathol. 29: 262-266.

Sprott, J. M., R. D. Lacewell, G. A. Niles, J. K. Walker, and J. R. Gannaway. 1976. Agronomic, economic and environmental implications of short season narrow row cotton production. Texas Agric. Exp. Stn. MP-1250.

Spurlock, S. R., and D. W. Parvin. 1988. A simulation model for cotton harvesting decisions. Staff Paper No. 84, Dept. Agric. Econ., Mississippi State University

Staal, G. B. 1975. Insect growth regulators with juvenile hormone activity. Annu. Rev. Entomol. 20: 417-460.

Staal, G. B. 1986. Anti-juvenile hormone agents. Annu. Rev. Entomol. 31: 391-429.

Stadelbacher, E. A. 1979. *Geranium dissectum*: an unreported host of the tobacco budworm and bollworm and its role in their seasonal and long term population dynamics in the Delta of Mississippi. Environ. Entomol. 8: 1153-1156.

Stadelbacher, E. A. 1985. Management of first generation bollworm and tobacco budworm populations on wild host plants, pp. 150-153. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Stadelbacher, E. A., J. R. Adams, R. M. Faust, and G. J. Tomkins. 1978. An iridescent virus of the bollworm, *Heliothis zea* (Lepidoptera: Noctuidae). J. Invertebr. Pathol. 32: 71-76.

Stadelbacher, E. A., and T. R. Pfrimmer. 1972. Winter survival of the bollworm at Stoneville, Mississippi. J. Econ. Entomol. 65: 1030-1034.

Stadelbacher, E. A., J. E. Powell, and E. G. King. 1984. Parasitism of *Heliothis zea* and *H. virescens* (Lepidoptera: Noctuidae) larvae in wild and cultivated host plants in the delta of Mississippi. Environ. Entomol. 13: 1167-1172.

Staety, C. A. 1985. Susceptibility of *Heliothis virescens* (F.) (Lepidoptera: Noctuidae) to permethrin from across the cotton belt: a five year study. J. Econ. Entomol. 78: 505-510.

Staetz, C. A. 1985. Susceptibility of *Heliothis virescens* (F.) (Lepidopera: Noctuidae) to permethrin from across the cotton belt: a five year study. J. Econ. Entomol. 78: 505-510.

Staetz, C. A. 1992. IRAC-Cotton-U.S. update of current projects and future plans, pp. 754-756. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Staetz, C. A., K. A. Boyler, E. E. Gage, D. G. Riley, and D. A. Wolfenbarger. 1992. Vial bioassay for contact insecticides for adult whiteflies, *Bemisia tabaci*, pp. 704-707. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Stamps, M. R. 1981. Coax insect feeding stimulant: a new approach to budworm/bollworm control, pp. 86. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Star, J., and J. Estes. 1990. Geographic information systems. Prentice Hall, Englewood Cliffs, NJ.

Starbird, I. R. 1974. Costs of producing upland cotton (selected years). U.S. Dept. Agr., CS-265.

Starbird, I. R., E. H. Glade Jr., W. C. McArthur, F. T. Cooke Jr., and T. Townsend. 1987. The U.S. cotton industry. USDA, Econ. Res. Serv., AER-567.

Stark, S. B., and K. R. Hopper. 1988. *Chrysoperla carnea* predation on *Heliothis virescens* larvae parasitized by *Microplitis croceipes*. Entomol. Exp. Appl. 48: 69-72.

Stark, S. B., and F. Whitford. 1987. Functional response of *Chrysopa carnea* (Neuroptera: Chrysopidae) larvae feeding on *Heliothis virescens* (Lepidoptera: Noctuidae) eggs on cotton in field cages. Entomophaga 32: 521-527.

Staten, R. T. 1987. Progress report: Coachella Valley management trial, pp. 18-21. *In* Report of the international cotton pest work committee San Diego.

Staten, R. T. 1987. The 1986 Coachella pink bollworm pheromone management project, pp. 17-20. *In* Cotton insect and production meeting, 1987, El Centro, California.

Staten, R. T., H. M. Flint, R. C. Weddle, E. Quintero, R. E. Zarate, C. M. Finnell, M. Hernandes, and A. Yamamoto. 1987. Pink bollworm (Lepidoptera: Gelechiidae): large-scale field trials with a high-rate gossyplure formulation. J. Econ. Entomol. 80: 1267-1271.

Staten, R. T., E. Miller, M. Grunnet, F. Gardner, and E. Andress. 1988. The use of pheromones for pink bollworm management in western cotton, pp. 206-209. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Steiner, W. W. M., and D. A. Teig. 1989. *Microplitis croceipes* (Cresson): genetic characterization and developing insecticide resistant biotypes, pp. 71-87. *In* J. E. Powell, D. L. Bull, and E. G. King (Eds.), Biological control of *Heliothis* spp. by *Microplitis croceipes*. Southwest. Entomol. Suppl. 12.

Steinkraus, D. C., T. J. Kring, and N. P. Tugwell. 1991. *Neozygites fresenii* in *Aphis gossypii* on cotton. Southwest. Entomol. 16: 118-122.

Sterling, W. L. 1971. Winter survival of the boll weevil in the High and Rolling Plains of Texas. J. Econ. Entomol. 64: 39-41.

Sterling, W. L. 1978. Fortuitous biological suppression of the boll weevil by the red imported fire ant. Environ. Entomol. 7: 564-568.

Sterling, W. L. (ed.). 1979. Economic thresholds and sampling of *Heliothis* species on cotton, corn, soybeans, and other host plants. S. Coop. Ser. Bull. 231.

Sterling, W. L. 1984. Action and inaction levels in pest management. Texas Agric. Exp. Stn. Bull. B-1480.

Sterling, W. L., and P. L. Adkisson. 1970. Seasonal rates of increase for a population of the boll weevil, *Anthonomus grandis*, in the High and Rolling Plains of Texas. Ann. Entomol. Soc. Amer. 63: 1696-1700.

Sterling, W. L., and P. L. Adkisson. 1971. Seasonal biology of the boll weevil in the High and Rolling Plains of Texas as compared with previous biological studies of this insect. Texas Ag. Exp. Stn., MP-993.

Sterling, W. L., and P. L. Adkisson. 1978. Population dynamics of the boll weevil inhabiting the High and Rolling Plains of Texas. Environ. Entomol. 7: 439-444.

Sterling, W. L., and D. A. Dean. 1990. Evidence of the need for improving the mortality component of boll weevil models. Texas Agric. Exp. Stn., Tech. Rept., DTR 89-02.

Sterling, W. L., D. A. Dean, and N. M. A. El-Salam. 1992. Economic benefits of spider (Araneae) and insect (Hemiptera: Miridae) predators of cotton fleahopper. J. Econ. Entomol. 85: 52-57.

Sterling, W. L., D. A. Dean, D. A. Fillman, and D. Jones. 1984. Naturally occurring biological control of the boll weevil (Col.: Curculionidae). Entomophaga 29: 1-9.

Sterling, W. L., D. A. Dean, and A. W. Hartstack. 1990a. Partitioning boll weevil mortality associated with high temperature: desiccation or thermal death? Environ. Entomol. 19: 1457-1462.

Sterling, W. L., A. W. Hartstack, and D. A. Dean. 1990b. TEXCIM40: testing and use on the farm, pp. 241-244. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Sterling, W. L., D. A. Dean, A. W. Hartstack, S. Shahed, and R. Burudgunte. 1993. The Texas cotton-insect-model-TEXCIM for Windows. Tex. Agric. Exp. Stn. Misc. Publ. MP-1646, Revised.

Sterling, W. L., K. M. El-Zik, and L. T. Wilson. 1989. Biological control of pest populations, pp. 155-189. *In* R. E. Frisbie, K. M. El-Zik, and L. T. Wilson (eds.), Integrated Pest Management Systems and Cotton Production. John Wiley and Sons, New York.

Sterling, W. L., G. C. Gaumer, J. Haffernik, and D. A. Dean. 1978. A checklist of insects found on cotton in East Texas. Tex. Agric. Exp. Stn. Misc. Pub. MP-1366.

Sterling, W. L., and R. L. Haney. 1973. Cotton yields climb, costs drop through pest management systems. Texas Agr. Prog. 19: 4-7.

Sterling, W. L., and A. W. Hartstack. 1979. Emergence threshold with validations for forecasting the spring emergence of cotton fleahoppers. Environ. Entomol. 8: 649-654.

Sterling, W. L., and A. W. Hartstack. 1987. TEXCIM - a fleahopper-*Heliothis*-plant model for on farm use, pp. 258-259. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Sterling, W. L., A. W. Hartstack, and D. A. Dean. 1989a. TEXCIM: synthesis and hypothesis. Texas Agric. Exp. Stn., Dept. Entomol. Tech. Rept. DTR 89-01.

Sterling, W. L., A. W. Hartstack, and D. A. Dean. 1989b. Conventions and protocol for testing and using the TEXCIM management model. Texas Agric. Exp. Stn., Tech. Rept. DTR 89-03.

Sterling, W. L., D. Jones, and D. A. Dean. 1979. Failure of the red imported fire ant to reduce entomophagous insect and spider abundance in a cotton agroecosystem. Environ. Entomol. 8: 976-981.

Sterling, W. L., A. W. Hartstack, and D. A. Dean. 1992. The Texas cotton-insect model-TEXCIM version 5.0. Texas Agric. Exp. Stn. Misc. Publ. MP-1646, (Revised).

Stern, V., and V. Sevacherian. 1978. Long-range dispersal of pink bollworm into the San Joaquin Valley. California Agriculture 32: 4-5.

Stern, V. M. 1966. Significance of the economic threshold in integrated pest control. Proc. FAO Symp. Integrated Pest Control 2: 41-56.

Stern, V. M. 1969. Interplanting alfalfa in cotton to control *Lygus* bugs and other insect pests. Proc. Tall Timbers Conf. on Ecol. Animal Control by Habitat Mgmt. Number I.

Stern, V. M. 1973. Economic thresholds. Annu. Rev. Entomol. 18: 259-280.

Stern, V. M. 1976. Ecological studies of lygus bugs in developing a pest management program for cotton pests in the San Joaquin Valley, California, pp. 38. *In* D. R. Scott, and L. E. O'Keefe (eds.), Lygus bug: host plant interactions. Univ. Idaho Press., Moscow.

Stern, V. M. 1979. Long and short range dispersal of the pink bollworm, *Pectinophora gossypiella*, in southern California. Environ. Entomol. 8: 524-527.

Stern, V. M., A. Mueller, V. Sevacherian, and M. Way. 1969. Lygus bug control in cotton through alfalfa interplanting. Calif. Agric. 23: 8-10.

Stern, V. M., R. F. Smith, R. van den Bosch, and K. S. Hagen. 1959. The integrated control concept. Hilgardia 29: 81-101.

Stern, V. M., R. van den Bosch, and T. F. Leigh. 1964. Strip cutting alfalfa for lygus bug control. Calif. Agric. 18: 4-6.

Stern, V. M., R. van den Bosch, T. F. Leigh, O. D. McCutcheon, W. R. Sallee, E. E. Houston, and M. J. Garber. 1967. *Lygus* control by strip cutting alfalfa. Univ. Calif. Agric. Ext. Serv. AXT-241.

Stevenson, A. B., and M. D. Roberts. 1973. Tarnished plant bug rearing on lettuce. J. Econ. Entomol. 66: 1354-1355.

Stewart, F. D. 1984. Mass rearing the pink bollworm, *Pectinophora gossypiella*, pp. 176-187. *In* E. G. King, and N. C. Leppla (eds.), Advances and challenges in insect rearing. USDA, Agric. Res. Serv., Washington D.C.

Stewart, S. D. 1987. Impact of insects and physical stress on cotton fruit abscission, retention, compensation and economic value. MS Thesis, Texas A&M University, College Station, Texas.

Stewart, S. D., and W. L. Sterling. 1987. Economic value of fruit based on size and time of season, pp. 256-258. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Still, G. G., and R. A. Leopold. 1978. The elimination of (*N*-[[(4-chlorophenyl)amino]carbonyl]2,6-diflurorbenamide0 by the boll weevil. Pestic. Biochem. Physiol. 9: 304-312.

Stillings, N. A., M. A. Feinstein, J. L. Garfield, E. L. Rissland, D. A. Rosenbaum, S. E. Weisler, and L. Baker-Ward. 1987. Cognitive science: an introduction. MIT Press, Cambridge.

Stimmann, M. 1986. Handbook of pesticide use, recommendation, and experimentation, 1986-1987. A supplement to policy. Communication 18. Univ. of Calif. Div. of Agric. & Nat. Resources.

Stinner, R. E. 1977. Efficacy of innundative releases. Annu. Rev. Entomol. 22: 515-531.

Stinner, R. E., G. D. Butler Jr., J. S. Bacheler, and C. Tuttle. 1975. Simulation of temperature-dependent development in population dynamics models. Can. Entomol 107: 1167-1174.

Stinner, R. E., R. L. Rabb, and J. R. Bradley. 1974a. Population dynamics of *Heliothis zea* (Boddie) and *H. virescens* (F.) in North Carolina: a simulation model. Environ. Entomol. 3: 163-168.

Stinner, R. E., A. P. Gutierrez, and G. D. Butler Jr. 1974b. An algorithm for temperature-dependent growth rate simulation. Can. Entomol. 106: 519-524.

Stinner, R. E., R. L. Rabb, and J. R. Bradley. 1977a. Population mortality and cyclicity as affected by intraspecific competition. Can. Entomol. 109: 879-890.

Stinner, R. E., R. L. Rabb, and J. R. Bradley. 1977b. Natural factors operating in the population dynamics of *Heliothis zea* in North Carolina, pp. 622-642. *In* Proc. XV Internl. Congr. Entomol., Washington, DC.

Stinner, R. E., R. L. Ridgway, J. R. Coppedge, R. K. Morrison, and W. A. Dickerson Jr. 1974. Parasitism of *Heliothis* eggs after field releases of *Trichogramma pretiosum* in cotton. Environ. Entomol. 3: 497-500.

Stinner, R. E., K. Wilson, C. Barfield, F. Regniere, A. Riordan, and J. Davis. 1982. Insect movement in the atmosphere, pp. 491. *In* J. L. Hatfield, and I. J. Thomason (eds.), Biometeorology in integrated pest management. Academic Press, New York.

Stitt, L. L. 1949. Host plant sources of *Lygus* species infesting the alfalfa seed crop in southern Arizona and southwestern California. J. Econ. Entomol. 42: 93-99.

Stokes, L. G., and W. P. Sappenfield. 1981. Registration of BW76-31 cotton germplasm. Crop Sci. 21: 991.

Stoll, J. 1987. Southwest Oklahoma pest management program. Annual Report. Okla. Coop. Ext. Ser. Circular E-844.

Stoltz, D. B., P. Knell, M. D. Summers, and S. B. Vinson. 1984. Polydnaviridae - a proposed family of insect viruses with segmented, double-stranded, circular DNA genomes. Intervirology 21: 1-4.

Stoltz, D. B., and S. B. Vinson. 1979. Viruses and parasitism in insects. Adv. Virus Res. 24: 125-171.

Stoltz, R. L., and V. M. Stern. 1978. Cotton arthopod food chain disruption by pesticides in the San Joaquin Valley, California. Environ. Entomol. 7: 703-707.

Stone, N. D. 1989. Knowledge-based systems as a unifying perspective for IPM, pp. 13-23. *In* Proc. Nat. IPM Symposium/Workshop, April 25-28, Las Vegas, Nevada.

Stone, N. D., R. E. Frisbie, J. W. Richardson, and C. Sansone. 1987. COTFLEX, a modular expert system that synthesizes biological and economic analysis: the pest management advisor as an example, pp. 194-197. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Stone, N. D., and A. P. Gutierrez. 1986a. Pink bollworm control in Southwestern desert cotton. I. A field-oriented simulation model. Hilgardia 54: 1-24.

Stone, N. D., and A. P. Gutierrez. 1986b. Pink bollworm control in Southwestern desert cotton. II. A strategic management model. Hilgardia 54: 25-41.

Stone, N. D., A. P. Gutierrez, W. M. Getz, and R. Norgaard. 1986. Pink bollworm control in Southwestern desert cotton. III. Strategies for control: an economic simulation study. Hilgardia 54: 42-56.

Stone, N. D., D. R. Rummel, S. Carroll, M. E. Makela, and R. E. Frisbie. 1990. Simulation of boll weevil (Coleoptera: Curculionidae) spring emergence and overwintering survival in the Texas rolling plains. Environ. Entomol. 19: 91-98.

Stone, N. D., and T. W. Toman. 1989. COTFLEX: an integrated expert and database system for decision support in Texas cotton production, *In* Proc. AAAI/ASAE Workshop: Integration of Expert Systems with Conventional Problem Solving Techniques in Agriculture, August 10-12, San Antonio, TX.

Stoner, A. 1970. Plant feeding by a predaceous insect, *Geocoris punctipes*. J. Econ. Entomol. 63: 286-298.

Strand, M. R., and S. B. Vinson. 1982. Behavioral response of the parasitoid Cardiochiles nigriceps to a kairomone. Entomol. Exp. Appl. 31: 308-315.

Strand, M. R., and S. B. Vinson. 1982. Stimulation of oviposition and successful rearing of *Telenomus heliothidis* (Hymenoptera: Scelionidae) on nonhosts by use of a host recognition kairomone. Entomophaga 27: 365-370.

Strand, M. R., and S. B. Vinson. 1983. Analyses of an egg recognition kairomone of *Telenomus heliothidis* (Hymenoptera: Scelionidae). Isolation and host function. J. Chem. Ecol. 9: 423-432.

Streams, F. A., M. Shahjahan, and H. G. LeMasurier. 1968. Influence of plants on the parasitization of the tarnished plant bug by *Leiophron pallipes*. J. Econ. Entomol. 61: 996-999.

Strickberger, M. W. 1968. Genetics. MacMillan, New York.

Stride, G. O. 1968. On the biology and ecology of Lygus *vosseleri* (Heteroptera: Miridae) with special reference to its host plant relationships. J. Entomol. Soc. South Africa 31: 17-59.

Stringer, S. J., and J. E. Jones. 1987. Genetic analysis of *Heliothis* spp. resistance and flower bud gossypol in advanced La. cottons, pp. 97. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Stringer, S. J., J. E. Jones, D. F. Clower, E. Burris, and S. Micinski. 1983. An evaluation of cotton germplasm for field resistance to *Heliothis* species, pp. 70. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Strong, F. E. 1968. The selective advantage accruing to lygus bugs that cause blasting of floral parts. J. Econ. Entomol. 61: 315-316.

Strong, F. E. 1971. A computer-generated model to simulate mating behavior of lygus bugs. J. Econ. Entomol. 64: 46-50.

Strunnikov, V. A. 1979. On the prospects of using balanced sex-linked lethals for insect pest control. Theor. Appl. Genet. 55: 17-21.

Sturm, M. M. 1989. Natural mortality of the boll weevil (Coleoptera: Curculionidae) within cotton squares. M.S. Thesis, Texas A&M University, College Station.

Sturm, M. M., and W. L. Sterling. 1986. Boll weevil (Coleoptera: Curculionidae) mortality factors within flower buds of cotton: assessment using durable evidence. Bull. Entomol. Soc. Amer. 32: 239-247.

Sturm, M. M., and W. L. Sterling. 1990. Geographical patterns of boll weevil mortality: observations and hypothesis. Environ. Entomol. 19: 59-65.

Sturm, M. M., W. L. Sterling, and D. A. Dean. 1989. Life tables and key mortality factors of boll weevils in Texas. Texas Agric. Exp. Stn. MP-1675.

Sturm, M. M., W. L. Sterling, and A. W. Hartstack. 1990. Role of natural mortality and boll weevil (Coleoptera: Curculionidae) management programs. J. Econ. Entomol. 83: 1-7.

Suguiyama, L., and C. Osteen. 1988. The economic importance of cotton insect pests on U.S. agriculture. USDA, Econ. Res. Serv. (unpublished manuscript).

Suguiyama, L. F., and G. A. Carlson. 1985. Field crop pests: farmers report the severity and intensity. USDA, Econ. Res. Serv., AIB-487.

Summer, D. D., and J. T. Stevens. 1986. Safety evaluation of pesticides in ground water, pp. 436-444. *In* W. Y. Garner, R. C. Honeycutt, and H. N. Nigg (eds.), Evaluation of pesticides in ground water, Symposium Series 315. American Chemical Society, Washington, D.C.

Summy, K. R. 1991. Late season parasitism of boll weevil in the Lower Rio Grande Valley of Texas, pp. 720-722. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Summy, K. R., J. R. Cate, and W. G. Hart. 1988. Overwintering strategies of boll weevil in southern Texas: reproduction on cultivated cotton. Southwest. Entomol. 13: 159-164.

Summy, K. R., W. G. Hart, and J. R. Cate. 1984. Aerial surveillance for regrowth cotton in the Lower Rio Grande Valley of Texas, pp. 191. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Summy, K. R., W. G. Hart, J. R. Cate, and D. Bar. 1985. Research on areawide cotton stalk destruction for cultural control of boll weevil in the Lower Rio Grande Valley, pp. 145. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Summy, K. R., M. D. Heilman, L. N. Namken, and W. G. Hart. 1986a. Control of boll weevils (Coleoptera: Curculionidae) through crop residue disposal: destruction of subtropical cotton under inclement conditions. J. Econ. Entomol. 79: 1662-1665.

Summy, K. R., W. G. Hart, M. D. Heilman, and J. R. Cate. 1986b. Late-season boll weevil control: combined impact of stalk shredding and lethal soil temperatures, pp. 233-235. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Summy, K. R., J. A. Morales-Ramos, E. G. King, D. A. Wolfenbarger, R. J. Coleman, S. Greenberg, A. W. Scott Jr., and J. V. French. 1994. Integration of boll weevil parasite augmentation into the short-season production system of the Lower Rio Grande Valley, pp. 953-957. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Summy, K. R., J. A. Morales-Ramos, E. G. King, and A.W. Scott. 1993. Suppression of boll weevil infestations by augmentative releases of *Catolaccus grandis*, pp. 908-909. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Sun, Y. P., and E. R. Johnson. 1972. Quasi-synergism and penetration of insecticides. J. Econ. Entomol. 65: 349-353.

Suski, Z. W., and J. A. Naegele. 1966. Light response in the two-spotted spider mites. II. Behavior of the sedentary and dispersal phases. Recent Adv. Acarol. Cornell Press, Ithaca, New York.

Sweet, M. H. 1960. The seed bugs: a contribution to the feeding habits of the Lygaeidae (Hemiptera: Heteroptera). Ann. Entomol. Soc. Amer. 53: 317-321.

Swift, J. E. 1958. Factors influencing the distribution and seasonal abundance of *Aphis gossypii* in California. Ph.D. Dissertation, University of California, Berkeley.

Swift, J. E. 1969. Unexpected effects from subsitute pest control methods. Symp. biological impact of pesticides in the environment, Aug. 18-20. Oregon State Univ., Corvallis, Oregon.

Swoboda, M. 1953. Cotton insect control guide for New Mexico-1953. NM A&M Col. Agric. Ext. Ser. Circ. 227.

Szczepanski, C. V. 1990. Today's research for tomorrow's markets or: How to hit a moving target, pp. 1-16. *In* L. Crombie (ed.), Recent Advances in the Chemistry of Insect Control II. Royal Society of Chemistry, London.

Szeicz, F. M., F. W. Plapp Jr., and S. B. Vinson. 1973. Tobacco budworm: penetration of several insecticides into larvae. J. Econ. Entomol. 66: 9-15.

Szmedra, P. I., R. W. McClendon, and M. E. Wetzstein. 1991. Economic risk efficiency of boll weevil eradication. S. J. Agric. Econ. 23: 237-245.

Tabashnik, B. E. 1986. Computer simulation as a tool for pesticide resistance management, pp. 194-206. *In* Pesticide resistance: strategies and tactics for management. National Academy of Sciences, Washington, D.C.

Tabashnik, B. E. 1991. Determining the mode of inheritance of pesticide resistance with backcross experiments. J. Econ. Entomol. 84: 703-712.

Tabashnik, B. E. 1992. Resistance risk assessment: realized heritability of resistance to *Bacillus thuringiensis* in diamondback moth (Lepidoptera: Plutellidae), tobacco budworm (Lepidoptera: Noctuidae) and Colorado potato beetle (Coleoptera: Chyrsomelidae). J. Econ. Entomol. 85: 1551-1559.

Tabashnik, B. E., N. L. Cushing, N. Finson, and M. W. Johnson. 1990. Field development of resistance to *Bacillus thuringiensis* in diamondback moth (Lepidoptera: plutellidae). J. Econ. Entomol. 83: 1671-1676.

Tabashnik, B. E., N. Finson, and M. W. Johnson. 1991. Managing resistance to *Bacillus thuringiensis*: Lessons from diamondback moth (Lepidoptera: plutellidae). J. Econ. Entomol. 84: 49-55.

Tabashnik, B. E., and F. Slansky Jr. 1987. Nutritional ecology of forb foliage-chewing insects, pp. 71-103. *In* F. Slansky Jr., and J. G. Rodriguez (eds.), Nutritional ecology of insects, mites, spiders, and related invertebrates. John Wiley & Sons, New York.

Taft, H. M., and A. R. Hopkins. 1963. A community effort in boll weevil control. USDA-ARS-33-82.

Taft, H. M., and A. R. Hopkins. 1967. Control of cotton pests with low-volume insecticides applied with a low-volume mist sprayer. J. Econ. Entomol. 60: 608-610.

Taft, H. M., A. R. Hopkins, and W. James. 1963. Differences in reproductive potential, feeding rate, and longevity of boll weevils mated in the fall and in the spring. J. Econ. Entomol. 56: 180-181.

Taft, H. M., A. R. Hopkins, W. James, and R. F. Moore Jr. 1973. Boll weevils: time of entry into hibernation sites and variations in survivial and emergence. J. Econ. Entomol. 66: 254-256.

Taft, H. M., A. R. Hopkins, C. E. Jernigan, and J. C. Webb. 1969. A new 8-row ground sprayer with auxiliary air for ULV application of pesticides to cotton. J. Econ. Entomol. 62: 570-574.

Taft, H. M., and C. E. Jernigan. 1964. Elevated screens for collecting boll weevils flying between hibernation sites and cottonfields. J. Econ. Entomol. 57: 773-774.

Taksdal, F. 1961. Ecology of plant resistance to the tarnished plant bug, *Lygus lineolaris* (P. de B.). M.S. Thesis, Cornell Univ., Ithaca.

Talpaz, H., G. L. Curry, P. J. H. Sharpe, D. W. DeMichele, and R. E. Frisbie. 1978. Optimal pesticide application for controlling the boll weevil on cotton. Am. J. Agric. Econ. 60: 469-475.

Tamaki, G., D. P. Olsen, and R. K. Gupta. 1978. Laboratory evaluation of *Geocoris bullatus* and *Nabis alternatus* as predators of *Lygus*. J. Entomol. Soc. Brit. Columbia 75: 35-37.

Tamaki, G., and R. E. Weeks. 1972. Biology and ecology of two predators, *Geocoris punctipes* (Say) and *G. bullatus* (Stal.). U.S. Dept. Agric. Bull. 1446.

Tanabe, A. M., and M. Tamashiro. 1967. The biology and pathogenicity of a microsporidian (*Nosema trichoplusiae* sp. n.) of the cabbage looper, *Trichoplusia ni* (Hubner) (Lepidoptera: Noctuidae). J. Invertebr. Pathol. 9: 188-195.

Tauber, C. A. 1974. Systematics of North American chrysopid larvae: *Chrysopa carnea* group (Neuroptera). Can. Entomol. 106: 1133-1153.

Tauber, M. J., and C. A. Tauber. 1983. Life history traits of *Chrysopa carnea* and *Chrysopa rufilabris* (Neuroptera: Chrysopidae): influence of humidity. Ann. Entomol. Soc. Amer. 76: 282-285.

Taylor, B. B. 1971. Suggestions on how to grow narrow-row, high-population cotton in 1971. Ariz. Agri-file Coop. Ext. Serv. Field Crops 300.0.

Taylor, C. R. 1980. The nature of benefits and costs of use of pest control methods. Amer. J. Agri. Econ. 62: 1007-1011.

Taylor, C. R., G. A. Carlson, F. T. Cooke, K. H. Reichelderfer, and I. R. Starbird. 1983. Aggregate economic effects of alternative boll weevil management strategies. Agricultural Economics Research 35: 19-28.

Taylor, C. R., and R. D. Lacewell. 1977. Boll weevil control strategies: regional benefits and costs. J. Agr. Econ. 9: 129-135.

Taylor, R. A. J. 1985. Migration behavior in the Auchenorrhyncha, pp. 259-288. *In* L. R. Nault, and J. G. Rodrigues (eds.), The leafhoppers and planthoppers. John Wiley and Son, New York.

Taylor, R. N. 1982. Insecticide resistance in house flies from the Middle East and North Africa with notes on the use of various bioassay techniques. Pestic. Sci. 13: 415-425.

Teague, T. G., J. R. Cate, and F. W. Plapp. 1983. Toxicity of azinphosmethyl and methyl parathion to three populations of boll weevil. Southwest. Entomol. 8: 107-112.

Teakle, R. E., and J. M. Jensen. 1985. *Heliothis punctiger*, pp. 313-322. *In* P. Singh, and R. F. Moore (eds.), Handbook of Insect Rearing, Vol. 2 Elsevier, New York.

Teal, P. E. A., J. R. McLaughlin, and J. H. Tumlinson. 1981. Analysis of the reproductive behavior of *Heliothis virescens* (F.) under laboratory conditions. Ann. Entomol. Soc. Amer. 74: 324-330.

Teal, P. E. A., J. H. Tumlinson, J. R. McLaughlin, R. Heath, and R. A. Rush. 1984. (Z)-11-Hexadecen-1-ol: a behavior modifying chemical present in the pheromone gland of female *Heliothis zea* (Lepidoptera: Noctuidae). Can. Entomol. 116: 777-779.

Tejada, L. O. 1971. Evaluation of the effectiveness of some general predators at different predator-prey densities, with special reference to their attack on *Heliothis zea* (Boddie). Ph.D. Thesis. University of California. Riverside.

Teske, M. E. 1984. Computer program for prediction of the deposition of material released from fixed and rotary wing aircraft. NASA Contractor Report 3780: 92.

TAEX. 1947. Guide for controlling cotton insects in Texas. Tex. Agric. Ext. Serv. C-182.

TAEX. 1948. Guide for controlling cotton insects in Texas. Tex. Agric. Ext. Serv. C-182.

TAEX. 1949. Guide for controlling cotton insects in Texas. Tex. Agric. Ext. Serv. C-182.

TAEX. 1951. Guide for controlling cotton insects in Texas. Tex. Agric. Ext. Serv. C-182.

TAEX. 1952a. Cotton insect control guide Lower Rio Grande Valley of Texas. Tex. Agric. Ext. Serv.

TAEX. 1952b. Guide for controlling cotton insects in Texas. Tex. Agric. Ext. Serv. C-182.

TAEX. 1953a. Cotton insect control guide Lower Rio Grande Valley of Texas.

TAEX. 1953b. Guide for controlling cotton insects in Texas. Tex. Agric. Ext. Serv. C-182.

TAEX. 1954a. Cotton insect control guide Lower Rio Grande Valley of Texas.

TAEX. 1954b. Guide for controlling cotton insects in Texas. Tex. Agric. Ext. Serv. C-182.

TAEX. 1956a. Texas guide for controlling cotton insects. Tex. Agric. Ext. Serv. L-218.

TAEX. 1956b. Cotton insect control guide Lower Rio Grande Valley of Texas.

TAEX. 1957a. Texas guide for controlling cotton insects. Tex. Agric. Ext. Serv. L-218.

TAEX. 1957b. Cotton insect control guide Lower Rio Grande Valley of Texas.

TAEX. 1959a. Cotton insect control guide Lower Rio Grande Valley of Texas.

TAEX. 1959b. Texas guide for controlling cotton insects. Tex. Agric. Ext. Serv. L-218.

TAEX. 1960. Cotton insect control guide Lower Rio Grande Valley of Texas.

TAEX. 1961a. Texas guide for controlling cotton insects. Tex. Agric. Ext. Serv. L-218.

TAEX. 1961b. Guide for controlling cotton insects in South Texas. Tex. Agric. Ext. Serv. L-561.

TAEX. 1961c. Guide for controlling cotton insects in the High Plains and Trans-Pecos area of Texas. Tex. Agric. Ext. Ser. L-508.

TAEX. 1962. Guide for controlling cotton insects in South Texas. Tex. Agric. Ext. Serv. L-561.

TAEX. 1963a. Texas guide for controlling cotton insects. Tex. Agric. Ext. Serv. L-218.

TAEX. 1963b. Guide for controlling cotton insects in South Texas. Tex. Agric. Ext. Serv. L-561.
TAEX. 1963c. Guide for controlling cotton insects in the High Plains and Trans-Pecos area of Texas. Tex. Agric. Ext. Ser. L-508.
TAEX. 1964a. Texas guide for controlling cotton insects. Tex. Agric. Ext. Serv. L-218.
TAEX. 1964b. Guide for controlling cotton insects in South Texas. Tex. Agric. Ext. Serv. L-561.
TAEX. 1964c. Guide for controlling cotton insects in the High Plains and Trans-Pecos area of Texas. Tex. Agric. Ext. Ser. L-508.
TAEX. 1966a. Texas guide for controlling cotton insects. Tex. Agric. Ext. Serv. L-218.
TAEX. 1966b. Guide for controlling cotton insects in South Texas. Tex. Agric. Ext. Serv. L-561.
TAEX. 1966c. Guide for controlling cotton insects in the High Plains, Rolling Plains and Trans-Pecos area of Texas. Tex. Agric. Ext. Ser. L-508.
TAEX. 1967a. Texas guide for controlling cotton insects. Tex. Agric. Ext. Serv. L-218.
TAEX. 1967b. Guide for controlling cotton insects in South Texas. Tex. Agric. Ext. Serv. L-561.
TAEX. 1967c. Guide for controlling cotton insects in the High Plains, Rolling Plains and Trans-Pecos area of Texas. Tex. Agric. Ext. Ser. L-508.
TAEX. 1968. Texas guide for controlling cotton insects. Tex. Agric. Ext. Serv. L-218.
TAEX. 1969a. Texas guide for controlling cotton insects. Tex. Agric. Ext. Serv. L-218.
TAEX. 1969b. Guide for controlling cotton insects in South Texas. Tex. Agric. Ext. Serv. L-561.
TAEX. 1969c. Guide for controlling cotton insects in the High Plains, Rolling Plains and Trans-Pecos area of Texas. Tex. Agric. Ext. Ser. L-508.
TAEX. 1970. Guide for controlling cotton insects in the High Plains, Rolling Plains and Trans-Pecos area of Texas. Tex. Agric. Ext. Ser. L-508.
TAEX. 1971a. Guide for controlling cotton insects in the High Plains, Rolling Plains and Trans-Pecos area of Texas. Tex. Agric. Ext. Ser. L-508.
TAEX. 1971b. Texas guide for controlling cotton insects. Tex. Agric. Ext. Serv. L-218.
TAEX. 1971c. Guide for controlling cotton insects in South Texas. Tex. Agric. Ext. Serv. L-561.
TAEX. 1972a. Guide for controlling cotton insects in North Texas, Blacklands and Gulf Coast counties of Texas. Texas Agric. Ext. Ser. L-218.
TAEX. 1972b. Guide for controlling cotton insects in South Texas. Tex. Agric. Ext. Serv. L-561.
TAEX. 1972c. Guide for controlling cotton insects in the High Plains, Rolling Plains and Trans-Pecos area of Texas. Tex. Agric. Ext. Ser. L-508.
TAEX. 1974a. Suggestions for controlling cotton insects in East & South Texas, counties of Texas. Texas Agric. Ext. Ser. L-218.
TAEX. 1974b. Suggestions for controlling cotton insects in the Texas Blacklands. Tex. Agric. Ext. Serv. L-1219.
TAEX. 1974c. Suggestions for controlling cotton insects in the Lower Rio Grande Valley of Texas. Texas Agric. Ext. Serv. L-561.
TAEX. 1974d. Guide for controlling cotton insects in the High Plains, Rollins Plains and Trans-Pecos area of Texas. Tex. Agric. Ext. Ser. L-508.
TAEX. 1975a. Suggestions for controlling cotton insects in the Lower Rio Grande Valley of Texas. Texas Agric. Ext. Serv. L-561.
TAEX. 1975b. Suggestions for controlling cotton insects in the High Plains, Rolling Plains and Trans-Pecos areas of Texas. Tex. Agric. Ext. Serv. L-508.
TAEX. 1975c. Suggestions for controlling cotton insects in the Texas Blacklands. Tex. Agric. Ext. Serv. L-1219.
TAEX. 1976a. Suggestions for controlling cotton insects in the Lower Rio Grande Valley of Texas. Texas Agric. Ext. Serv. L-561.
TAEX. 1976b. Suggestions for controlling cotton insects in the High Plains, Rolling Plains and Trans-Pecos areas of Texas. Tex. Agric. Ext. Serv. L-508.
TAEX. 1977a. Suggestions for controlling cotton insects in East & South Texas, counties of Texas. Texas Agric. Ext. Ser. L-218.
TAEX. 1977b. Suggestions for controlling cotton insects in the Texas Blacklands. Tex. Agric. Ext. Serv. L-1219.

TAEX. 1977c. Suggestions for controlling cotton insects in the Lower Rio Grande Valley of Texas. Texas Agric. Ext. Serv. L-561.

TAEX. 1978a. Suggestions for controlling cotton insects in East & South Texas, counties of Texas. Texas Agric. Ext. Ser. L-218.

TAEX. 1978b. Suggestions for controlling cotton insects in the Texas Blacklands. Tex. Agric. Ext. Serv. L-1219.

TAEX. 1978c. Suggestions for controlling cotton insects in the Lower Rio Grande Valley of Texas. Texas Agric. Ext. Serv. L-561.

TAEX. 1978d. Suggestions for controlling cotton insects in the High Plains, Rolling Plains and Trans-Pecos areas of Texas. Tex. Agric. Ext. Serv. L-508.

TAEX. 1979a. Management of cotton insects in the High Plains, Rolling Plains and Trans-Pecos areas of Texas. Tex. Agric. Ext. Serv. B-1209.

TAEX. 1979b. Management of cotton insects in South & East Texas counties. Tex. Agric. Ext. Serv. B-1204.

TAEX. 1979c. Management of cotton insects in the Texas Blacklands. Tex. Agric. Ext. Serv. L-1219.

TAEX. 1979d. Management of cotton insects in the Lower Rio Grande Valley of Texas. Tex. Agric. Ext. Serv. B-1210.

TAEX. 1980. Management of cotton insects in the High Plains, Rolling Plains and Trans-Pecos areas of Texas. Tex. Agric. Ext. Serv. B-1209.

Texas Department of Water Resources. 1984. The state of Texas water quality inventory, 7th edition, December, Texas.

Thead, L. G., H. N. Pitre, and T. F. Kellong. 1985. Feeding behavior of adult *Geocoris punctipes* (Say) (Hemiptera: Lygaeidae) on nectaried and nectariless cotton. Environ. Entomol. 14: 134-137.

Thomas, D. 1989. What's in an object? Byte 14: 231-240.

Thomas, W. M. 1989a. Modeling within-plant distribution of *Heliothis* spp. (Lepidoptera: Noctuidae) damage in cotton. Agric. Sys. 30: 71-80.

Thomas, W. M. 1989b. Validation of the *Heliothis* spp. damage submodel, HELDMG, pp. 220-222. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Thomas, W. M., M. E. Roof, and R. G. Jones. 1988. Predicting *Heliothis* spp. oviposition peaks using TEXCIM. J. Agric. Entomol. 5: 253-256.

Thompson, C. G., and E. A. Steinhaus. 1950. Further tests using a polyhedrosis virus to control the alfalfa caterpillar. Hilgardia 19: 411-445.

Thompson, C. M., and T. R. Fukuto. 1982. Mechanism of cholinesterase inhibition by methamidophos. J. Agric. Food Chem. 30: 282-284.

Thompson, M. O. 1951. More $$$$$ for your cotton. NM A&M College Ext. Circ. 233.

Thompson, W. H. 1951. Hosts of the Coleoptera and Diptera. Pt. 1, *In* W. H. Thompson (ed.), A catalogue of the parasites and predators of insect pests [q.v.]. Sect. 2 Ottawa, Ontario.

Thompson, W. H. 1985. Agricultural chemicals, book 1. Thompson Publications, Fresno.

Thorpe, K. 1984. Seasonal distribution of *Trichogramma* (Hymenoptera: Trichogrammatidae) species associated with a Maryland soybean field. Environ. Entomol. 13: 127-132.

Threadgill, E. D. 1985. Chemigation via sprinkler irrigation: current status and future development. Appl. Engr. Agric. 1: 16-23.

Threadgill, E. D., and D. B. Smith. 1975. Effects of physical and meteorological parameters on the drift of controlled-size droplets. Trans ASAE 18: 51-56.

Thresh, J. M. 1981. Pests pathogens and vegetation: the role of weeds and wild plants in the ecology of crops pests and diseases. Pitman Pub. Co. 517 pp., London.

Tietz, H. M. 1972. An index to the described life histories, early stages, and hosts of the *Macrolepidoptera* of the continental United States and Canada. Vol. I and II. A. C. Allyn, Allyn Museum of Entomology, Sarasota.

Tillman, P. G. 1993. Preference of *Catolaccus grandis* for boll weevils on cotton plants versus on the ground. Southwest. Entomol. 18: 169-172.

Tingey, W. M., T. F. Leigh, and A. H. Hyer. 1975a. *Lygus hesperus*: Growth, survival, and egg laying resistance of cotton genotypes. J. Econ. Entomol. 68: 28-31.

Tingey, W. M., T. F. Leigh, and A. H. Hyer. 1975b. Glandless cotton: susceptibility to *Lygus hesperus* Knight. Crop Sci. 15: 251-253.

Tingle, F. C., and E. P. Lloyd. 1969. Influence of temperature and diet on attainment of firm diapause in the boll weevil. J. Econ. Entomol. 7: 295-309.

Tinsley, T. W., and D. C. Kelley. 1985. Taxonomy and nomenclature of insect pathogenic viruses, pp. 3-25. *In* K. Maramarosch, and K. E. Sherman (eds.), Viral insecticides for biological control. Academic Press, New York.

Tinsworth, E. F. 1990. Regulation of pheromones and other semiochemicals in the United States, pp. 569-603. *In* R. L. Ridgway, R. M. Silverstein, and M. N. Inscoe (eds.), Behavior-modifying Chemicals for Insect Management: Applications of Pheromones and Other Attractants. Marcel Dekker, Inc., New York.

Tippins, H. H., and C. M. Beckham. 1962. Boll weevil resistance to several chlorinated hydrocarbon insecticides in Georgia. J. Econ. Entomol. 55: 944-947.

Todd, E. L., and R. W. Poole. 1980. Keys and illustrations for the armyworm moths of the Noctuid genus *Spodoptera* Guenee from the western hemisphere. Ann. Entomol. Soc. Amer. 73: 722-738.

Todd, J. W. 1989. Ecology and behavior of *Nezara viridula*. Annu. Rev. Entomol. 34: 273-292.

Todd, J. W., and W. J. Lewis. 1976. Incidence and oviposition patterns of *Trichopoda pennipes* (F.), a parasite of the southern green stink bug, *Nezara viridula* (L.). J. Ga. Entomol. Soc. 11: 50-54.

Tollefson, M. S., and T. F. Watson. 1981. Seasonal effects on the biology of and damage by tobacco budworm in cotton. J. Econ. Entomol. 74: 714-717.

Toscano, N. C., M. Blua, G. Ballmer, and M. Madore. 1992. The impact of sweetpotato whitefly, *Bemisia tabaci*, upon cotton quantity and quality in California, pp. 684-687. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Toscano, N. C., and V. Sevacherian. 1980. Pink bollworm monitoring methods, pp. 40-45. *In* H. Graham (ed.), Pink bollworm control in the western United States. USDA, Science and Education Administration, ARM-W-16,.

Toscano, N. C., V. Sevacherian, and R. A. van Steenwyk. 1979. Pest management guide for insects and nematodes of cotton in California. Agricultural Sciences Publications, University of California, Berkeley.

Toschi, C. A. 1965. The taxonomy, life history, and mating behavior of the green lacewings of Strawberry Canyon (Neuroptera: Chrysopidae). Hilgardia 36: 391-431.

Toth Jr., S. J., and T. C. Sparks. 1988. Influence of treatment technique on the temperature-toxicity relationships of *cis*- and *trans*-permethrin in the cabbage looper, *Trichoplusia ni* (Hubner) (Lepidoptera: Noctuidae). J. Econ. Entomol. 81: 115-118.

Townsend Jr., J. R. 1973. Economic threshold studies of *Heliothis* spp. on cotton. M.S. Thesis, Mississippi State Univ., Mississippi State.

Townsend, C. H. T. 1895. Report on the Mexican cotton boll weevil in Texas. (*Anthonomus grandis* Boh.). Insect Life 7: 295-309.

Treacy, M. F., J. H. Benedict, and K. M. Schmidt. 1986. Toxicity of insecticide residues to the boll weevil: comparison of ulv-oil vs. conventional/water and water-oil sprays in evaluation of petroleum and crop oils as carriers and adjuvants for insecticides. Southwest. Entomol. 11: 19-24.

Treacy, M. F., J. H. Benedict, K. M. Schmidt, R. M. Anderson, and T. L. Wagner. 1987. Behavior of tobacco budworm larvae on cotton treated with chlordimeform, pp. 318-20. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Treacy, M. F., J. H. Benedict, J. D. Lopez, and R. K. Morrison. 1987a. Functional response of a predator (Neuroptera: Chrysopidae) to bollworm (Lepidoptera: Noctuidae) eggs on smoothleaf, hirsute, and pilose cottons. J. Econ. Entomol. 80: 376-379.

Treacy, M. F., J. H. Benedict, M. H. Walmsley, J. D. Lopez, and R. K. Morrison. 1987b. Parasitism of bollworm (Lepidoptera: Noctuidae) eggs on nectaried and nectariless cotton. Environ. Entomol. 16: 420-423.

Treacy, M. F., G. R. Zummo, and J. H. Benedict. 1985. Interactions of host plant resistance in cotton with predators and parasites. Agric. Ecosy. Environ. 13: 151-157.

Trumble, J. T., and M. P. Parella. 1987. California law and the development of pesticide resistance. California policy seminar research report.

Tschinkel, W. R. 1982. History and biology of fire ants, pp. 16-35. *In* Proc. Symposium on the Imported Fire Ant. Environmental Protection Agency: USDA; Animal, Plant Health Inspection Service, Atlanta, Georgia.

Tucker, T. C., and B. B. Tucker. 1968. Nitrogen nutrition, pp. 184-211. *In* F. C. Elliot, M. Hoover, and W. K. Porter Jr. (eds.), Advances in production and utilization of quality cotton: principles and practices. The Iowa State Univ. Press, Ames.

Tugwell, P., S. C. Young Jr., B. A. Dumsas, and J. R. Phillips. 1976. Plant bugs in cotton: importance of infestation time, types of cotton injury, and significance of wild hosts near cotton. Arkansas Agr. Exp. Sta. Rep. Ser. 227.

Tumlinson, J. H., R. C. Gueldner, D. D. Hardee, A. C. Thompson, P. R. Hedin, and J. P. Minyard. 1971. Identification and synthesis of the four compounds comprising the boll weevil sex attractant. J. Org. Chem. 36: 2616-2621.

Tumlinson, J. H., D. D. Hardee, R. C. Gueldner, A. C. Thompson, P. A. Hedin, and J. P. Minyard. 1969. Sex pheromones produced by male boll weevil: isolation, identification, and synthesis. Science 166: 1010-1012.

Tumlinson, J. H., D. E. Hendricks, E. R. Mitchell, R. E. Doolittle, and M. M. Brennan. 1975. Isolation, identification, and synthesis of the sex pheromone of the tobacco budworm. J. Chem. Ecol. 1: 203-214.

Turnbull, A. L. 1973. Ecology of the true spiders (Araneomorphae). Annu. Rev. Entomol. 18: 305-348.

Turner, J. 1981. White gold comes to California. Book Publishers Inc., Fresno.

Turney, H. A., W. E. Buxkemper, and J. Cocke Jr. 1982. Management of cotton insects in the Texas Blacklands. Tex. Agric. Ext. Ser. B-1205.

Tweeten, L. 1983. Economic instability in agriculture: the contributions of prices, government programs and exports. Amer. J. Agri. Econ. 65: 922-930.

Twine, P. H., and H. T. Reynolds. 1980. Relative susceptibility and resistance of the tobacco budworm to methyl parathion and synthetic pyrethroids in Southern California. J. Econ. Entomol. 73: 239-242.

Tyler, F. J. 1910. Varieties of American upland cotton. USDA Bur. Plant Health Ind. Bull. 163.

USDA. 1961. The pink bollworm in Arizona, July 1958 through September 1960. Agric. Res. Serv. Plant Pest Cont.Div., Oakland, California.

USDA. 1981a. Executive overview of alternative boll weevil/cotton insect management programs.

USDA. 1981b. Biological evaluation of alternative Beltwide boll weevil/cotton insect management programs. Overall evaluation. Appendix A. SEA-AR Staff Report.

USDA. 1985. Agricultural statistics. U.S. Govt. Printing Office, Washington, DC.

USDA. 1993. Conference report and 5-year national research and action plan for development of management and control methodology for the sweetpotato whitefly, *In* R. M. Faust and J. R. Coppedge (eds.), USDA-ARS, ARS-107, U.S. Govt. Printing Office Washington, D.C.

USDA, APHIS. 1977. Task force review report of the pink bollworm program. Washington, DC.

USDA, APHIS. 1978-87. Annual budgets.

USDA, ARS. 1965. Losses in agriculture. AH-291.

USDA, CSRS. 1978-1986. Annual inventories of agricultural research.

USDA, ERS. 1984-87. Objective yield survey.

USDA, ERS. 1986. Agricultural resources: inputs outlook situation report, AR-1.

USDA, ERS. 1986. Agricultural resources-input situation and outlook report. AR-3.

USDA, ERS. 1992. Cotton and wool, situation and outlook report. CWS-69. Washington, D.C.

USDA, ERS. 1993. Cotton and wool, situation and outlook report. CWS-69. Washington, D.C.

U.S. Senate. 1979. Costs of producing selected crops in the United States—selected years. Prepared for the Committee on Agriculture, Nutrition and Forestry.

Udagawa, T., S. Numata, K. Oda, S. Shiraishi, K. Kodaka, and K. Nakatani. 1985. A new type of snythetic pyrethroid insecticide, pp. 192-204. *In* N. F. Janes (ed.), Recent advances in the chemistry of insect control. Royal Society of Chemistry, London, U.K.

Uk, S., and R. J. Courshee. 1982. Distribution and likely effectiveness of spray deposits within a cotton canopy from fine ulv spray applied by aircraft. Pesti. Sci. 13: 529-536.

Underhill, G. W. 1934. The green stink bug. Va. Ag. Exp. Stn. Bull. 294.

Uvarov, B. P. 1931. Insects and climate. Trans. Entomol. Soc. London 79: 1-274.

Vaeck, M., A. Reynaerts, H. Hofte, S. Jansens, M. de Beuckeleer, C. Dean, M. Zabeau, M. van Montagu, and J. Leemans. 1987. Transgenic plants protected from insect attack. Nature 328: 33-37.

Vail, P. V., T. J. Henneberry, and M. R. Bell. 1977. Cotton leafperforator: effect of a nuclear polyhedrosis virus on field populations. J. Econ. Entomol. 70: 727-728.

Vail, P. V., and D. L. Jay. 1973. Pathology of a nuclear polyhedrosis virus of the alfalfa looper in alternate hosts. J. Invertebr. Pathol. 21: 198-204.

Vail, P. V., D. L. Jay, and D. K. Hunter. 1970. Cross infectivity of a nuclear polyhedrosis virus from the alfalfa looper, *Autographa californica*, pp. 297-304. *In* Proc. Fourth Intern. Colloq. Insect Pathology.

Vail, P. V., D. L. Jay, D. K. Hunter, and R. T. Staten. 1972. A nuclear polyhedrosis virus infective to the pink bollworm. J. Invertebr. Pathol. 20: 124-128.

van den Bosch, R., and K. S. Hagen. 1966. Predaceous and parasitic arthropods in California cotton fields. Calif. Ag. Exp. Stn. Bull. 820.

van den Bosch, R., T. F. Leigh, L. A. Falcon, V. M. Stern, D. Gonzalez, and K. Hagen. 1971. The developing program of integrated control of cotton pests in California, pp. 377-394. *In* C. B. Huffaker (ed.), Biological control. Plenum Press, New York.

van den Bosch, R., T. F. Leigh, D. Gonzalez, and R. E. Stinner. 1969. Cage studies on predators of the bollworm in cotton. J. Econ. Entomol. 62: 1486-1489.

van den Bosch, R., H. T. Reynolds, and E. J. Dietrick. 1956. Toxicity of widely used insecticides to beneficial insects in California cotton and alfalfa fields. J. Econ. Entomol. 49: 359-363.

van Emden, H. F., and K. S. Hagen. 1976. Olfactory reactions of the green lacewing, *Chrysopa carnea*, to tryptophan and certain breakdown products. Environ. Entomol. 5: 469-473.

van Lenteren, J. C. 1981. Host discrimination by parasitoids, pp. 153-179. *In* D. A. Nordlund, R. L. Jones, and W. J. Lewis (eds.), Semiochemicals: their role in pest control. Wiley, New York.

Van Steenwyck, R. A., N. C. Toscano, G. R. Balmer, and H. T. Reynolds. 1975. Increase of *Heliothis* spp. in cotton under various insecticide treatment regimes. Environ. Entomol. 4: 993-996.

Van Steenwyk, R. A., and V. M. Stern. 1976. The biology of *Peristenus stygicus* (Hymenoptera: Braconidae), a newly imported parasite of lygus bugs. Environ. Entomol. 5: 931-934.

Van Steenwyk, R. A., and V. M. Stern. 1977. Propagation, release, and evaluation of *Peristenus stygicus*, a newly imported parasite of lygus bugs. J. Econ. Entomol. 70: 66-69.

Van Steenwyk, R. A., N. C. Toscano, and A. L. Pager. 1978. Dispersal of rubidium-marked pink bollworm. Environ. Entomol. 7: 608-613.

Vanderzant, E. S. 1967. Rearing *Lygus* bugs on artificial diets. J. Econ. Entomol. 60: 813-816.

Vanderzant, E. S., and T. B. Davich. 1958. Laboratory rearing of the boll weevil: a satisfactory larval diet and oviposition studies. J. Econ. Entomol. 51: 288-291.

Vanderzant, E. S., and R. Reiser. 1956. Aseptic rearing of the pink bollworm on synthetic media. J. Econ. Entomol. 49: 7-10.

Vanderzant, E. S., C. D. Richardson, and S. W. Fort Jr. 1962. Rearing of the bollworm on artificial diet. J. Econ. Entomol. 55: 140.

Verloop, A., and C. D. Ferrell. 1977. Benzolphenyl ureas - a new group of larvicides interfering with chitin deposition, pp. 237-270. *In* J. A. Plimmer (ed.), Pesticide chemistry in the 20th century. American Chemical Society, Washington, D.C.

Vickery, R. A. 1915. Notes on three species of *Heliophila* which injure cereal and forage crops at Brownsville, TX. J. Econ. Entomol. 8: 389-392.
Vickery, R. A. 1926. Observations of *Cirphis latiuscula* H. Sch. in the gulf coast region of Texas. J. Agric. Res. 32: 1099-1119.
Vickery, R. A. 1929. Studies on the fall armyworm in the gulf coast district of Texas. U.S. Dept. Agric. Tech. Bull. 138.
Villavaso, E. J. 1981. Field competitiveness of sterile male boll weevils released in the boll weevil irradiation trial - 1979. J. Econ. Entomol. 74: 373-375.
Villavaso, E. J. 1982. Boll weevil: field competitiveness of diflubenzuron-fed irradiated males - 1980-1981. J. Econ. Entomol. 75: 662-664.
Villavaso, E. J., J. C. Dickens, W. L. McGovern, and F. D. Brewer. 1988. Field competitiveness of sterile boll weevils (Coleoptera: Curculionidae) reared on standard diets versus diets supplemented with carotenoids. J. Econ. Entomol. 812: 1102-1106.
Villavaso, E. J., and N. W. Earle. 1976. Competitiveness of busulfan-fed sterile vs. native male boll weevils. Environ. Entomol. 5: 279-280.
Villavaso, E. J., E. P. Lloyd, P. S. Lue, and J. E. Wright. 1980. Boll weevils: competitiveness of sterile males in isolated field plots. J. Econ. Entomol. 73: 213-217.
Villavaso, E. J., S. S. Nilakhe, and W. L. McGovern. 1979. Field competitiveness of sterile male boll weevils. J. Ga. Entomol. Soc. 14: 113-120.
Villavaso, E. J., J. L. Roberson, and R. W. Seward. 1989a. Effectiveness of sterile boll weevils (Coleoptera: Curculionidae) against a low density population in commercially grown cotton in north-central Mississippi. J. Econ. Entomol. 82: 472-476.
Villavaso, E. J., W. L. McGovern, and J. E. Leggett. 1989b. Competitiveness and longevity of sterile boll weevils in isolated plots of cotton in Arizona. Southwest. Entomol. 14: 111-115.
Villavaso, E. J., J. L. Roberson, P. P. Sikorowski, and M. J. Thompson. 1986a. Competitiveness of sterile boll weevils (Coleoptera: Curculionidae) relative to a native population in small field plots. J. Econ. Entomol. 79: 76-78.
Villavaso, E. J., J. L. Roberson, R. W. Seward, and M. J. Thompson. 1986b. Effectiveness of sterile boll weevils (Coleoptera: Curculionidae) against naturally occurring populations in commercially grown cotton. J. Econ. Entomol. 79: 79-83.
Villavaso, E. J., and M. J. Thompson. 1984. Field competitiveness of boll weevils (Coleoptera: Curculionidae) sterilized by the feeding of chemosterilants followed by irradiation or fumigation. J. Econ. Entomol. 77: 583-587.
Villavaso, E. J., G. Wiygul, and M. J. Thompson. 1983. Pheromone production in boll weevils (Coleoptera: Curculionidae) sterilized by three methods. J. Econ. Entomol. 76: 1030-1040.
Vinson, S. B. 1968a. Immunological relationships between the parasite *Cardiochiles nigriceps* Vierick and certain *Heliothis* species. J. Insect Physiol. 14: 613-626.
Vinson, S. B. 1968b. Source of a substance in *Heliothis virescens* that elicits a searching response in its habitual parasite, *Cardiochiles nigriceps*. Ann. Entomol. Soc. Amer. 61: 8-10.
Vinson, S. B. 1972. Factors involved in successful attack on *Heliothis virescens* by the parasitoid *Cardiochiles nigriceps*. J. Invertebr. Pathol. 20: 118-123.
Vinson, S. B. 1975. Biochemical coevolution between parasitoids and their hosts, pp. 14-48. *In* P. Price (ed.), Evolutionary strategies of parasitic insects and mites. Plenum, New York.
Vinson, S. B. 1976. Host selection by insect parasitoids. Annu. Rev. Entomol. 21: 109-133.
Vinson, S. B. 1977. Behavioral chemicals in the augmentation of natural enemies, pp. 237-299. *In* R. L. Ridgway, and S. B. Vinson (eds.), Biological control by augmentation of natural enemies. Plenum Press, New York.
Vinson, S. B. 1978. Courtship behavior and source of a sexual pheromone from *Cardiochiles nigriceps*. Ann. Entomol. Soc. Amer. 71: 832-837.
Vinson, S. B. 1981. Habitat location, pp. 51-77. *In* D. A. Nordlund, R. L. Jones, and W. J. Lewis (eds.), Semiochemicals: their role in pest control. Wiley, New York.

Vinson, S. B. 1988. The potential use of synamones, kairomones, and pheromones in the management of enemies of cotton pests, pp. 217-223. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Vinson, S. B., and J. R. Brazzel. 1966. The penetration and metabolism of C`14`-labeled DDT in resistant and susceptible tobacco budworm larvae, *Heliothis virescens* (F.). J. Econ. Entomol. 59: 600-604.

Vinson, S. B., and D. L. Dahlman. 1989. Physiological relationship between braconid endoparasites and their hosts: the *Microplitis croceipes* - *Heliothis* spp. system, pp. 17-37. *In* J. E. Powell, D. L. Bull, and E. G. King (Eds.), Biological control of *Heliothis* spp. by *Microplitis croceipes*. Southwest. Entomol. Suppl. 12.

Vinson, S. B., and L. Greenberg. 1986. The biology, physiology, and ecology of imported fire ants, pp. 193-226. *In* S. B. Vinson (ed.), Economic impact and control of social insects. Praeger Publishers, New York.

Vinson, S. B., and F. S. Guillot. 1972. Host marking: source of a substance that results in host discrimination in insect parasitoids. Entomophaga 17: 241-245.

Vinson, S. B., F. S. Guillot, and D. B. Hays. 1973. Rearing of *Cardiochiles nigriceps* in the laboratory, with *Heliothis virescens* as hosts. Ann. Entomol. Soc. Amer. 66: 1170-1172.

Vinson, S. B., R. D. Henson, and C. S. Barfield. 1976. Ovipositional behavior of *Bracon mellitor* Say (Hymenoptera: Braconidae), a parasitoid of boll weevil (*Anthonomus grandis* Boh). I. Isolation and identification of a synthetic releaser of ovipositor probing. J. Chem. Ecol. 2: 431-440.

Vinson. S. B., R. L. Jones, P. E. Sonnet, B. A. Bierl, and M. Beroza. 1975. Isolation, identification and synthesis of host-seeking stimulants for *Cardiochiles nigriceps*, a parasitoid of tobacco budworm. Entomol. Exp. Appl. 18: 443-450.

Vinson, S. B., and W. J. Lewis. 1965. A method of host selection by *Cardiochiles nigriceps*. J. Econ. Entomol. 58: 869-871.

Vinson, S. B., and A. A. Sorensen. 1986. Imported fire ants: life history and impact. Texas Dept. Agric. Publ., Austin, TX.

Voegele, J. 1981. Lutte biologique centre *Ostrinia nubilalis* a l'aid des trichogrammes. Bull. OEPP 11: 91-95.

Volterra, V. 1926. Variations and fluctuations of the number of individuals in animal species living together, pp. 409-448. *In* R. N. Champan (ed.), Animal ecology. McGraw-Hill, New York.

von Arx, R., J. Baumgartner, and V. Delucchi. 1983. A model to simulate the population dynamics of *Bemisia tabaci* Genn. (Stern., Aleyrodidae) on cotton in the Sudan Gezira. Z. Ang. Entomol. 96: 341-363.

von Foerster, H. 1959. Some remarks on changing populations, pp. 382-407. *In* F. Stohlman Jr. (ed.), The kinetics of cellular proliferation. Grune and Stratton, New York.

Voronin, K. E., and A. M. Grinberg. 1981. The current status and prospects of *Trichogramma* utilization in the USSR, pp. 49-51. *In* J. R. Coulson (ed.), Proc. Joint American-Soviet Conference on the Use of Beneficial Organisms in the Control of Crop Pests.. Entomol. Soc. Amer., College Park, MD.

Voss, G. 1980. Cholinesterase autoanalysis; a rapid method for biochemical studies on susceptible and resistant insects. J. Econ. Entomol. 73: 189-192.

Voss, G., and R. Neumann. 1992. Invertebrate neuroscience and its potential contribution in insect control, pp. 18-20. *In* I. Duce (ed.), Neurotox '91. Molecular basis of drug and pesticide action. Society of chemical industry, London.

Waddle, B. A. 1957. Rex, a new Arkansas cotton. Ark. Farm Res. 6.

Wade, L. J., and D. R. Rummel. 1978. Boll weevil immigration into winter habitat and subsequent spring and summer emergence. J. Econ. Entomol. 71: 173-178.

Wagner, F. 1980. The boll weevil comes to Texas. Occasional papers. Friends of the Corpus Christi Museum, Corpus Christi, Texas.

Waiss Jr., A. C., B. G. Chan, C. A. Elliger, and R. G. Binder. 1981. Biologically active cotton constituents and their significance in HPR, pp. 61. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Walhood, V. T., T. J. Henneberry, L. A. Bariola, D. L. Ballard, and C. Brown. 1983. Insect pest management potential of cotton produced in narrow row, short season cultures in the irrigated Far West. USDA, Agric. Res. Ser., ARR-W-30.

Walhood, V. T., T. J. Henneberry, L. A. Bariola, D. L. Kittock, and C. Brown. 1981. Effect of short-season cotton on overwintering pink bollworm larvae and spring moth emergence. J. Econ. Entomol. 74: 297-302.

Walhood, V. T., and H. Yamada. 1972. Varietal characteristics and irrigation practices as harvest aids in narrow row cotton, pp. 43-44. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Walker Jr., J. K. 1967. Studies in the fall and winter of oviposition prior to diapause in the boll weevil with observation on reversion from diapause to reproduction. J. Econ. Entomol. 60: 798-802.

Walker Jr., J. K. 1980a. Earliness in cotton and escape from boll weevil, pp. 113-123. *In* Biology and breeding for resistance to arthropods and pathogens in agricultural plants. Texas Agric. Exp. Stn., MP-1451.

Walker Jr., J. K. 1980b. The development of short-season cotton production in Texas, pp. 153-155. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Walker Jr., J. K. 1984. The boll weevil in Texas and the cultural strategy. Southwest. Entomol. 9: 444-463.

Walker Jr., J. K., and D. G. Bottrell. 1970. Infestations of boll weevils in isolated plots of cotton in Texas. J. Econ. Entomol. 63: 1646-1650.

Walker Jr., J. K., R. E. Frisbie, and G. A. Niles. 1978. A changing perspective: *Heliothis* in short season cottons in Texas. Entomol. Soc. Amer. Bull. 24: 385-391.

Walker Jr., J. K., J. R. Gannaway, and G. A. Niles. 1977. Age distribution of cotton bolls and damage from the boll weevil. J. Econ. Entomol. 70: 5-8.

Walker Jr., J. K., and R. L. Hanna. 1963. Development of populations of the boll weevil in fields treated with various insecticides during 1959, 1960, and 1961. J. Econ. Entomol. 56: 350-356.

Walker Jr., J. K., and G. A. Niles. 1971. Population dynamics of the boll weevil and modified cotton types: implications for pest management. Texas Agric. Exp. Stn. Bull. 1109.

Walker Jr., J. K., and G. A. Niles. 1980. Primordial square formation in cotton and the cotton fleahopper. Southwest. Entomol. 9: 104-108.

Walker Jr., J. K., G. A. Niles, J. R. Gannaway, J. V. Robinson, C. B. Cowan, and M. J. Lukefahr. 1974. Cotton fleahopper damage to cotton genotypes. J. Econ. Entomol. 67: 537-542.

Walker Jr., J. K., R. D. Parker, A. A. Armstrong, G. A. Niles, and J. R. Mulkey. 1984. Management of the boll weevil in cotton of the Winter Garden of Texas based on early-season control. Southwest. Entomol. 9: 427-442.

Walker Jr., J. K., and L. G. Pickens. 1962. Egg deposition by boll weevils isolated from males during hibernation period and after spring emergence. J. Econ. Entomol. 55: 268-269.

Walker, C. H., K. S. Lee, A. R. McCaffery, and E. J. Little. 1990. Resistance to cypermethrin in the PEG87 strain of *Heliothis virescens*-The enzymatic factor, pp. 177-180. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Walters, M. L., O. C. Jenkins, and J. K. Walker. 1990. Texas threshold recommendations in cotton: sample size and accuracy for *Heliothis* spp. Southwest. Entomol. 15: 346-357.

Wang, Y., A. P. Gutierrez, G. Oster, and R. Daxl. 1977. A population model for plant growth and development: coupling cotton-herbivore interaction. Can. Entomol. 109: 1359-1374.

Wannamaker, W. K. 1957. The effect of plant hairiness of cotton strains on boll weevil attack. J. Econ. Entomol. 50: 418-423.

Ward, C. R. 1982. Cotton insect management suggestions for 1982. NM State Univ. Coop Ext. Ser. Guide 400 J-7.

Ward, C. R. 1985. Early season cotton pests-An IPM perspective from the New Mexico Pecos Valley, pp. 30-35. *In* Proc. Western Cotton Prod. Conf.

Ward, C. R. 1991a. Cotton insect management suggestions for 1991-1992. NM State Univ. Coop Ext. Ser. Guide 400 J-7A.

Ward, C. R. 1991b. Insecticides for use with cotton insect management suggestions for 1991. NM State Univ. Coop Ext. Ser. Guide 400 J-7B.

Ware, G. W. 1974. Ecological history of DDT in Arizona. J. Ariz. Acad. Sci. 9: 61-65.

Ware, G. W., N. B. Akesson, R. P. Cromwell, J. E. Dewey, R. King, W. Helms, C. G. McWhorter, J. V. Osmun, L. O. Roth, D. B. Smith, and W. J. Walla. 1983. Reducing pesticide application drift-losses. Univ. of Ariz. Coop. Ext. Ser.

Ware, G. W., N. A. Buck, and B. J. Estesen. 1983. Dislodgeable insecticidal residues on cotton foliage: comparison of ulv/cottonseed oil vs. aqueous solutions of 12 insecticides. Bull. Environ. Contam. Toxicol. 31: 551-558.

Ware, G. W., N. A. Buck, and B. J. Estesen. 1984. Deposit and drift losses from aerial ulv and emulsion sprays in Arizona. J. Econ. Entomol. 7: 298-303.

Ware, G. W., W. P. Cahill, B. J. Estesen, W. C. Kronland, and N. A. Buck. 1975. Pesticide drift: deposit efficiency from ground sprays on cotton. J. Econ. Entomol. 68: 549-550.

Ware, J. O. 1930. Cotton spacing. II. Effect of blooming on earliness, fruit set, and yield. Arkansas Agr. Exp. Sta. Bull. 253.

Ware, J. O. 1951. Origin, rise, and development of American upland cotton varieties and their status at present. Arkansas Agr. Exp. Sta. Agron. Dept. Misc. Publ. unnumbered.

Warren, G. W., N. B. Carozzi, N. Desai, and M. G. Koziel. 1992. Field evaluation of transgenic tobacco containing a *Bacillus thuringiensis* insecticidal protein. J. Econ. Entomol. 85: 1651-1659.

Wartenberg, D. 1988. Ground water contamination by Temik aldicarb pesticide: the first 8 months. Water Resources Research 24: 185-194.

Watanabe, H. 1971. Pathophysiology of cytoplasmic polyhedrosis in the silkworm, pp. 151-167. *In* H. Aruga, and Y. Tanada (eds.), The cytoplasmic-polyhedrosis virus of the silkworm. University of Tokyo Press, Tokyo.

Waterman, D. A. 1986. A guide to expert systems. Addison-Wesley, Reading.

Watson, F. L. 1973. An optimal control of *Lygus hesperus* on cotton. Ph.D. Thesis, Univ. of Arizona, Tucson.

Watson, T. F. 1965. Influence of thrips on cotton yields in Alabama. J. Econ. Entomol. 1118-1122.

Watson, T. F. 1974. Tobacco budworm and bollworm control in western cotton, pp. 38. *In* Proc. West Coast Prod. Conf.

Watson, T. F. 1977. Pink bollworm, *Pectinophora gossypiella* (Saunders), pp. 426-429. *In* J. Kranz. H. Schmutterer, and W. Koch (eds.), Diseases, pests and weeds in tropical crops. Verlag, Berlin.

Watson, T. F. 1980. Methods for reducing winter survival of the pink bollworm, pp. 24-34. *In* H. Graham (ed.), Pink bollworm control in the Western United States.. USDA, Science and Education Administration, ARM-W-16..

Watson, T. F. 1993. Insecticide resistance management: principles of resistance, pp. 13-14. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Watson, T. F., D. Bergman, and J. Palumbo. 1986a. Effect of temperature and food on developmental time of the boll weevil in Arizona. Southwest. Entomol. 11: 281-286.

Watson, T. F., L. A. Crowder, and S. Kelly. 1986b. Pyrethroid and methyl parathion susceptibility of the tobacco budworm in Arizona. Southwest. Entomol. 11: 281-286.

Watson, T. F., F. M. Carasso, D. T. Langston, E. B. Jackson, and D. G. Fullerton. 1978. Pink bollworm suppression through crop termination. J. Econ. Entomol. 71: 638-641.

Watson, T. F., and D. G. Fullerton. 1969. Timing of insecticidal applications for control of pink bollworm. J. Econ. Entomol. 62: 682-685.

Watson, T. F., and P. H. Johnson. 1972. Life cycle of the cotton leafperforator. Univ. of AZ.. Prog. Agric. XXIV.

Watson, T. F., and S. E. Kelly. 1991a. Inheritance of resistance to permethrin by the tobacco budworm, *Heliothis virescens* (F.): Implications for resistance management. Southwest. Entomol. Suppl. 15: 135-141.

Watson, T. F., and S. E. Kelly. 1991b. Response of the tobacco budworm to permethrin and methyl parathion in Arizona, 1977-1989. Southwest. Entomol. Suppl. 15: 53-57.

Watson, T. F., S. E. Kelly, and B. J. Estesen. 1991. Residual activity of permethrin, chlordimeform and permethrin + chlordimeform against susceptible and resistant tobacco budworm. Southwest. Entomol. Suppl. 15: 129-134.

Watson, T. F., and W. E. Larsen. 1968. Effects of winter cultural practices on the pink bollworm in Arizona. J. Econ. Entomol. 61: 1041-1044.

Watson, T. F., M. L. Lindsey, and J. E. Slosser. 1973. Effect of temperature, moisture and photoperiod on diapause termination in the pink bollworm. J. Econ. Entomol. 2: 967-970.

Watson, T. F., L. Moore, and G. W. Ware. 1976. Practical insect pest management: a self-instruction manual. W. H. Freemann & Co., San Francisco.

Watson, T. F., J. C. Silvertooth, A. Tellez, and L. Lastra. 1992. Seasonal dynamics of sweetpotato whitefly in Arizona. Southwest. Entomol. 17: 149-167.

Watson, T. F., K. K. Barnes, J. E. Slosser, and D. G. Fullerton. 1974. Influence of plowdown dates and cultural practices on spring emergence of pink bollworm. J. Econ. Entomol. 67: 207-210.

Watt, K. E. F. 1961. Mathematical models for use in insect pest control. Can. Entomol. 93: 1-62.

Watt, K. E. F. 1966. Systems analysis in ecology. Academic Press, Inc., New York.

Watt, K. E. F. 1970. The systems point of view in pest management, pp. 71-83. *In* R. L. Rabb, and F. E. Guthrie (eds.), Concept of Pest Management. N.C. State Univ., Raleigh.

Watts, J. G. 1938. Reduction of cotton yield by thrips. J. Econ. Entomol. 30: 860-863.

Watts, J. G. 1980. Publications of entomologists at New Mexico State University 1890 to 1978. NMSU Agricultural Experiment Sta. Memoir Series No. 7.

Watve, C. M., and D. F. Clower. 1976. Natural enemies of the banded wing whitefly in Louisiana. Environ. Entomol. 5: 1075-1078.

Watve, C. M., D. F. Clower, and J. B. Graves. 1977. Resistance to methyl parathion and monocrotophos in the bandewinged whitefly in Louisiana. J. Econ. Entomol. 70: 263-266.

Weaver, J. B., and M. S. Reddy. 1977. Boll weevil nonpreference, antibiosis, and hatchability studies utilizing cotton lines with multiple nonpreferred characters. J. Econ. Entomol. 70: 283-285.

Webster's New Twentieth Century Dictionary. 1971. Webster's New Twentieth Century Dictionary. The World Publishing Company, New York.

Webster, J. P. G. The analysis of risky farm management decisions: Advising farmers about the use of pesticide. J. Agric. Econ. Vol. 28

Weiler, J. 1976. Mexican viceroy played role in establishing king cotton's reign in south. The Commercial Appeal, (April 25, 1976)

Weiser, J. 1982. Persistence of fungal insecticides: influence of environmental factors and present and future application, pp. 387-423. *In* E. Kurstak (ed.), Microbial and viral pesticides. Marcel Dekker, Inc., New York.

Weiser, J. 1987. Patterns over place and time, pp. 215-243. *In* J. R. Fuxa, and Y. Tanada (eds.), Epizootiology of insect diseases. John Wiley & Sons, New York.

Weld, D. S., and J. de Kleer. 1990. Readings in qualitative reasoning about physical systems. Morgan Kaufmann, San Mateo, CA.

Wene, G. P., and L. W. Sheets. 1962. Relationship of predatory and injurious insects in cotton fields in the Salt River Valley Area of Arizona. J. Econ. Entomol. 55: 395-398.

Wene, G. P., and L. W. Sheets. 1964a. Notes on and control of stink bugs affecting cotton in Arizona. J. Econ. Entomol. 57: 60-62.

Wene, G. P., and L. W. Sheets. 1964b. Lygus bug injury to presquaring cotton. Ariz. Ag. Exp. Stn. Tech. Bull. 166.

Werner, F. G., and G. D. Butler Jr. 1979. Tachinid flies collected in a Phoenix, Arizona cotton field. Southwest. Entomol. 4: 282-284.

Werner, F. G., L. Moore, and T. F. Watson. 1979. Arizona cotton insects. Univ. of Ariz. Coop. Ext. Serv. Bull. A23R.

Weseloh, R. M. 1981. Host location by parasitoids, pp. 79-95. *In* D. A. Nordlund, R. L. Jones, and W. J. Lewis (eds.), Semiochemicals: their role in pest control. Wiley, New York.

Wetzstein, M. E. 1988. Comments on integrated pest management: risk implications for natural resources, *In* Incorporation of risk in analysis of farm management decisions affecting natural resource use. Agric. Exp. Sta. Special Rept. 821. Oregon State University, Corvallis.

Whalon, M. E., and W. H. McGaughey. 1993. Insect resistance to *Bacillus thuringiensis*, pp. 215-232. *In* L. Kim (ed.), Advanced engineered pesticides. Macel Dekker, New York.

Whitcomb, W. H. 1967a. Bollworm predators in northeast Arkansas. Ark. Farm Res 16: 2.

Whitcomb, W. H. 1967b. Field studies on predators of the second-instar bollworm, *Heliothis zea* (Boddie) (Lepidoptera: Noctuidae). J. Ga. Entomol. Soc. 2: 113-118.

Whitcomb, W. H. 1971. History of integrated control as practiced in the cotton fields of the south central United States, pp. 147-155. *In* Proc. Tall Timbers Conference on Ecol. Anim. Contr. Habitat Manage.

Whitcomb, W. H. 1974. Natural populations of entomophagous arthropods and their effect on the agroecosystem, pp. 50-164. *In* F. G. Maxwell and F. A. Harris (eds.), Proc. Summer Instit. Biol. Contrl. Plant Insects and Diseases. Univ. Press Miss., Jackson, Mississippi.

Whitcomb, W. H., and K. Bell. 1964. Predaceous insects, spiders, and mites of Arkansas cotton fields. Ark. Agr. Exp. Stn. Bull. 690.

Whitcomb, W. H., and R. Eason. 1967. Life history and predatory importance of the striped lynx spider (Araneida: Oxyopidae). Ark. Acad. Sci. Proc. 21: 54-58.

Whitcomb, W. H., H. Exline, and R. C. Hunter. 1963. Spiders of the Arkansas cotton field. Ann. Entomol. Soc. Amer. 56: 653-660.

Whitcomb, W. H., M. Hite, and R. Eason. 1966. Life history of the green lynx spider, *Peucetia viridans* (Araneida: Oxyopidae). J. Kansas Entomol. Soc. 39: 259-267.

White, H. C. 1896. The cotton plant. USDA Bull. 33.

White, J. R., and D. R. Rummel. 1978. Emergence profile of overwintered boll weevil and entry into cotton. Environ. Entomol. 7: 7-14.

White, R. W. 1953. The quarantine and control program for pink bollworm, pp. 60-61. *In* Proc. Beltwide Cotton Prod. Res. Conf.

White, R. W. 1960. History of pink bollworm infestation in the United States 1917-1959. USDA, Agric. Res. Serv. Plant Pest Control Div., unpublished report.

White, W. H. 1981. Evaluation of chemical and genetic analysis as predictors of resistance to the tobacco budworm. Ph.D., Mississippi State University, Mississippi State.

White, W. H., J. N. Jenkins, W. L. Parrott, J. C. McCarty Jr., D. H. Collum, and P. A. Hedin. 1982a. Generation mean analyses of various allelochemics in cottons. Crop Sci. 22: 1046-1049.

White, W. H., J. N. Jenkins, W. L. Parrott, J. C. McCarty Jr., D. H. Collum, and P. A. Hedin. 1982b. Strain and within-season variability of various allelochemics within a diverse group of cottons. Crop Sci. 22: 1235-1238.

Whittaker, R. H., and P. P. Feeny. 1971. Allelochemics: chemical interactions between species. Science 171: 757-770.

Whitten, C. J., and D. L. Bull. 1970. Resistance to organophosphorus insecticides in tobacco budworm. J. Econ. Entomol. 63: 1492-1495.

Whitten, C. J., and D. L. Bull. 1974. Comparative toxicity, absorption and metabolism of chlorpyrifos and its dimethyl homolog in methyl parathion-resistant and -susceptible tobacco budworms. Pestic. Biochem. Physiol. 4: 266-274.

Whitten, C. J., and D. L. Bull. 1978. Absorption and metabolism of methyl parathion by tobacco budworms resistant or susceptible to organophosphorus insecticides. Pestic. Biochem. Physiol. 9: 196-202.

Whitten, M. J. 1985. Conceptual basis for genetic control, pp. 465-528. *In* G. A. Kerkut, and L. I. Gilbert (eds.), Comprehensive insect physiology, biochemistry and pharmacology. Pergamon Press, Oxford.

Widstrom, N. W. 1979. The role of insects and other plant pests in aflatoxin contamination of corn, cotton, and peanuts—a review. J. Environ. Quality 8: 5-11.

Wilborn, W., and J. Ellington. 1984. The effect of temperature and photoperiod on the coloration of *Lygus hesperus*, *desertinus*, and *lineolaris*. Southwest. Entomol. 9: 187-197.

Wilding, N., G. Lateur, and C. A. Dedryver. 1986. Evaluation of entomophthorales for aphid control: laboratory and field data, pp. 159-162. *In* R. A. Samson, J. M. Vlak, and D. Peters (eds.), Fundamental and applied aspects of invertebrate pathology. Foundation of the Fourth International Colloquium of Invertebr. Pathol., Wageningen.

Wilkes, L. H. 1961. Effects of nozzle types and spray application methods on cotton insect control. Trans. ASAE 4: 166-169.

Wilkes, L. H., B. J. Cochran, O. T. Robertson, and A. J. Chapman. 1962. Crop residue disposal for the control of the pink bollworm, *In* A summary of recent research basic to cultural control of the pink bollworm. Tex. Agr. Exp. Sta. MP. 579.

Wilkinson, C. F. 1976a. Insecticide biochemistry and physiology. Plenum Press, New York.

Wilkinson, C. F. 1976b. Insecticide synergism, pp. 195-218. *In* R. L. Metcalf, and J. J. McKelvey Jr. (eds.), The future for insectcides. John Wiley and Sons, New York.

Wilkinson, C. F. 1983. Role of mixed-function oxidases in insecticide resistance, pp. 175-205. *In* G. P. Georghiou, and T. Saito (eds.), Pest resistance to pesticides. Plenum Press, New York.

Wilkinson, C. F. 1985. Role of mixed-function oxidases in insect growth and development, pp. 161-176. *In* P. A. Hedin (ed.), Biogregulators for pest control. American Chemical Society, Washington, D.C.

Wille, J. E. 1951. Biological control of certain cotton insects and the application of new organic insecticides in Peru. J. Econ. Entomol. 44: 13-18.

Willers, J. L., D. L. Boykin, J. M. Hardin, T. L. Wagner, R. L. Olson, and M. R. Williams. 1990. A simulation study on the relationship between the abundance and spatial distribution of insects and selected sampling schemes, *In* Proc. Applied Stat. Agric., Kansas State University.

Williams III, L., J. R. Phillips, and N. P. Tugwell. 1987. Field technique for identifying causes of pin-head square loss in cotton. J. Econ. Entomol. 80: 527-531.

Williams, C. B. 1957. Insect migration. Annu. Rev. Entomol. 2: 163-180.

Williams, C. M. 1967. Third-generation pesticides. Scientific Amer. 27: 13-17.

Williams, H. J., G. W. Elzen, and S. B. Vinson. 1988. Parasitoid-host-plant interactions, emphasizing cotton (*Gossypium*), pp. 171-200. *In* P. Barbosa, and D. K. Letourneau (eds.), Novel aspects of insect-plant interactions. John Wiley & Sons, New York.

Williams, M. R., T. L. Wagner, J. L. Willers, and R. L. Olson. 1991. Scouting protocol for arthropod pests of cotton in the midsouth. Miss. Agric. For. Exp. Stn. Bull. 977 39 pp.

Williams, M. R., J. L. Willers, T. L. Wagner, and R. L. Olson. 1990. Using knowledge-based insect management systems at the farm level, pp. 325-328. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Williamson, D. R., and W. R. Deaton. 1991. Field performance of cotton genetically modified to express insecticidal protein from *Bacillus thuringiensis*. VII. Loxley, AL, pp. 577. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Willis, G. H., and L. L. McDowell. 1987. Pesticide persistence on foliage. Rev. Environ. Contam. Toxicol. 100: 24-73.

Wilson, A. G., R. D. Hughes, and N. Gilbert. 1972. The response of cotton to pest attack. Bull. Entomol. Soc. Amer. 61: 405-414.

Wilson, F. D. 1982. Present state of the art and science of cotton breeding for insect resistance in the West, pp. 111-116. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Wilson, F. D. 1986. Registration of seven cotton germplasm lines. Crop. Sci. 26: 206-207.

Wilson, F. D. 1987. Registration of three cotton germplasm lines. Crop Sci. 27: 820-821.

Wilson, F. D. 1988. Yield, earliness, and fiber properties of cottons carrying combined traits for pink bollworm resistance. Crop Sci. 29: 7-12.

Wilson, F. D. 1991. Twenty years of HPR—Progress, problems, prognostications, pp. 542-544. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Wilson, F. D. 1992. Registration of eight cotton germplasm lines with pink bollworm resistance traits. Crop Sci. 32: 288-289.

Wilson, F. D., J. Brown, and G. D. Butler Jr. 1989. Reaction of cotton cultivars and lines to cotton leaf crumple virus. J. Ariz. Nev. Acad. Sci. 23: 7-10.

Wilson, F. D., and H. M. Flint. 1991. Field performance of cotton genetically modified to express insecticidal protein from *Bacillus thuringiensis*. VI. Maricopa, AZ, pp. 579. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Wilson, F. D., and B. W. George. 1984. Pink bollworm (Lepidoptera: Gelechiidae): selecting for antibiosis in artificially and naturally infested cotton plants. J. Econ. Entomol. 77: 720-724.

Wilson, F. D., and B. W. George. 1985. Innovations in the X-ray technique of evaluating cotton germplasm for resistance to pink bollworm. USDA—Agric. Res. Serv. ARS-40.

Wilson, F. D., B. W. George, and R. L. Wilson. 1981. Screening cotton for resistance to pink bollworm. USDA-Sci. and Educ.—Agric. Res. ARM-W-22.

Wilson, F. D., and B. R. Stapp. 1979. Flowers with abnormal numbers of involucral bracts in cotton. Crop Sci. 19: 204-208.

Wilson, L. 1989. Selective miticidal material give control in Australian cotton. Australian Cotton Grower. Aug.-Oct.

Wilson, L. T. 1985. Developing economic thresholds in cotton, pp. 308-344. *In* R. E. Frisbie and P. L. Adkisson (eds.), CIPM: Integrated Pest Management on Major Agricultural Systems. Texas Agric. Exp. Stn. MP-1616.

Wilson, L. T. 1993. Estimating abundance, impact and interactions among arthropods in cotton agroecosystems, pp. 475-514. *In* L. P. Pedigo, and G. D. Buntin (eds.), Handbook of Sampling Methods for Arthropods in Agriculture. CRC Press, Ann Arbor.

Wilson, L. T., D. Gonzalez, and T. F. Leigh. 1982. Bollworm damage and yield of cotton infested at different time periods. J. Econ. Entomol. 75: 520-523.

Wilson, L. T., D. Gonzalez, and R. E. Plant. 1985. Predicting sampling frequency and economic status of spider mites on cotton, pp. 168-170. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Wilson, L. T., and A. P. Gutierrez. 1980. Fruit predation submodel: *Heliothis* larvae feeding upon cotton fruiting structures. Hilgardia 48: 24-36.

Wilson, L. T., and A. P. Gutierrez. 1980. Within-plant distribution of predators on cotton: comments on sampling and predator efficiencies. Hilgardia 48: 3-11.

Wilson, L. T., T. F. Leigh, D. Gonzalez, and C. Foristiere. 1984. Distribution of *Lygus hesperus* (Knight) (Miridae: Hemiptera) on cotton. J. Econ. Entomol. 77: 1313-1319.

Wilson, L. T., R. E. Plant, T. A. Kerby, L. Zelinski, and P. B. Goodell. 1987. Transition from a strategic to a tactical crop and pest management model: use as an economic decision aid, pp. 207-213. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Wilson, L. T., P. M. Room, and A. S. Bourne. 1983. Dispersion of arthropods, flower buds and fruit in cotton fields: effects of population density and season on the fit of probability distributions. J. Aust. Ent. Soc. 22: 129-134.

Wilson, N. L., and A. D. Oliver. 1969. Food habits of the imported fire ants in pasture and pine forest areas in southern Louisiana. J. Econ. Entomol. 62: 1268-1271.

Wilson, R. L., and F. D. Wilson. 1976. Nectariless and glabrous cottons: effect on pink bollworm in Arizona. J. Econ. Entomol. 69: 623-624.

Wilson, R. L., and F. D. Wilson. 1977. Effects of pilose, pubescent and smooth cottons on the cotton leaf perforator. Crop Sci. 15: 807-809.

Wilson, R. L., F. D. Wilson, and G. H. Abel Jr. 1977. Mutants of *Gossypium barbadense*: effect of pink bollworm and cotton leaf-perforator in Arizona. J. Econ. Entomol. 70: 672-674.

Wilson, R. L., F. D. Wilson, and B. W. George. 1979. Mutants of *Gossypium hirsutum*: effect on pink bollworm in Arizona. J. Econ. Entomol. 72: 216-219.

Wilson, T. G., and J. Fabian. 1986. A *Drosophila melanogaster* mutant resistant to a chemical analog of juvenile hormone. Dev. Biol. 118: 190-201.

Wing, K. D. 1988. RH-5849, a nonsteroidal ecdysone agonist: effects on a *Drosophila* cell line. Science 241: 467-469.

Wing, K. D., and H. E. Aller. 1990. Ecdysteroid agonists as novel insect growth regulators, pp. 251-257. *In* J. E. Casida (ed.), Pesticides and alternatives: innovative chemical approaches to pest control. Elsevier, New York.

Wing, K. D., A. H. Glickman, and J. E. Casida. 1982. Oxidative bioactivation of *S*-alkyl phosphorothiolate pesticides: stereospecificity of profenofos insecticide activation. Science 219: 63-65.

Wing, K. D., R. A. Slawecki, and G. R. Carlson. 1988. RH-5849, a nonsteroidal ecdysone agonist: effects on larval Lepidoptera. Science 241: 470-472.

Witz, J. A., D. C. Akins, J. M. McKinion, and W. M. Thomas. 1990. Programming the combination of the cotton insect model, TEXCIM, with the cotton physiology model, GOSSYM, using the *Heliothis* damage model, HELDMG: a status report, pp. 343-345. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Witz, J. A., A. W. Hartstack, E. G. King, W. A. Dickerson, and J. R. Phillips. 1985. Monitoring and prediction of *Heliothis* spp. Southwest. Entomol. Suppl. 8: 56-70.

Witz, J. A., A. W. Hartstack, E. P. Lloyd, and E. B. Mitchell. 1981. Effect of infield trap spacing on potential catch of adult boll weevils entering cotton: a computer simulation. Environ. Entomol. 10: 454-457.

Wofford, J. T. 1985. The effects of spray characteristics of vegetable oil and water sprays of permethrin on mortality of *Heliothis* spp. larvae. M.S. Thesis, Mississippi State University, Mississippi State.

Wofford, J. T., R. G. Luttrell, and D. B. Smith. 1987. Relative effect of dosage, droplet size, deposit density, and droplet concentration on mortality of *Heliothis virescens* (Lepidoptera: Noctuidae) larvae treated with vegetable-oil and water sprays containing permethrin. J. Econ. Entomol. 80: 460-464.

Wojcik, D. P. 1983. Comparison of the ecology of red imported fire ants in North and South America. Fla. Entomol. 66: 101-111.

Wolf, W. W., J. K. Westbrook, and A. N. Sparks. 1986. Relationship between radar entomological measurements and atmospheric structure in south Texas during March and April 1982, pp. 84-97. *In* A. N. Sparks (ed.), Long-range migration of moths of agronomic importance to the United States and Canada: specific examples of occurrence and synoptic weather patterns to migration. USDA ARS-43.

Wolfe, H. R., W. F. Durham, and J. F. Armstrong. 1967. Exposure of workers to pesticides. Arch. Environ. Health 14: 622-633.

Wolfenbarger, D. A., P. R. Bodegas, and R. Flores. 1981. Development of resistance in *Heliothis* spp. in the Americas, Australia, Africa, and Asia. Bull. Entomol. Soc. Amer. 27: 181-185.

Wolfenbarger, D. A., and A. A. Guerra. 1972. Toxicity of endosulfan and its isomers to the bollworm and tobacco budworm. J. Econ. Entomol. 65: 1122-1123.

Wolfenbarger, D. A., and A. A. Guerra. 1986. Toxicity and hypoxia of three petroleum oil hydrocarbons and cottonseed oil to adult boll weevils and larvae of tobacco budworm. Southwest. Entomol. 11: 69-75.

Wolfenbarger, D. A., and J. A. Harding. 1980. Activity of certain alkyl and aryl phosphoramides against *Heliothis* spp. Southwest. Entomol. 5: 125-127.

Wolfenbarger, D. A., A. W. Johnson, G. A. Herzog, and W. B. Tappan. 1985. Activity of avermectin in the laboratory and the field against the boll weevil and *Heliothis* spp. on cotton and flue-cured tobacco. Southwest. Entomol. 7: 17-26.

Wolfenbarger, D. A., and R. L. McGarr. 1971. Low-volume and ulv sprays of malathion and methyl parathion for control of three lepidopterans. USDA Prod. Res. Rep. 126.

Womack, C. L., and M. F. Schuster. 1987. Host plants of the tarnished plant bug (Heteroptera: Miridae) in the northern blackland prairies of Texas. Environ. Entomol. 16: 1266-1272.

Wood, H. A., and R. Granados. 1991. Genetically engineered baculoviruses as agents for pest control. Annu. Rev. Entomol. 45: 69-87.

Wood, R. J. 1981. Strategies for conserving susceptibility to insecticides. Parasitology 82: 69-80.

Wood, R. J., and G. S. Mani. 1981. The effective dominance of resistance genes in relation to the evolution of resistance. Pestic. Sci. 12: 573-581.

Woodring, W. L., and H. K. Kaya. 1988. Steinernematid and Heterorhabditid nematodes: a handbook of techniques. South Coop. Ser. Bull. 331.

Woodside, A. M. 1946. Life history studies of *Euschistus servus* and *E. tristigmus*. J. Econ. Entomol. 39: 161-163.

Woodside, A. M. 1947. Weed hosts of bugs which cause cat-facing of peaches in Virginia. J. Econ. Entomol. 40: 231-233.

Wright Jr, D. P. 1985. *Spodoptera eridania*, pp. 459-464. *In* P. Singh, and R. F. Moore (eds.), Handbook of Insect Rearing, Vol. 2 Elsevier, New York.

Wright, J. E. 1992. Whiteflies: development of Naturalis, a biorational mycoinsecticide for control, pp. 887-888. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Wright, J. E. 1993. Control of the boll weevil (Coleoptera: Curculionidae) with Naturalis-L: A mycoinsecticide. J. Econ. Entomol. 86: 1355-1358.

Wright, J. E., L. F. Bouse, I. W. Kirk, J. B. Carlton, E. Franz, M. A. Latheef, and R. Rektorik. 1993. Full season control of cotton insects in the Rio Grande Valley of Texas with Naturalis-L: an insect specific fungus, pp. 849-856. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Wright, J. E., and L. D. Chandler. 1991. Field evaluation of Naturalis against the boll weevil: a biorational mycoinsecticide, pp. 677-679. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Wright, J. E., and A. Retnakaran (eds.). 1987. Chitin and benzolphenyl ureas. Dr. W. Junk Publishers, Boston.

Wright, J. E., J. L. Roberson, and J. R. Dawson. 1980. Boll weevil: effects of diflubenzuron on sperm transfer, mortality and sterility. J. Econ. Entomol. 73: 803-805.

Wright, J. E., and E. J. Villavaso. 1983. Boll weevil sterility, pp. 153-177. *In* R. L. Ridgway, E. P. Lloyd, and W. H. Cross (eds.), Cotton Insect Management with Special Reference to the Boll Weevil. USDA Agr. Handb. No. 589.

Xie, X., and W. L. Sterling. 1987. Computer simulation of cotton aphid population dynamics. ACTA Phytophylacica Sinica 14: 151-156.

Yamamoto, T., and G. K. Powell. 1993. *Bacillus thuringiensis* crystal proteins: recent advances in understanding its insecticial activity, pp. 3-42. *In* L. Kim (ed.), Advanced engineered pesticides. Macel Dekker, New York.

Yang, R. S. H. 1976. Enzymatic conjugation and insecticide metabolism, pp. 177-225. *In* C. F. Wilkinson (ed.). Insecticide biochemistry and physiology. Plenum Press, New York.

Yates, W. E. 1962. Spray pattern analysis and evaluation of deposits from agricultural aircraft. Trans. ASAE 5: 49-53.

Yates, W. E., R. E. Cowden, and N. B. Akesson. 1982. Effect of airspeed, nozzle orientation and spray concentration on drop size spectrums. ASAE and NAAA Paper No. AA-82-003.

Yates, W. E., R. E. Cowden, and N. B. Akesson. 1985. Drop size spectra from nozzles in high-speed airstreams. Trans. ASAE 28: 405-410, 414.

Yearian, W. C., and S. Y. Young. 1974. Persistence of *Heliothis* nuclear polyhedrosis virus on cotton parts. Environ. Entomol. 3: 1035-1036.

Yearian, W. C., and S. Y. Young. 1982. Control of insect pests of agricultural importance by viral insecticides, pp. 720. *In* E. Kurstak (ed.), Microbial and viral pesticides. Marcel Dekker, Inc., New York.

Yokoyama, V. Y. 1978. Relation of seasonal changes in extrafloral nectar and foliar protein and arthropod populations in cotton. Environ. Entomol. 7: 799-802.

Yoshioka, H. 1992. Structural evolution of synthetic pyrethroid insecticides in correlational views guided by template procedure as applied to natural models with high structural multiplicity, pp. 185-217. *In* W. Draber, and T. Fujita (eds.), Rational approaches to structure, activity, and ecotoxicity of agrochemicals. CRC Press, Boca Raton, FL.

Young Jr., D. F. 1969a. Operation of areawide diapause programs and results in Mississippi, pp. 7-9. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Young Jr., D. F. 1969b. Cotton insect control. Oxmoor House, Birmingham.

Young, D. F. 1983. Symposium: a decade of extension cotton integrated pest management, 1972-1982, pp. 227. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Young, J. H., and R. G. Price. 1975. Incidence, parasitism, and distribution patterns of *Heliothis zea* on sorghum, cotton, and alfalfa for southwestern Oklahoma. Environ. Entomol. 4: 777-779.

Young, J. H., and L. J. Wilson. 1984. A model to predict damage reduction to flower buds or fruit by *Heliothis* spp. in the absence or presence of two Coleoptera predators. Southwest. Entomol. 6: 33-38.

Young, J. H., L. J. Wilson, and R. G. Price. 1986. Cotton fleahopper preference of cotton cultivars as oviposition sites, pp. 488-489. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Young, J. R., J. J. Hamm, R. L. Jones, W. D. Perkins, and R. L. Burton. 1976. Development and maintenance of an improved laboratory colony of corn earworms. USDA ARS-S-110.

Young, O. P. 1986. Host plants of the tarnished plant bug, *Lygus lineolaris* (Heteroptera: Miridae). Ann. Entomol. Soc. Amer. 79: 747-762.

Young, O. P., and G. B. Edwards. 1990. Spiders in United States field crops and their potential effect on crop pests. J. Arachnol. 18: 1-27.

Young, O. P., and T. C. Lockley. 1985. The striped lynx spider, *Oxyopes salticus* (Araneae: Oxyopidae), in acroecosystems. Entomophaga 30: 329-346.

Young, O. P., and T. C. Lockley. 1986. Predation of striped lynx spider, *Oxyopes salticus* (Araneae: Oxyopidae), on tarnished plant bug, *Lygus lineolaris* (Heteroptera: Miridae): a laboratory evaluation. Ann. Entomol. Soc. Amer. 79: 879-883.

Young, S. Y., and W. C. Yearian. 1974. Persistence of *Heliothis* NPV on foliage of cotton. Environ. Entomol. 3: 253-255.

Youngman, R. R., N. C. Toscano, V. P. Jones, K. Kido, and E. T. Natwick. 1986. Correlations of seasonal trap counts of *Bemisia tabaci* (Homoptera: Aleyrodiade) in southeastern California. J. Econ. Entomol. 79: 67-70.

Yu, S. J., and E. L. Hsu. 1985. Induction of hydrolases by allelochemicals and host plant in fall armyworm (Lepidoptera: Noctuidae). larvae. Environ. Entomol. 14: 512-515.

Zadeh, L. A. 1965. Fuzzy sets. Information and Control 8: 338-353.

Zaki, F. N. 1985. Reactions of the egg parasitoid *Trichogramma evanescens* to certain insect sex pheromones. Z. Angew. Entomol. 99: 448-453.

Zeoli, L. T., A. F. Kydonieus, and A. R. Quisumbing. 1982. Controlled release technologies, pp. 131-144. *In* A. F. Kydonieus, and M. Beroza (eds.), Insect suppression with controlled release pheromone systems. Vol. I. CRC Press, Boca Raton, FL.

Ziser, S. W., and W. C. Nettles Jr. 1978. The larval development of *Eucelatoria* sp. in the host *Heliothis virescens*. Ann. Entomol. Soc. Amer. 71: 383-388.

Zvirgzdins, A., and T. J. Henneberry. 1983. *Heliothis* spp. sex pheromone trap studies, pp. 176-180. *In* Proc. Beltwide Cotton Prod. Res. Conf.

INSECT, MITE, AND SPIDER INDEX

[1]The following species do not have common names (Source: Common Names of Insects and Related Organisms. 1989. Entomological Society of America)

INSECTICIDE AND ACARICIDE INDEX

[1]Some insecticides are sold under several trade names. The listing here may be incomplete. We have tried to use the first and most recognizable trade names. Also, some of these products are no longer available.

SUBJECT INDEX

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