Chapter 1

MAJOR DEVELOPMENTS IN MANAGEMENT OF INSECT AND MITE PESTS IN COTTON

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INTRODUCTION

The intent of this chapter is to set the stage for this monograph by providing a summary of key events leading to the state-of-the-art of insect and mite pests in cotton. Selection of the events included herein was very difficult because of the long and rich association of arthropods and cotton culture. Because cotton may be produced in the United States only in warmer regions and requires a long growing season to reach physiological maturity, it is subject to the depredations of many herbivorous (plant feeding) arthropods. Exotic pests such as the boll weevil, *Anthonomus grandis grandis* Boheman, and the pink bollworm, *Pectinophora gossypiella* (Saunders), pose particularly difficult management problems as attempts to limit their population growth often result in the development of secondary pest problems. In most regimes, cotton is grown in a virtual monoculture involving extensive areas that generally favor pest buildup and minimize the impact of naturally occurring biological control agents. The potential for losses to arthropod pests is greater in cotton than in any other field crop and no other crop has been the target of more entomological attention. As a result, many of the outstanding entomological contributions have been made by scientists studying arthropods associated with cotton culture.

INVASION OF THE UNITED STATES BY THE BOLL WEEVIL

Prior to 1892, when the boll weevil crossed the Rio Grande River near Brownsville, Texas, insect damage to cotton was largely limited to lepidopterous pests, primarily the bollworm, *Helicoverpa zea* (Boddie) and the cotton leafworm, *Alabama argillacea* Hübner. The bollworm had been recognized as a pest of cotton since 1820 (Quaintance and Brues, 1905), but damaging populations were sporadic in occurrence and rarely developed in the southeastern states.

The entry of the boll weevil into the United States is probably the single most important entomological event to have occurred in cotton. In the United States, the boll weevil found an optimal environment consisting of small cotton fields surrounded by ample overwintering habitats that stretched from southern Texas to Virginia. By 1922, the boll weevil had added 600,000 square miles to its range, and eleven years later had infested the entire Cotton Belt except for northwestern Texas (Pencoe and Phillips, 1987). The boll weevil is the major factor responsible for the westward shift in cotton production in this country as well as the crop diversity that developed in the Southeast early in the twentieth century. Also, the boll weevil is largely responsible for the early development of the entomological profession in the southern states.

CLASSIC EARLY STUDIES ON BOLLWORM BIOLOGY AND MANAGEMENT

The classic investigation of the bollworm by Quaintance and Brues (1905) obviously deserves attention as it is an ageless example of quality entomological science. This often cited publication may be considered as the most thorough single work on the bollworm, and it has served as the foundation for all subsequent studies on biology and management of bollworms. These researchers observed temporal (of or relating to time) and spatial (of or relating to space) distribution patterns of the bollworm in agroecosystems across the Cotton Belt and developed an understanding of how host complexes, host phenologies, farming practices, weather and biological agents affected bollworm population dynamics. They were the first to conduct detailed studies of the predaceous (arthropods that prey on others) and parasitic arthropods associated with the bollworm/tobacco budworm and to recognize the important contribution that biological control agents make toward pest population regulation. Many of the cultural management tactics they recommended, particularly early crop maturity, are as relevant today as they were at the beginning of this century.

CLASSIC EARLY STUDIES ON BOLL WEEVIL BIOLOGY AND MANAGEMENT

The significance of the boll weevil as a cotton pest was recognized very soon after it entered the United States and research was initiated toward the alleviation of the problem (Townsend, 1895). The culmination of early investigations into boll weevil biology and management was a multicomponent suppression system based on cultural tactics that farmers could employ to reduce the impact of the boll weevil on cotton production (Quaintance, 1905; Hunter, 1912; Howard, 1896; Malley, 1901; Hunter and Hinds, 1905; Pierce, 1917). By the early 1920s, these scientists had developed sufficient information to form the nucleus of a sound, multifaceted pest management program for the boll weevil based on the principles of applied ecology. The specific tactics employed to promote crop earliness, and thus escape from the highest number of boll weevils in late season, in concert with thorough post-harvest crop residue destruction still serve as key components in modern day boll weevil management systems. Later investigators (Isely and Baerg, 1924; Isely, 1934) added to the repertoire by advancing the "trap crop" concept for control of weevils during early season and by demonstrating that controlled burning and clearing of favorable overwintering habitat were effective in reducing boll weevil populations. The latter is likely the major factor leading to a decline in boll weevil population levels in the Mississippi Delta since the 1950s.

CALCIUM ARSENATE PERIOD

Among the most profound developments in the control of insect pests of cotton was the discovery that calcium arsenate dust was an effective control for the boll weevil (Coad, 1918; Coad and Cassidy, 1920). These experiments demonstrated that the application of calcium arsenate on 4- or 5-day intervals, from the point when 15-20 percent of the cotton squares were damaged until boll maturity, would protect the cotton crop from boll weevil depredation. The additional discovery that calcium arsenate could be rapidly applied by aircraft, with no loss in boll weevil control effectiveness (Coad *et al.*, 1924; Hinds, 1925), set the stage for a period in the history of insect control on cotton that may best be characterized as excessive reliance upon use of insecticides. Control of boll weevils with calcium arsenate made cotton production much more profitable over most of the Cotton Belt.

As an omen of future events, the extensive use of calcium arsenate often had undesirable side-effects; destruction of natural enemies of such insect pests as the bollworm and the cotton aphid, *Aphis gossypii* Glover, led to more frequent outbreaks of these pests (Sherman, 1930; Ewing and Ivy, 1943). During the period 1920 to 1945, a high percentage of research on cotton insects was devoted to the evaluation of calcium arsenate for boll weevil control and various additives as a means of controlling infestations of the cotton aphid and the bollworm/tobacco budworm (Newsom, 1974).

COTTON INSECT SCOUTING AND THE THRESHOLD CONCEPT

Very soon after demonstration of effectiveness of calcium arsenate, Isely and Baerg (1924) reported that scouting and treating as needed provided the most economical methods of utilizing the new chemical control technology. The employment of James R. Horsfall to scout cotton in Arkansas during 1926 was the genesis of systematic cotton insect scouting. Scouting became the key step beltwide in cotton insect management (Lincoln *et al.*, 1975). Most of the early thresholds were derived from a research base supplemented by intuition; nevertheless, they were founded on the concept that some level of insect damage was tolerable. Eaton's (1931) early work showing the ability of the cotton plant to compensate for shedding of floral buds early in the fruiting cycle supported the threshold concept. Successful boll weevil control through use of calcium arsenate never reached its full potential because the cooperative extension service was not prepared to carry out the needed educational program and sufficient trained scouts were unavailable during that era (Lincoln *et al.*, 1975). The advent of the chlorinated hydrocarbon insecticides and devastating outbreaks of the boll weevil in 1949 and 1950 brought about the general use of "scouting" in cotton (Isely, 1950; Lincoln, 1951). Adoption of scouting and the threshold concept across the Cotton Belt led to widespread acceptance of integrated pest management (IPM) as a general practice in the 1970s.

THE PINK BOLLWORM AS A PEST OF COTTON IN THE UNITED STATES

The pink bollworm was first found in the United States in Texas in 1917, but rigid quarantine and cultural control programs prevented the pest from causing widespread economic problems until the early 1950s (Newsom and Brazzel, 1968). Similarly, the pink bollworm was discovered in Florida in 1932, but an eradication program conducted during 1932-36 eliminated the pest from the commercial cotton producing counties of northern Florida and southern Georgia; has not been a pest in the Southeast since. Since that time, the pink bollworm has been known to exist in the eastern United States only on wild cottons in southern Florida (Noble, 1969).

In 1952, the pink bollworm caused serious losses to the cotton crop in southern Texas which resulted in a joint state and federal research effort designed to provide means for immediate control of the pest. The program was highly successful and by the late 1950s the infestation had declined and losses were minimal. The objective of the program was to reduce the overwintering population of pink bollworms to such an extent that damaging infestations did not develop during the subsequent growing season. This was accomplished by early crop maturity, use of defoliants or desiccants for rapid boll opening to facilitate machine harvesting, early harvesting, early crop residue destruction, winter and early-spring irrigations in desert areas and uniform planting of cotton during a designated period to allow moths to emerge and die before cotton fruit was available for oviposition. Proper ginning techniques and sanitation ensured that no larvae overwintered in stored or waste cottonseed (Bottrell and Adkisson, 1977). The pink bollworm provides a classic example of a major pest of cotton that may be successfully managed through a combination of cultural controls, sanitation and quarantine tactics when employed over a wide area.

The pink bollworm has become a key pest in Arizona and southern California since the mid-1960s and its management in the irrigated regions of the West has been much less successful than in Texas. The practices of long-season production and stubbing (ratooning) of cotton resulted in the development of a pink bollworm pest problem of major proportions in the irrigated West. The situaton was exacerbated by more frequent outbreaks of secondary pests in response to increased insecticide used to control pink bollworm. During the late 1980s, the problem was ameliorated through the regulatory prohibition of stubbing and the general application of more stringent pest management practices.

INTRODUCTION OF THE SYNTHETIC ORGANIC INSECTICIDES

No single event in the history of cotton production in the United States, other than perhaps the spread of the boll weevil across the Cotton Belt, impacted the cotton agroecosystem and cotton production more dramatically than the introduction and use of the synthetic organic insecticides. The general use of these insecticides shortly after World War II quickly revolutionized prevailing attitudes and practices of growers and entomologists toward cotton insect control. With the introduction of DDT followed by benzene hexachloride, toxaphene, chlordane, aldrin, heptachlor, dieldrin, endrin and others, cheap and highly effective insecticides were available for the first time to combat insect pests of cotton. Technological advancements in formulations led to the development of emulsifiable concentrates which were more convenient to use than dust formulations. They were easier to package, transport, store, handle and apply.

Initial successes with these new chemicals were so spectacular that cotton production systems were radically modified to take maximum advantage of the new technology. Cultural practices were rapidly adopted to attain the goal of maximum yields. By the early 1950s, many of the growers in the South had adopted a "womb-to-tomb" or "wash day" program of insecticide application. Treatments began with seedling emergence and terminated with crop maturity. Hence extensive treatment of the crop with insecticides provided an inexpensive, reliable and high-return form of insurance. Ecological principles of regulating pest populations that had been effective against boll weevil and other pests were quickly forgotten or completely ignored for almost two decades by most growers and entomologists (Newsom, 1974).

Subsequently, organophosphorous compounds such as parathion, methyl parathion, azinphosmethyl (Guthion®), demeton (Systox®), EPN, and the carbamates such as carbaryl (Sevin®) were developed and widely used, often in combination with organochlorines. The prevailing philosophy was toward further exploitation of the chemical control technology as new and more complex arthropod pest problems arose.

EMERGENCE OF NEW PEST PROBLEMS IN RESPONSE TO INSECTICIDE USE

Sherman (1930) was perhaps the first to observe an outbreak of a secondary pest in response to insecticide use in cotton. He reported that bollworms were much worse in fields where calcium arsenate had been used for boll weevil control, but he had no explanation for the event. Later Ewing and Ivy (1943) confirmed Sherman's observation by showing that the use of insecticides could cause an increase in bollworm infestations resulting from loss of natural enemy efficiency. The emergence of the cotton aphid as a cotton pest following use of calcium arsenate for boll weevil control (Gaines *et al.*, 1940) is another early product of the disruption of naturally-occuring biological control agents.

Observations were reported that the new organic insecticides were highly toxic to a wide variety of arthropods other than pest species. Soon after, resurgence of pest populations and the emergence of new pests were observed. It was demonstrated as early as 1947 that the organochlorine insecticides were much more toxic than calcium arsenate to the predaceous arthropod complexes in cotton fields (Newsom and Smith, 1949). These authors observed that predator population densities were reduced more in cotton plots treated with organochlorines than in plots treated with calcium arsenate. Also, bollworm/ tobacco budworm populations were found to be inversely proportional to predator populations.

Within a few years of the introduction and widespread use of the synthetic organic insecticides on cotton, the bollworm evolved from an occasionally occurring pest to a major pest occurring annually across much of the Cotton Belt. During the same period, the tobacco budworm, *Heliothis virescens* (F.), arose from relative obscurity to become a major cotton pest. Spider mites, previously unknown as pests of cotton over most of the Cotton Belt, also achieved widespread pest status. Other arthropod pests have followed this same pattern as a consequence of synthetic organic insecticide usage.

DEVELOPMENT OF INSECT STRAINS RESISTANT TO INSECTICIDES

The use of insecticidal mixtures temporarily solved problems resulting from changes in pest status of various arthropod species. For example, BHC-DDT-sulfur mixtures gave excellent control of the insect pest complex of cotton and satisfactory suppression of spider mites for several years. The prevailing philosophy of insect control during this era was to add another insecticide to the spray tank as new pest problems developed.

A far more serious problem began to develop within five years after chlorinated hydrocarbon insecticides were adopted for general use on cotton; resistant populations of the cotton leafworm and the cotton aphid were reported (Newsom, 1970). The significance of this phenomenon was not realized until resistance to the chlorinated hydrocarbon insecticides in populations of boll weevil in Louisiana was reported in 1955 (Roussel and Clower, 1957). In the case of the boll weevil, the major change was increased use of insecticide mixtures or wholesale switches from the organochlorines to the organophosphates. To date, the boll weevil has not developed strains resistant to the organophosphates, and representatives of that chemical class are still widely used for weevil management.

Control difficulty with the bollworm/tobacco budworm complex was first encountered during the late 1950s when field efficacy of DDT decreased. Resistance to DDT in strains of bollworms/tobacco budworms generally occurred across the Cotton Belt by 1970, and populations of these species were resistant to endrin, carbaryl (Sevin®) and toxaphene-DDT by 1980 (Sparks, 1981). The switch from chlorinated hydrocarbon insecticides to organophosphates, notably methyl parathion, provided a short-term solution. Methyl parathion resistance in the tobacco budworm appeared in Texas in the late 1960s (Whitten and Bull, 1970) and in most other regions of the United States

Cotton Belt during the 1970s. Although organophosphorous insecticide resistance in the bollworm was reported for several states, the levels of resistance were much lower than those in tobacco budworm (Sparks, 1981).

Since the introduction of the pyrethroids in 1978 as highly effective, economical insecticides for bollworm/tobacco budworm control on cotton, there has been great concern that their overuse would result in the development of pyrethroid resistant strains. This concern was particularly relevant because DDT and the pyrethroids have demonstrated degrees of cross-resistance (Sparks, 1981). Since the mechanism of resistance was known to be of the knockdown resistance or target insensitivity type, bollworm or tobacco budworm strains possessing the resistance gene would be resistant to all pyrethroids (Plapp *et al.*, 1989). As predicted, resistant strains of the tobacco budworm have developed in response to intensive selection pressure by pyrethroids (Crowder *et al.*, 1984; Martinez-Carrillo and Reynolds, 1983; Luttrell *et al.*, 1987; Staetz, 1985). A coordinated effort of pyrethroid resistance management is currently underway in the United States to stem pyrethroid resistance development in the tobacco budworm (Plapp *et al.*, 1990). This program has been embraced by most cotton producers, consultants, extension workers and chemical industry representatives in hopes of continued successful use of the pyrethroids on cotton, as replacement insecticides are yet undeveloped.

The success of this resistance management strategy appears threatened by proponents of full-season cotton insect control who advocate the "womb-to-tomb" philosophy of insect control with little regard to the economic threshold concept and the application of insecticides based upon need. Entomologists have warned that the short-term benefits accrued through full-season application of insecticides do not justify creation of the catastrophic problems that are known to be products of the overuse of insecticides. But, history seems to have a way of being repeated.

Resistant strains of many other arthropod pests (e.g. cotton aphid, beet armyworm) of cotton have developed across the Cotton Belt in response to our insecticide use patterns, but these are too numerous for discussion here. A complete discussion of the insecticide resistance phenomenon is presented by the National Research Council (1986).

DEVELOPMENT OF SYNTHETIC DIETS FOR COTTON INSECTS

Among the most significant research achievements on cotton insects were the early nutritional studies which led to the development of synthetic diets for boll weevil, pink bollworm and the bollworm/tobacco budworm (Vanderzant and Reiser, 1956; Vanderzant and Davich, 1958; Vanderzant *et al.*, 1962). The contributions of R. T. Gast Laboratory (Mississippi State, Mississippi) toward mechanized rearing and mass production of cotton insects must also be noted (Gast, 1961). Many others contributed toward the present technology for laboratory rearing of large numbers of quality insects which, in most aspects, physiologically and behaviorally mimic their field-produced counterparts. Rapid advancements in the knowledge of insect diapause, pheromones, resistance, nutrition and many other critical entomological areas have been achieved since the advent of artificial diets and other rearing technology.

REPRODUCTION-DIAPAUSE CONTROL OF BOLL WEEVIL

As previously reported, entomologists early in this century recognized that the boll weevil was most vulnerable to management tactics applied during the overwintering period; thus, cultural controls were employed against the late-season population. However, the diapause phenomenon in the boll weevil was not described until 1959 (Brazzel and Newsom, 1959). Once the diapause phenomenon and its temporal (of or relating to time) development was described, the concept of "reproduction-diapause" control of the boll weevil was advanced (Brazzel *et al.*, 1961; Lloyd *et al.*, 1966). This system is based on denying diapausing boll weevil populations access to the amount of food required to accumulate sufficient fat to successfully overwinter. A combination of insecticide applications, chemical defoliation, rapid harvest and stalk destruction is employed to achieve the objective of killing outright or starving weevils that would otherwise constitute the overwintering population. Where the "reproduction-diapause" control system has been enacted over a wide area, boll weevil populations in the subsequent year often have not reached economically damaging levels (Rummell and Frisbie, 1978). Much of the success of the Southeast Boll Weevil Eradication Program must be attributed to the proper application of this technology as it is the "backbone" of the program (Brazzel, 1989).

THE DISCOVERY, DEVELOPMENT AND UTILIZATION OF PHEROMONES

Soon after Karlson and Luscher (1959) coined the term "pheromone" to designate chemical substances secreted by an animal to influence the behavior of other animals, laboratory and field tests confirmed pheromone communication in the boll weevil (Bradley *et al.*, 1967; Cross and Mitchell, 1966; Cross *et al.*, 1969; Keller *et al.*, 1964). The design and construction of an olfactometer (Hardee *et al.*, 1967) that permitted rapid, accurate assessment of air-borne odors was a significant development that led to the isolation, identification and synthesis of the boll weevil pheromone (Tumlinson *et al.*, 1969).

Pheromones were demonstrated in the tobacco budworm and bollworm in the early 1960s (Gentry *et al.*, 1964; Berger *et al.*, 1965), but their identification was not accomplished until ten years later (Roelofs *et al.*, 1974; Tumlinson *et al.*, 1975). At about the same time, the sex pheromone of the pink bollworm was identified (Hummel *et al.*, 1973; Bierl *et al.*, 1974).

Over the past two decades, very significant advancements in pheromone technology have occurred. Synthetic pheromones and dispensing systems are now commercially available for the major insect pests. Pheromones are key components of management and eradication programs for they are the only practical tools available for effectively detecting low-level pest populations. The evaluation of control strategies and studies of population dynamics and dispersal are among the research areas significantly enhanced through pheromone technology. Furthermore, the use of pheromone systems to disrupt sexual communication and to annihilate males appears to be a promising management tactic for the pink bollworm (Henneberry and Beasley, 1984). Similar concepts may eventually be employed as components in management or eradication programs for the boll weevil and the bollworm/tobacco budworm.

THE EVOLUTION OF THE INTEGRATED PEST MANAGEMENT CONCEPT

The conflict between California entomologists—one group advocating insect control with chemicals and a competing group that wanted to utilize biological controls to regulate insect pest populations—spawned the first use (Stern *et al.*, 1959) of the term "integrated pest control." The concept emphasized the integration of the tactics of biological control and chemical control toward the alleviation of insect pest problems. This approach received impetus from the phenomena of pest resistance to insecticides, pest resurgence, secondary pest outbreaks and widespread environmental ailments that had become frequent problems associated with the increased dependency on organic insecticides for insect pest control. While there was general agreement among entomologists that this single-method approach to effective insect control was neither possible nor desirable, many felt that the integrated control concept needed to be expanded to embrace all possible control tactics. A much broader concept, "pest management", rapidly evolved in which all available techniques are evaluated and may be consolidated into unified programs designed to manage pest populations so that economic damage is avoided and adverse side effects on the environment are minimized (National Academy of Sciences, 1969). The contemporary integrated pest management concept (IPM) became a political and intellectual entity during the 1970s through a major research program known as "The Huffaker Project" (Perkins, 1982). This National Science Foundation/ Environmental Protection Agency supported project assumed a lead role in providing the mechanisms for multidisciplinary plant protection as a component of crop production.

Other programs initiated in the 1970s that significantly advanced the IPM concept were: (a) pilot projects for implementing extension pest management programs in all cotton-producing states; (b) pilot pest management research projects within the USDA's Agricultural Research Service; (c) the project of the Consortium for Integrated Pest Management (CIPM); and (d) curriculum development for training and certification of crop production specialists by the land-grant universities. These actions were paralleled with an intensification of integrated pest management research within state agricultural experiment stations and federal agencies financed by both state and federal sources.

The IPM concept requires an indepth knowledge of the agroecosystem to be successfully implemented. The analysis of all factors and processes in the crop's production and protection, and the effects of abiotic factors on these development processes as well as their interactions is far too complex for intuitive solutions. It was soon realized that a new technology was needed that could utilize the power of computers and systems analysis in a manner similar to that pioneered by the fields of engineering, industry and commerce. Computer technology has been developed and is now utilized in all phases of IPM, environmental monitoring, biological monitoring and the information delivery systems. Crop production models are being perfected that will guide farmers and consultants toward optimal decision making for increased profitability. Promising developments in the areas of expert systems and artificial intelligence provide even greater hope for the future.

The culmination of the IPM concept and its promotion has been the development of ecologically sound pest management systems that are both effective and economical. Multitactical management programs have evolved to replace the programs of the 1950s and 1960s that almost solely relied on chemicals for insect control. These more sophisticated, modern-day systems are made possible because of a much expanded knowledge of the agroecosystem, computer technology and a great increase in trained personnel from the public as well as private sectors.

According to Adkisson (1986), IPM has had two major impacts: one on science and the other on agricultural production. Scientifically, IPM research has expanded our knowledge of basic ecological and physiological principles governing insect population dynamics, insect behavior and crop-pest interactions. It has also pioneered the use of systems science in agriculture. Furthermore, IPM has reshaped crop protection philosophies and has provided the mechanism for long-term, more sustainable agricultural productivity.

There are numerous outstanding examples that could be used here to document the impact of the IPM concept on cotton production in the United States, but none more impressive than the "short-season" cotton production systems that were developed in Texas in the 1970s (Parker *et al.*, 1980; Namken *et al.*, 1983). Entomologists, agronomists, economists and other cotton specialists structured low-input production systems which minimized insect damage potential and the problems previously associated with total reliance on chemicals for insect control. The short-season concept resulted in increased profitability of cotton production in all regions of Texas where it could be practiced and impacted cotton production systems across the Cotton Belt. Other notable cotton IPM programs include the "Community-Wide Bollworm Management Program" implemented in Arkansas (Phillips *et al.*, 1980; Frisbie *et al.*, 1983) and the "Optimum Pest Management Trial" conducted in Mississippi (Hamer *et al.*, 1983). These IPM programs and the concepts upon which they are based will be discussed in more detail in other chapters of this monograph.

INTRODUCTION OF THE PYRETHROID INSECTICIDES

The pyrethroids were introduced as a new class of insecticides in the United States cotton market in 1978. They offered great promise for insect pest control because they were highly effective, particularly against bollworm/tobacco budworm, and they did not pose the environmental problems associated with other organic insecticide classes. Problems of persistent residues and biological magnification in food chains (typical of many organochlorines) and acute toxicity and adverse effects on crop physiology (typical of certain organophosphates) were not associated with the pyrethroids. For the first time, highly effective insect control could be achieved on cotton without obvious adverse environmental effects.

The pyrethroids gave a decade of unparalleled cotton insect control and provided a "fail-safe" mechanism that allowed for the unprecedented application of the economic threshold concept. Therefore, they were far superior to other insecticide classes for IPM programs. Throughout most of the Cotton Belt, management programs based upon pyrethroid use ensured minimum losses to insect pests and maximum crop production potential. Overall cotton production, on a per-acre basis, for the first ten years following introduction of the pyrethroids, was the highest in history.

The many positive attributes of the pyrethroids have led to greater dependence on this class of chemicals, not only for control of insects on cotton, but on many other crop hosts of cotton pests. Furthermore, the simplicity of insect management afforded by the pyrethroids has led to a ground-swell of support for return to the philosopy of full-season insecticide control that prevailed during the 1950s and 1960s. This short-sighted approach threatens the long term existence of the pyrethroids as effective tools for cotton insect management. Strains of the tobacco budworm that are resistant to the pyrethroids have evolved in many United States cotton production regions in response to the intensive selection pressure of current management programs. The return to sensible approaches to insect control, including resistance management strategies for the pyrethroids, is an absolute necessity because of a rapidly declining insecticide arsenal.

BOLL WEEVIL ERADICATION

Elimination of the boll weevil from the United States Cotton Belt became the goal of entomologists and the cotton industry very soon after the pest entered Texas in the late 1800s. Early attempts at eradication failed because the necessary technology was unavailable; thus the concept of boll weevil eradication lay dormant for 50 years.

The successful eradication of the screwworm, *Cochliomyia hominovorax* (Coquerel) from the southeastern United States, and resistance to the chlorinated hydrocarbons in Mid-South boll weevil strains provided impetus for revival of the goal of boll weevil eradication. The introduction and passage of a resolution at the 1958 annual meeting of the National Cotton Council, which declared the boll weevil as the number one enemy of cotton production, signaled a renewed effort to eradicate the boll weevil from the United States (Perkins, 1982). This resolution resulted in monies to construct the Boll Weevil Research Laboratory (Mississippi State, Mississippi). This Laboratory developed and refined the technologies, which justified pilot eradication tests leading to operational eradication programs.

THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT (PBWEE)

The three-year Pilot Boll Weevil Eradication Experiment (PBWEE) (1971-1973) was designed to determine the technical and operational feasibility for eliminating a boll weevil population from a delineated area by use of available population suppression techniques (Parencia, 1978). The PBWEE was jointly conducted by federal and state personnel in southern Mississippi. Results of the PBWEE were inconclusive as boll weevils were found in pheromone traps within the core area during program evaluation and there was no way to acertain their origin (Perkins, 1982; Pencoe and Phillips, 1987). The general conclusion was that the basic technology necessary to achieve eradication required improvements in several areas and that further demonstrations must be conducted in a region with greater isolation.

THE BOLL WEEVIL ERADICATION TRIAL (BWET)

The Boll Weevil Eradication Trial (BWET) was conducted in northeastern North Carolina and adjacent Virginia from 1978 to 1980 to demonstrate conclusively that eradication of the boll weevil was technically possible. The site chosen provided the desired degree of isolation from other cotton producing regions. The BWET was a much more successful program as results indicated that it was highly probable (0.9983 level of probability) that the native boll weevil population was eradicated from the core evaluation area (Knipling, 1983; McKibben and Cross, 1984). Though cotton in North and South Carolina is now weevil free, it is continually monitored in such a way to maintain this status. The expanded program in Georgia, South Alabama, and Florida is in the final stages of eliminating the boll weevil as an economic pest. Suppression comparable to that obtained in the original North Carolina/South Carolina program appears attainable.

BELTWIDE ERADICATION PROGRAM

The successful results from the Boll Weevil Eradication Trial (BWET) provided the incentive to extend the eradication program from North Carolina westward across the Southeast. The program has passed through the Carolinas and is in the latter stages of completion in Georgia, Florida and South Alabama. The boll weevil is no longer an economic pest in the Carolinas, Georgia, Florida and Southeast Alabama. While total elimination (eradication) of the species appears improbable, the BWET results and subsequent benefits to the cotton industry in the area confirm that total population management over a large geographic region may be the optimum management strategy to employ against the boll weevil in the Southeast (Carlson and Suguiyma, 1983).

A boll weevil eradication program was initiated in the western United States concurrently with the expansion of the southeastern program (Brazzel, 1989). Boll weevil populations have been dramatically reduced in the West (Arizona and California), and it is no longer viewed as an economic pest.

A thorough discussion of the above eradication programs including the specific technology utilized in each is presented in Chapter 19 of this book.

SUMMARY

Because of the limitations imposed on cotton production by arthropods, entomologists over the past century have diligently sought methods to limit growth of arthropod populations or to eradicate them. Many technological advancements have been made toward understanding insect behavior and physiology and the interactions of insects with their hosts and other arthropods. Much progress has been achieved toward describing insect population dynamics and the many factors affecting insect numbers. Management tactics and systems have been developed and effectively utilized as well as exploited. The challenge of beltwide boll weevil eradication remains. However, continued success of southeastern and southwestern eradication programs justifies the belief that the boll weevil eventually can be eliminated as an economic pest in the United States.

Cotton insect management will remain an exciting and dynamic endeavor characterized by the resolution of one problem and the genesis of another, ad infinitum. Presently, the silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, and its biotypes pose a perplexing problem of mammoth proportions, particularly in the desert valleys of the Southwest. What will be the next challenge for cotton entomologists?