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 Güidance 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).

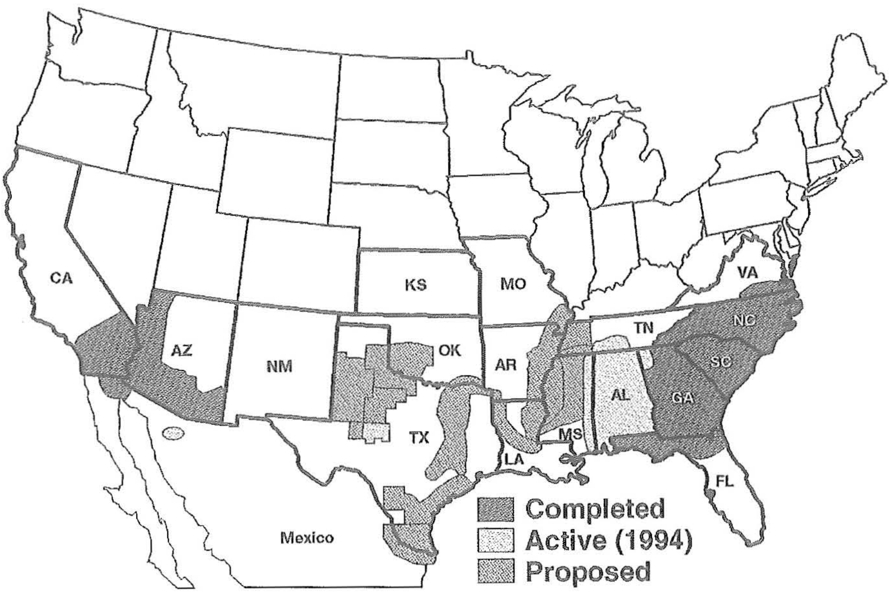

Figure 1. Increments of boll weevil eradication. Areas where boll weevil eradication is complete are heavily shaded. Areas where eradication is currently active are lightly shaded. Areas proposed for eradication (contingent on approval of grower referenda) are moderately shaded. (Figure provided courtesy 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 area-wide 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.