Chapter 20

INSECT AND MITE PEST MANAGEMENT IN THE SOUTHEAST

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INTRODUCTION

The economy, indeed the history, of the Southeast (Alabama, Florida, Georgia, North Carolina, South Carolina and Virginia) has been intimately tied to the production of cotton. Insects and mites have been major factors affecting the success of cotton culture, and as such, have influenced the history of the region.

Although wild cottons were discovered in 1528 growing in the territory that is now the states of Louisiana and Texas, the first commercial United States production occurred in the Jamestown settlement of Virginia in approximately 1621. North Carolina traces its cotton production back to 1664 when colonists from Barbados planted cottonseed at Cape Fear. South Carolina started producing cotton early in its colonial history, and became an early exporter, shipping the first boatload from Charleston in 1754. Cotton was soon produced in every county, and until 1825, South Carolina was the leading cotton-producing state (Frank, 1985).

Georgia's cotton history parallels that of other southeastern states. The first cotton in Georgia was grown in Trustees Garden, Savannah, in 1733. Cultivated commercial cotton was introduced in 1734 by Philip Miller. Seven years later, a sample of Georgia grown cotton was sent to England where it became known as "Georgia Cotton" and in France, as "Sea Island Cotton." Until slavery was allowed in the Georgia Colony in 1749, most cotton was consumed domestically. But with the advent of slave labor, production increased and cotton became a major export (Linden, 1954). By 1825, Georgia passed South Carolina as the nation's leading producer. Production increased in Georgia until 1911 when nearly five million acres were planted to cotton.

Florida, historically, has never been a major producer of cotton, although cotton was cultivated as early as 1765 along the St. Johns River. Alabama traces its cotton production back to pre-Revolutionary War years when cotton was planted along the Tensas and Tombigbee Rivers and in French settlements near Mobile. Cotton acreage increased until Alabama rivaled Mississippi in production by 1840 (Frank, 1985).

The boll weevil entered the United States from Mexico in 1892, and spread at the rate of 40 to 160 miles per year entering Alabama about 1910 (Howard, 1895; Gaines, 1952; Metcalf *et al.*, 1962). The boll weevil invaded Georgia in 1916, and by 1923 was causing considerable damage. Yield dropped to 90 pounds per acre in 1921 in Georgia compared to 314 pounds in North Carolina, a state only lightly infested at that time (Brown, 1938).

Although many factors were involved, a single insect pest, the boll weevil, contributed significantly to the decline of cotton in the Southeast. Georgia, for example, grew five million acres in 1911, prior to infestation by the pest. By 1978, only 115,000 acres were devoted to the crop (Snipes and Hammer, 1984). But improved pest management practices in the late 1970s and 1980s—including the use of pyrethroids, faster fruiting cotton varieties and production practices designed to shorten the fruiting season—stimulated new interest in cotton. Elimination of the boll weevil contributed to increased plantings in the Carolinas in the early- to mid-1980s, and increasing yields and improved profitability caused Georgia's acreage to triple by the late 1980s.

The Southeast is in a transition period because of the boll weevil eradication program. Elimination of the boll weevil has been and will continue to be the dominant factor determining overall cotton insect management strategies. This chapter traces cotton insect control technology from the early 1900s through the 1980s, and emphasizes the role of the boll weevil and eradication efforts now and in the future. The authors hope that our experience may serve as a guide to those who may yet become involved in similar eradication programs and the changes they inevitably cause.

EVOLUTION OF CONTROL TECHNOLOGY

EARLY CONTROL EFFORTS

Cotton insect control really began in the Southeast with the arrival of the boll weevil into southwestern Alabama in 1909. By this time reports indicated that the boll weevil was already causing at least $200 million in damage annually in the remainder of the United States. Within nine years the weevil had completed its trek across

Alabama and was advancing through Georgia and into the Carolinas. By 1922 the weevil had infested the entire cotton producing area of the eastern United States.

All this took place despite monumental efforts by farm leaders of that day to halt the weevil's advance. Yet, the transition from quarantines to mechanical and cultural devices to poisons is a dramatic story that involved entomologists, agronomists, chemists and engineers.

The first move by Alabama was passage of a quarantine law in 1903. It was intended to prevent the weevil from hitching rides to fresh territory in seed cotton, old pick sacks, cottonseed, Spanish moss, and even household goods. Transport of such items from infested to weevil-free territory was prohibited.

But the weevil was no respecter of law. Under favorable weather conditions it enveloped 75 to 100 mile strips of "new territory" in a year.

Forefront in the fight were farmers, bankers, businessmen and personnel of the Alabama Polytechnic Institute's Agricultural Experiment Station. Beginning in 1904, the Alabama Station produced many publications concerning the boll weevil, methods of combating the pest and even one on "Heading Off Boll Weevil Panic".

With no known insecticide effective against the weevil, the logical attack was to cut off its food supply. Destruction of green cotton at least three to four weeks before usual killing frost was recommended. This was said to be the most important single step in a cultural system under boll weevil conditions. There were those that predicted that in the presence of weevils there could never be late-cotton. In addition to planting early, various mechanical contraptions were devised. Two such devices used were chain drags to sweep fallen, infested squares into middles for exposure to the hot sun; and a long sack fastened to a sugar-barrel hoop for collecting overwintered weevils and infested squares on young cotton.

Before the boll weevil migrated across the Rio Grande River into Texas in 1892, very little insect and spider mite damage occurred to cotton. Occasionally there would be outbreaks of armyworm or the cotton leafworm (many current growers, consultants and entomologists have never seen these pests). The arsenical insecticides were about all that was available to control these pests. These insecticides were commonly known as Paris Green, London Purple, lead arsenate and calcium arsenate. Another sporadic pest was the cotton aphid. Nicotine sulfate dust was sometimes used to control this insect. Buildups of aphids occurred as far back as the late 1800s when weather conditions were abnormal or when the good and harmful insects got out of balance.

However, the boll weevil changed much of this balance since it had few natural enemies. It has been very difficult to profitably produce cotton in the United States with a natural biological balance since the invasion of the weevil. Once insecticides were used for weevils, artificial man-made balances between insects in cotton fields were established.

THE ARSENICAL ERA

The first insecticide recommended for controlling the boll weevil was a mixture using Paris Green, London Purple or lead arsenate in combination with molasses.

These combinations were used in the late 1800s and early 1900s. Lack of adequate formulations and application technologies were major problems with these insecticides.

The first Alabama experiments involving calcium arsenate were in 1918 at Auburn, Hartford and Smyrna, Alabama. In 1923, improved weevil control was obtained by applying undiluted calcium arsenate dust by airplane. This technique had been used the previous year to control the cotton leafworm. Dusting with calcium arsenate from airplanes proved to be very successful in Georgia and Texas during the period 1925 to 1927. Aerial dusting became the primary method of applying insecticides for the boll weevil on large acreages of cotton until the early 1950s. Between 1919 and 1925, the use of calcium arsenate increased from 3 million to 15 million pounds. This is in sharp contrast with today's rates of pyrethroids where both weevils and bollworms can be controlled on many acres within the Cotton Belt with less than one pound of insecticide per acre per season. The production of calcium arsenate had increased to 84 million pounds by 1942. During the period from 1919 to 1948, it has been estimated that United States cotton fields received a total of about 850 million pounds of calcium arsenate.

Unfortunately, calcium arsenate was toxic to the beneficial insects which served as enemies for the cotton aphid. As a result the aphid became a serious problem and nicotine sulfate had to be added to the arsenical dust. About one million pounds of nicotine sulfate were produced between 1928 and 1940. Most of this was used on cotton and by 1945 growers were applying about 1.5 million pounds annually. It was during this period that the bollworm became a significant pest of cotton. As was the case with the cotton aphid, this was caused by the destruction of the beneficial insects by calcium arsenate. However, adequate control of the bollworm was maintained because the larvae were fairly susceptible to calcium arsenate.

Calcium arsenate also had an effect on the natural enemies of the cotton fleahopper and the tarnished plant bug, and sulfur dusts were added to control these pests and outbreaks of "red" spider mites. However, during the arsenical era of cotton insect control, most insecticides were applied for the boll weevil.

ARRIVAL OF ORGANIC INSECTICIDES

Calcium arsenate was to remain for almost 30 years as the standard insecticide for boll weevil control. Following World War II came new organic compounds—the chlorinated hydrocarbons (DDT, BHC, toxaphene, heptachlor, dieldrin and endrin) and the organic phosphates (parathion, malathion, methyl-parathion, and Guthion®).

Control of the boll weevil and other cotton pests shifted from an ecological (management) or cultural to a chemical approach. However, over the following ten to fifteen years, problems developed such as insecticide resistance, secondary pest outbreaks, environmental damage and increased insect control costs.

Chlorinated Hydrocarbons — In 1945 the chlorinated hydrocarbon (or organochlorine) insecticide DDT became available for grower use. DDT brought about a revolution in cotton insect control. DDT was a long-lasting contact insecticide which was oil-soluble and could be applied as a spray. Applications by plane with low volume sprays almost totally replaced dust applications. Later BHC and toxaphene also became widely used cotton insecticides. They were followed by aldrin, dieldrin, endrin, heptachlor and DDD (TDE).

The United States production of DDT increased to 164 million pounds by 1960. In addition, almost 200 million pounds of BHC and aldrin-toxaphene were being used annually by 1960. Some estimates indicate that up to one-third of all the organochlorine insecticides produced between 1945 and 1960 were applied to cotton.

These insecticides provided two important advantages. First, they were highly effective against a wide variety of pests. Second, they were very persistent or had long residual pesticidal activity which made it possible to control newly emerging insects or insects migrating into treated areas.

Spectacular yield increases were obtained for many years, and growers were producing cotton at a high profit level. At this time it appeared that all our cotton pest problems were solved forever. However, these insecticides also killed the parasites and predators of the damaging cotton insects and often resulted in "red" spider mite buildups. In addition, environmental problems began developing. This long residual activity also proved to be a disadvantage. Some of these insecticides were also shown to build up or magnify as they passed up food chains to higher animals.

Most growers know the "rest of the story" about the DDT related insecticides. All are now gone as insecticides in United States agricultural production. Perhaps the evidence against them was not always presented accurately, but that is all history now.

Organic Phosphates — In 1955, boll weevil resistance to DDT, toxaphene, endrin and related compounds was discovered. This resulted in a gradual but significant shift to organophosphorus insecticides such as parathion, methyl-parathion, Guthion®, malathion and EPN.

These materials were effective against the boll weevil at lower rates than the DDT-related chemicals. However, the parathions were not as effective in controlling bollworms and tobacco budworms, which became major pests about that time.

To control all the major pests, growers then began applying mixtures of DDT, toxaphene, endrin, methyl parathion, Guthion®, malathion, and EPN. Many can still remember the old days when the standard insecticide was 4-2-1 (toxaphene, DDT and methyl parathion). It was used at one gallon per two acres.

At first these mixtures gave good control of boll weevils, bollworms and budworms, aphids, fleahoppers, plant bugs, armyworms and spider mites. During this period of the late 1950s growers expected, and essentially obtained, cotton fields that were sterile of all insects.

SCOUTING AND IPM

Cotton "scouting" began in the late 1950s in the Southeast. Arkansas and Mississippi in the Mid-South and Alabama in the Southeast were the first three southern states to train and promote extension scouts to growers. In Alabama, for example, one scout was employed in 1959 and the program expanded slowly through the 1960s. By 1968, 26 scouts were employed and the number increased to 87 in 1972, the first year of the intensified scout promotion that was to usher in the decade of the 1970s. Between 1972 and 1987, over 4,000 persons attended scout training shortcourses in Alabama alone. In recent years over 95 percent of all cotton acres in Alabama have been scouted by extension service trained scouts, private consultants or trained growers. Other southeastern states have followed similar patterns.

In the late 1960s, budworms developed a resistance to DDT in the Southeast. Within a few years, budworm resistance increased in other southeastern states and in Arkansas and Mississippi. Resistance reached such high levels that it was nearly impossible to control budworms with any insecticide.

In the late 1960s and the early 1970s, it was obvious that growers would need insect control strategies other than insecticide applications. It was at that point that the idea of integrated pest management (IPM) was brought back into being. Management practices taught and used in the early 1900s had been left behind when new, effective insecticides became available. In the early 1970s, those management strategies, such as cultural practices, gained new educational emphasis under the term "IPM". Additional persons were employed in pest management positions. Scout training, sampling techniques, life cycles and the use of treatment thresholds were emphasized.

In December 1972, EPA banned the use of DDT on cotton. The ban resulted in a shift to a more intensive use of the organophosphate insecticides in combination with toxaphene or endrin. Insect control became more costly and the application of the chemicals became more dangerous to loaders, mixers and applicators. At the same time, the chemicals became less effective, despite the development and widespread use of the first ovicide, chlordimeform (Fundal®, Galecron®).

ARRIVAL OF THE PYRETHROIDS

Since 1977, cotton growers in the Southeast have utilized pyrethroids as the foundation of their cotton insect control programs. Organophosphate insecticides were tank-mixed for control of boll weevils and occasional secondary pests. Some carbamates were used for armyworm outbreaks.

Growers experienced another period of excellent insect control in the earlier years of pyrethroid use. However, after five to seven years, secondary pests began emerging as problems.

During the early and mid-1970s, the greatest problem facing cotton producers was delayed maturity. With very few exceptions, delayed maturity has not been a problem since the pyrethroids became available in the late 1970s for widespread use. Since the type of insecticide was the only production practice that changed distinctly during the late 1970s, it is possible that the use of pyrethroids had more to do with eliminating delayed maturity than any other factor.

When looking at yields since the pyrethroids entered the marketplace, a significant upward trend can be observed. When the extremely hot and dry years of the 1980s are considered, this trend strongly suggests that improved insect control has been a major factor in increased yields.

DEVELOPMENT OF RESISTANCE TO PYRETHROIDS

Due to development of resistance to the pyrethroids, by the late 1980s the greatest single concern of cotton entomologists was how to most effectively extend the life of this important group of insecticides. Concern among some entomologists about resistance actually began about the time the pyrethroids entered the market. This was probably due to several reasons. Problems associated with tobacco budworm resistance to organophosphate insecticides were still fresh on the minds of entomologists. Additionally, the pyrethroids have a similar mode-of-action (killing mechanism) as some of our earlier organochlorine insecticides against which resistance had developed. Finally, pyrethroids were extremely effective. This meant that the selection pressure for resistance was high.

Pyrethroid use on cotton in the United States was going along quite smoothly through the 1983 season. Growers, consultants and many entomologists paid little attention to the potential for development of resistance. Other than a few areas in the western states where budworms changed their tolerance to pyrethroids from year to year, little evidence for increasing resistance was present.

However, this changed suddenly with a report from Australia in January of 1984. This report confirmed what a few entomologists had been fearful of—the Australian bollworm had developed resistance to all the pyrethroids. This same bollworm had previously developed resistance to earlier insecticides such as DDT, parathion and others.

Several factors involved in the Australian cotton production situation were different than most of the United States Cotton Belt. First of all, it was a dry, arid location where the cotton was irrigated. All other crops grown in this area, such as sorghum, were also irrigated and treated with pyrethroids. This means that there were few alternate crops or wild hosts for bollworms where they were not being exposed to pyrethroids. Therefore, the selection pressure was heavy. The Australians quickly determined that other insecticides such as Bolstar®, Curacron®, Thiodan®, Galecron®, Fundal®, Lannate® and Nudrin®, were still effective against their bollworms. A spray strategy using these materials was developed for the 1984 crop year. Indications at this time are that this strategy has bought some time, but may not offer a long-term solution to the problem. Resistance levels fall after each crop season, but not to levels of the previous season.

However, during the 1984 crop year, several countries around the world reported pyrethroid resistance by their bollworm species. Then, in late- season 1985, late maturing cotton fields near Uvalde, Texas had high numbers of tobacco budworms. Pyrethroid insecticides were applied and all failed to give acceptable control. In 1986, additional pockets of control problems began occurring. The College Station area of Texas, Louisiana, the Mississippi Delta and even the Tennessee Valley area of northern Alabama had control failures with all pyrethroid insecticides. In the meantime, researchers monitoring budworm larvae confirmed resistance. Therefore, entomologists began developing plans of action to delay the spread of this resistance and prolong the life of pyrethroid insecticides. A basic part of this plan for the United States was to produce the earliest crop of cotton possible and to not use pyrethroids against the late May-early June generation of tobacco budworms.

In summary, it appears that the resistance of tobacco budworms to pyrethroids is present. There are those that feel that the ultimate fate of all insecticides is resistance. History supports this thinking. The question that no one has an answer for is " how much time do we have?" Growers and consultants control part of the answer to this question. How pyrethroids are used will likely have a major impact on how long they are effective.

At this time the pyrethroids continue to do an excellent job on bollworm-budworm control in most areas of the Southeast. One disadvantage of certain pyrethroids is that they do not control secondary pests such as spider mites and aphids. Also, most pyrethroids are rather ineffective on armyworms. Third, they are not as effective as organophosphates on boll weevils when used on longer intervals common with bollworm schedules. Some of the new pyrethroids currently under development may initially overcome some of these disadvantages.

History must ultimately evaluate the manner in which this remarkable class of insecticides was employed. Thankfully this era is not over.

BOLL WEEVIL ERADICATION: A SUMMARY OF PROGRAM EVENTS AND EXPANSIONS IN THE SOUTHEAST

THE BOLL WEEVIL ERADICATION TRIAL

The current Southeastern Boll Weevil Eradication Program evolved from The Boll Weevil Eradication Trial which was conducted from 1978 to 1980 in northeastern North Carolina and southeastern Virginia. The Eradication Trial was accompanied by an Optimum Pest Management Trial conducted simultaneously in Panola County, Mississippi. The objective of the Optimum Pest Management Trial was to test and demonstrate the ability to manage the boll weevil and other cotton insects on an area-wide basis. The objective of the Boll Weevil Eradication Trial was to test and demonstrate the technological and operational capability to eradicate the boll weevil from a geographically specified area.

The Boll Weevil Eradication Trial was conducted under the authority of the North Carolina Uniform Boll Weevil Eradication Act passed by the North Carolina General Assembly in 1975 as amended in 1977 (Chapter 106, Article 4F of the North Carolina General Statues). Subsequently, a grower referendum was conducted and received the required two thirds support for passage. Funding for the Eradication Trial was provided by the growers (50 percent), states of North Carolina and Virginia (25 percent) and the federal government (25 percent). The grower cost of the three-year Trial Program was estimated to be $100.00 per acre. Actual grower cost was $89.86 per acre. The Trial Program began in the spring of 1978 and concluded in December, 1980. Components of the program included both border and infield pheromone traps; pinhead square, in-season and diapause applications of insecticides, including diflubenzuron (Dimilin®); and the release of sexually sterile insects in 1979. During 1978 only, the control of all cotton insects after June 30 was the responsibility of Program personnel and was included in the cost of the Boll Weevil Eradication Program. The Biological Evaluation Team reported that, with a probability of at least 0.9983[1], the boll weevil was eradicated from the Trial Program Area (Anonymous, 1981).

Operational details of this Trial Program, including boll weevil captures, are discussed by Ganyard *et al.* (1981). A comprehensive review of the results of the Eradication and Pest Management Trials is provided by Lloyd *et al.* (1981) and Parencia *et al.* (1981), respectively. The economic impact of eradicating the boll weevil from the Trial Program Area is discussed by Carlson and Suguiyama (1983).

Upon completion of the Eradication Trial in 1980, a Boll Weevil Containment Program was initiated to prevent the reinfestation of the Trial Eradication Zone; concurrently, the results of the Trial Program were being evaluated. The Containment Program was funded by the North Carolina and United States Departments of Agriculture. In the spring of 1982, cotton producers in the Trial Area voted 90 percent in favor of assessing themselves a $10.00 per acre fee to support containment activities. These activities included: (a) monitoring of all cotton in the Trial Area with boll weevil pheromone traps; (b) suppression of boll weevil populations to below economic levels in the Buffer Zone; and (c) elimination of any reinfestations in the Eradication Zone.

Boll weevil populations outside the Trial Area increased substantially during the period 1981-1983. Dispersing weevils from these populations threatened to reinfest the southern portion of the Eradication Zone in 1982 and 1983. Intensive trapping followed by selected insecticide applications prevented this threat from materializing. Pheromone trap captures of boll weevils and chemical treatments during this period are presented by Ridgway *et al.* (1985).

ERADICATION EXPANSION INTO THE CAROLINAS

By the end of 1981 the evaluation of the Boll Weevil Eradication Trial was nearing completion and USDA policy regarding possible expansion of this Program began to be expressed. In January of 1982, in a speech to members of the National Cotton Council, H. C. Mussman, the Administrator of the USDA Animal and Plant Health Inspection Service (APHIS), stated, ". . . the Department holds the view that the future of cotton insect management is in the hands of the producers and the industry. They and only they can determine what is best or most applicable under different sets of circumstances — one or another of a combination of program options may be chosen in any area. USDA stands ready to contribute its skill and backup to producer-industry initiatives on boll weevil suppression or eradication."

A letter of May 24, 1982, from the USDA Boll Weevil Policy Group to, and concurred with by, Secretary of Agriculture John Block, included the following recommendations: "1. Postpone implementation of beltwide boll weevil programs because

[1]From a statistical standpoint, they were 99.8 percent sure of eradication.

of budget constraints, lack of appropriate regulatory authority to implement the eradication options in several states, and uncertainties associated with economic and operational feasibility of beltwide programs. 2. Assist short-term maintenance of the boll weevil containment area in North Carolina and evaluate the longterm cost effectiveness of containment technology to provide a better basis for evolving management and/or eradication strategies. 3. Facilitate testing and expansion of areawide cotton insect management trials and programs throughout the cotton belt, including possible future expansion of boll weevil eradication in the southeastern United States. Federal support should be determined on a case-by-case basis, through evaluation of state and producer proposals. 4. Continue to provide leadership in the decision making process and in the coordination of program activities. A Departmental position on program direction should include discussions with State Departments of Agriculture, State Agriculture Experiment Stations, Cooperative Extension Services, and grower organizations."

In response to grower and industry requests for possible expansion of the Eradication Program, the USDA and grower leadership established a general funding formula of 70 percent grower and 30 percent Federal. This formula combined with the contents of the speech by APHIS Administrator H. C. Mussman, and the four recommendations from the USDA Boll Weevil Policy Group provides the general framework of federal participation in boll weevil eradication/suppression programs.

Based on this understanding of federal support, cotton producers in the remainder of North Carolina not included in the Trial Area and all of South Carolina, conducted a referendum February 26 to March 5, 1982, to provide grower funding and mandatory participation for the expansion of the Eradication Program into those areas. This referendum passed in North Carolina but was narrowly defeated in South Carolina. Due to the improved cotton harvest and the dramatic resurgence of the boll weevil in these two states in 1982, an additional referendum was held January 21 - 28, 1983. This referendum was approved by 79.2 percent in North Carolina and 72 percent in South Carolina. This Expanded Boll Weevil Eradication Program was initiated with the application of a series of insecticide treatments to prevent boll weevils from entering diapause. The first of these treatments was applied the last week of August, 1983. This Expanded Program differed from the Trial Program in that release of sterile boll weevils, scouting and control of other cotton insects, and extensive use of diflubenzuron (Dimilin®) were not included. Operational components of this Expanded Program consisted of intensive trapping for both detection and suppression and timing of insecticide treatments to prevent weevils from entering diapause and those overwintered weevils that do survive from infesting the pinhead square stage of cotton. A more detailed discussion of the application of this technology is provided by Dickerson (1986). Program status for 1983-1986 as documented by weevil captures in pheromone traps is reviewed by Dickerson *et al.* (1986, 1987). The eradication of the boll weevil as an economic pest from Virginia, North Carolina and South Carolina is reported by Carlson and Suguiyama (1985). They reported that the profitability of cotton production in those states increased by $50 to $70 per acre. To emphasize the importance of the absence of the boll weevil, a funeral service was conducted in North Carolina in March of 1987 to celebrate the weevil's demise.

The expansion of the Boll Weevil Eradication Program to include all cotton grown in Virginia, North Carolina and South Carolina resulted in the establishment of the Southeastern Boll Weevil Eradication Foundation. Each participating state organized a state foundation consisting of appointed or elected grower representatives and a state regulatory official. Two grower representatives and the state regulatory official from each participating state Foundation serves as the Board of Directors of the Southeastern Foundation. A common cooperative agreement is signed by all participating state foundations. This agreement allows for funds to be collected and spent irrespective of state boundaries. The Foundation also provides for expeditious and efficient purchasing and contracting of needed supplies and services and the hiring of employees.

ERADICATION EXPANSION INTO GEORGIA, FLORIDA AND ALABAMA

As the success of this Expanded Program in the Carolinas became apparent, cotton producers in Georgia, Florida and Alabama expressed interest in expanding the Program into their areas. A series of cotton producer referenda was conducted between the fall of 1985 and early summer 1987. A referendum was held in 13 southeastern Alabama counties during December 5-12, 1985; it received a 67.17 percent favorable vote. An additional referendum was held during July 6-10, 1987, in eight adjoining Alabama counties; approval was by a 78 percent margin. The inclusion of these additional Alabama counties allowed all cotton in the Florida Panhandle to be included in this phase of expansion. The Florida referendum held June 30, 1987, received 77 percent approval. The Georgia referendum, conducted from November 15 - December 15, 1985, included the total state except for 23 northwestern counties. This referendum received 45 percent of the necessary 50 percent grower participation. Of those voting, 66 percent favored participating in the Eradication Program. An additional referendum was conducted from October 1 to November 1, 1986, with 68 percent of eligible voters voting. This referendum was approved by a margin of 89 percent.

This series of successful referenda coupled with the availability of 30 percent federal funding in July of 1987 allowed the Southeastern Boll Weevil Eradication Program to expand in August of 1987 from Virginia and the Carolinas into Georgia, Florida and southeastern Alabama. The lateness of federal funding allowed marginal time for program startup. Grower leadership decided a late start in 1987 was preferable to delaying expansion until the fall of 1988.

The intensive eradication phase of the Georgia, Florida and southeastern Alabama Program was anticipated to be completed in 1990.

COTTON INSECT MANAGEMENT FOLLOWING BOLL WEEVIL ERADICATION

NORTH CAROLINA

The start of the Boll Weevil Eradication Trial in 1978 also signaled the beginning of profound shifts in the dynamics of cotton insects in northeastern North Carolina and adjacent Virginia. A change as drastic as the removal of a key pest from an insect-susceptible crop such as cotton, with its annual protective blanket of insecticides, was bound to also greatly influence, both positively and negatively, the interaction of that host crop with other associated pest species. A decade of post-eradication research and survey information in northeastern North Carolina suggests that the benefits of reducing boll weevils to subeconomic levels and the present ease of bollworm/ tobacco budworm control thus far outweigh the negative impact of species such as the European corn borer, *Ostrinia nubilalis* (Hübner) and the green stink bug, *Acrosternum hilare* (Say) which have increased their population levels following "eradication".

Assuming that the boll weevil can be kept out of this and other regions in the coming decades, the relative contributions of boll weevil eradication in other cotton production regions will likely vary and await quantification. However, the dynamics of insect-related changes in the various regional cotton agroecosystems induced by the elimination of the boll weevil likely share some similarities. A look at the North Carolina-Virginia experience documents the impact of eradication on insect management in a selected area.

Bollworms/Tobacco Budworms — For most of the past two decades, the bollworm/tobacco budworm complex, primarily bollworm, has constituted North Carolina's most economically important cotton insect pest (Neunzig, 1969). After undergoing two larval generations in field corn, high numbers of bollworm moths invade cotton fields in late July to early August, usually overwhelming beneficial insect populations. Remedial treatment is, almost without exception, a necessity. Collectively, boll weevil eradication and the introduction of the pyrethroid insecticides greatly enhanced producers' ability to effectively and economically control this major bollworm generation. Attempts to control this generation with biological insecticides, primarily *Bacillus thuringiensis* both with and without chlordimeform (Fundal®, Galecron®), were generally futile when compared with the new synthetic pyrethroids. The microbial treatments typically resulted in more applications, higher costs, greater boll damage and lower yields even under light pressure (1 to 2 applications) (Bacheler, 1984). Research comparing various bollworm/tobacco budworm action thresholds has consistently pointed toward action based on an egg threshold as the most economical approach to bollworm control in North Carolina in the post-eradication era. This protective approach (as opposed to waiting for a specified larval population) places a premium upon the virtual elimination of the initial larvae of the major flight, resulting in significant yield increases without increasing the total number of applications. Three years of producer experience and extensive fall-damaged boll surveys confirmed that this post-eradication approach to controlling predictably moderate to high bollworm levels, particularly when coupled with maturity-enhancing crop production tactics, has resulted in a bollworm management scheme unique in the Southeast.

Stink Bugs — The elevation of the green stink bug, and to a lesser degree the brown stink bug, *Euschistus servus* (Say), and the European corn borer to legitimate pest status has been due in no small measure to the boll weevil's demise. Multiple applications of organophosphate insecticide directed against boll weevils and bollworms up through the late 1970s coincidentally tended to keep both green stink bugs and European corn borers at acceptably low levels. Of these two "new" post-eradication pests, the green stink bug relationship with eradication is the more easily understood.

Green stink bugs damage cotton by injecting their stylets through the carpal wall of medium-sized bolls and feeding upon the developing seeds (Glover, 1855); they often inject a hardlock-inducing pathogen, primarily *Nematospora coryli*, which is expressed at boll opening (James D. Barbour, Dept. Entomology, Louisiana State University; personal communication). Multiple feeding upon very young bolls (about 1 week old or less) sometimes either "freezes" the dead boll on the plant or results in the shedding of the damaged boll. This species is usually present in most North Carolina cotton fields in low numbers in June through mid July. In late July or early August, immigration into cotton fields from senescing wild hosts, such as wild cherry, augments the typically low infested population. The subsequent appearance of nymphs, indicating successful reproduction, marks the beginning of a potentially damaging population. In situations where bollworm does not reach treatable levels or where biological insecticides are employed, stink bugs have accounted for over 30 percent boll losses in some fields (personal observation). In these low bollworm situations, stink bugs must now be managed in their own right. Fortunately, due to the usual parallel appearance of bollworm moths along with increasing stink bug populations, employment of the bollworm egg threshold (Bacheler, 1988) for initiating bollworm/tobacco budworm control (2-5 applications) usually suppresses stink bugs to low, tolerable levels. The green stink bug in particular appears to be a consistent post-eradication cotton pest in North Carolina; it accounted for higher levels of boll damage in 1987 than either the bollworm or the European corn borer as documented in extensive late season surveys (King *et al.*, 1988).

European Corn Borer — The European corn borer's rise as an economic pest of cotton in North Carolina (King *et al.*, 1986; Gourd and Gouger, 1983; Savinelli *et al.*, 1986) following boll weevil eradication appears to be multi-causal. Although reported to have over 100 hosts in the southeastern United States, field corn is the predominant host of the European corn borer for its first two generations in North Carolina (Anderson, 1984). Like the corn earworm, the major, damaging third generation of European corn borer adult flies to cotton and to other cultivated and wild hosts such as cocklebur in late July to early August. Unlike bollworm adults, European corn borer female moths deposit egg masses deep within the plant canopy on the undersides of leaves (Savinelli, 1988). Neonate (very young) larvae feed briefly (only 24 hours on occasion) upon leaves and petioles before seeking out medium-to-large bolls (Savinelli, 1984, 1986). With their propensity to feed within large, lower bolls as second through last instars, these larvae are virtually impossible to control once they are established.

In North Carolina, the European corn borer has risen gradually in economic status throughout the 1980s to the point where it is now regarded as almost co-equal to the bollworm as the most significant insect pest of cotton (Jack S. Bacheler, personal observation). One factor in this species' elevation, as was the case with the green stink bug, is the absence of insecticides formerly directed against the boll weevil. Although the insecticides usually selected for boll weevil control, such as methyl parathion and Guthion®, are only marginally effective against European corn borer, their multiple usage patterns undoubtedly suppressed European corn borer larvae to a degree. This species is also becoming a more widely recognized pest of field corn, both due to a gradual appreciation of the physiological damage to corn caused by second generation larvae and to the noted greater mean level of abundance of this species in corn (John Van Duyn, V. G. James Research and Extension Center, Plymouth, North Carolina; personal communication). This rise in field corn translates into a spillover into other crops such as cotton, also explaining some of the changing status of the European corn borer on this crop.

Because the European corn borer and corn earworm adults often annually migrate into cotton fields from field corn at approximately the same time, insecticides applied against the bollworm egg stage (presently recommended in North Carolina) often result in residue of one or two applications being on the cotton plants at the time that European corn borer eggs hatch. This phenomenon appears to help explain the relatively high percent control of European corn borers in screening tests where treatments have been applied at egg threshold for corn earworms. Earlier tests conducted in 1984, primarily against the European corn borer larval stage, yielded controls varying from 2 to 48 percent after four applications (J. R. Bradley, Jr., Dept. Entomology, North Carolina State University, Raleigh, North Carolina; personal communication). Although the effect of boll weevil eradication on European corn borer damage to cotton is difficult to accurately quantify and will likely vary greatly from one region to the next, higher boll damage by the European corn borer in the southeastern United States is a likely prospect following boll weevil eradication wherever significant corn acreage occurs.

Other Cotton Insect Pests — Boll weevil eradication's long term impact on less significant, more sporadic, North Carolina cotton insect pests—such as aphids, spider mites and beet and fall armyworms—is largely speculative. The switch to synthetic pyrethroids was thought by many entomologists in the late 1970s to inevitably lead to higher mite populations on cotton. Mite numbers here have not increased with greater pyrethroid use and apparently have not been significantly affected by boll weevil eradication. Evidence suggests that with the cotton aphid, however, pyrethroid applications have been followed by the establishment of numerous small aphid colonies annually in many cotton fields.

The post-eradication lack of boll weevil insecticides such as Guthion® and methyl parathion (both active against the cotton aphid) in mid-season and in diapause programs appears to have exacerbated aphid problems in general; this, in turn, may be related to the present increase in honeydew-induced sooty mold and sticky cotton problems, in opening cotton in particular. Beet and fall armyworms are such infrequent pests of cotton in North Carolina that the impact of boll weevil eradication on these and other lepidopterous pests must await evaluation in other regions where their damage is more significant.

As has been well documented throughout the Southeast, cultural practices which hasten cotton crop maturity also generally render the cotton crop less attractive and less susceptible to many damaging mid- and late-season insect pests, especially corn earworms and tobacco budworms (Bradley *et al.*, 1986; Bradley, 1988). This also appears to be the case in North Carolina with the European corn borer and the green stink bug, as shown in both research plots (Savinelli, 1986; Barbour, 1988) and in statewide damaged boll surveys where late maturing, rank cotton is particularly attractive and/or susceptible to the European corn borer. Although difficult to forecast with certainty, early crop maturity and cut-out will probably offer a significant moderating influence on the potential destructiveness of some of the emerging cotton pests which will inevitably follow eradication in the southern United States.

SOUTH CAROLINA

Since the Eradication Program was expanded in 1983 to include South Carolina cotton, fields have been relatively free of boll weevils. A small percentage of fields has been infested with weevils during the program, but for the most part there has been no economic damage. Cotton farmers didn't have to worry about either scouting for boll weevils or controlling them from 1984 through 1988. This has presented a unique opportunity to re-evaluate management strategies for other cotton insect pests free from constraints inherent in a boll weevil control program.

Bollworms/Tobacco Budworms — The bollworm/tobacco budworm complex constitutes the most important cotton insect pest problem in South Carolina. Second generation larvae of both species attack cotton in June. In most years 15 to 25 percent of the cotton acreage in the Coastal Plain is treated one or more times with an insecticide between June 15 and July 1 for bollworm/tobacco budworm control. Infestations in July and August are generally bollworms.

Prior to the Boll Weevil Eradication Program, control efforts targeted at boll weevils in late June and early July often contributed to early-season bollworm/tobacco budworm problems by depleting populations of beneficial arthropods (A. R. Hopkins, USDA, ARS, Florence, South Carolina; personal communication). In the majority of cotton fields, beneficials will provide adequate control of second generation bollworms/tobacco budworms in most years if their populations are not drastically reduced by insecticides.

Following a cotton season with intense boll weevil pressure it was a common practice to apply organophosphate insecticides from late June to early July. Two or three applications were made five days apart beginning at the 8-leaf stage of cotton growth and ending about July 1. This coincided with the movement of beneficial arthropods into cotton. Disruptions of beneficial populations by insecticides applied during that time often flared bollworm/ tobacco budworm infestations.

After boll weevil populations were reduced to levels no longer causing economic damage to cotton, cotton growers were in a better position to manage infestations of bollworm/tobacco budworm. This was substantiated by Carlson (1985) who reported that in the Eradication Zone in North Carolina, following the Eradication Trial that began in 1978, the average number of insecticide treatments for bollworm/boll weevil and bollworm alone was 7.78. In 1978, the first year of the Trial, growers applied a total of 4.4 insecticide treatments for bollworms. The average number of treatments applied in the same area from 1979 to 1982 was 1.86.

From 1979 through 1982, USDA, APHIS entomologists investigated a biological approach to bollworm/tobacco budworm management in Chowan County, North Carolina (Robert G. Jones, USDA, APHIS, Mississippi State, Mississippi; personal communication). They utilized *Bacillus thuringiensis* (Bt) in combination with chlordimeform (Fundal®, Galecron®) to control bollworm/tobacco budworm infestations in cotton. Since both materials were easy on beneficial arthropods, populations of beneficials were maintained in treated fields to augment bollworm/tobacco budworm control. The cotton growers who utilized this strategy achieved bollworm/tobacco budworm control with an average of about two treatments per season.

After the eradication program expanded to include South Carolina in 1983, bollworm/tobacco budworm management was investigated in the absence of economic infestations of boll weevils. The objective of this study was to determine if bollworm/tobacco budworm in cotton could be economically controlled full season with Bt plus chlordimeform.

From 1985 to 1987 a bollworm/tobacco budworm management strategy with Bt plus chlordimeform (4 to 12 BIU's + 0.125 pounds of active ingredient per acre) was compared with a standard approach utilizing cypermethrin (Ammo®, Cymbush®) + chlordimeform (0.50 + 0.125 pounds of active ingredient per acre). This comparison was made at 19 on-farm locations in the following counties: Lee, Marlboro, Sumter, Darlington and Dillon. Yield comparisons for the two treatments are shown in Table 1 (Mitchell Roof and Robert Jones, unpublished data). At nine of the locations, lint yields under the biological approach were as good or better than the standard treatment over the three year study. There was no significant difference between treatments within years or when averaged over years. Populations of beneficial arthropods were higher where the biological approach was used.

When the bollworm/tobacco budworm management program was begun in 1985, Bt plus chlordimeform was tested as a full-season alternative to the pyrethroids (yield data presented for 1985 were based on full-season control). Then, reports began to surface in the Mid-South concerning tobacco budworms that were resistant to the pyrethroids. Development of early-season alternatives to pyrethroids was becoming increasingly important. Thereafter, Bt plus chlordimeform was viewed as a possible resistance management tool. In 1986 and 1987, Bt plus chlordimeform was used successfully in an early season control program.

Clemson University then included Bt plus chlordimeform as a recommendation for early-season control of bollworm/tobacco budworm on cotton (Roof, 1988). (Editors'

Table 1. Control of bollworm/tobacco budworm in cotton in South Carolina in the absence of boll weevils.

Year	Number of on-farm locations	Cotton lint yield	
		Biological[1] treatment	Standard[2] treatment
		lbs./acre	lbs./acre
1985	7	1030 a	1186 a
1986	7	637 a	681 a
1987	5	665 a	697 a

[1]Bt + chlordimeform
[2]Cypermethrin + chlordimeform
Means in rows followed by the same letter are not significantly different ($P < 0.05$; ANOVA).

note: Chlordimeform is no longer available.) The use of bollworm/tobacco budworm control alternatives such as this will be encouraged and the use of pyrethroids discouraged prior to July 1. Hopefully, this management philosophy will forestall the development of pyrethroid resistance in tobacco budworm. Extending the useful life of the pyrethroids could be an important spin-off of boll weevil eradication.

Other Cotton Insect Pests — Elimination of economic infestations of boll weevils may alter the importance of insect pests other than the bollworm/ tobacco budworm complex. Applications of organophosphate insecticides that were detrimental to beneficial arthropods may have also kept some potential pests under control.

Stink bugs were a pest in South Carolina cotton from 1985 to 1987, but no economic problems were observed in 1988. The green stink bug appears to be the major species involved. Whether or not this phenomenon is attributed to the eradication program remains to be seen. Three consecutive mild winters may have contributed as much or more to the problem. Furthermore, there have been similar reports of stink bug damage in cotton from other states, such as Tennessee, that were not involved in a boll weevil eradication program.

Cotton fleahoppers, *Pseudatomoscelis seriatus* (Reuter), have been more abundant in cotton since 1984. Prior to 1984, it was rare to see a cotton fleahopper in a cotton field. There also appear to be more tarnished plant bugs, *Lygus lineolaris* (Palisot de Beauvois). These insects are not causing widespread economic problems at this time, but the situation will bear watching.

Problems with cotton aphids, *Aphis gossypii* Glover, also appear to be increasing. Most infestations are occurring in late July and early to mid August. Aphid infestations may be more related to the use of pyrethroid insecticides for bollworm/tobacco budworm control than to eradication of the boll weevil.

THE FUTURE

The future for cotton production in the Southeast looks brighter because of the eradication program. Interest in producing cotton has increased where boll weevils no longer pose an economic threat. Acreage has increased in both North Carolina and South Carolina as a result of the program. There is every indication that this trend will continue as other states become involved in the expanded program.

Eliminating the boll weevil as an economic pest will provide farmers a method of reducing their cost of cotton production. Insect pest management will be vastly different without a pest that generally requires the disruptive application of an insecticide. Scouts won't have to concentrate on scouting for weevils; consequently they will be able to key on bollworm/tobacco budworm and other pests. Farmers won't have to tank-mix insecticides for weevils and worms—nor will they have to sandwich insecticides for weevils between bollworm/tobacco budworm sprays. There will be no insecticide costs for boll weevil control, and there will be no weevil-damaged cotton resulting in reduced yields and quality.

For the foreseeable future, the use of insecticides will continue to be an essential part of producing cotton. At the same time, concern for the environment, clean air, clean water and preservation of wildlife will intensify. The demand for food and fiber free of insecticide residues will increase. Eradicating boll weevils will put cotton production agriculture in a position to comply with these demands.

When the boll weevil is no longer an economic pest of cotton, the use of organophosphate insecticides will be drastically reduced. In terms of total quantity of insecticides (pounds of active ingredient per acre) applied to cotton, a considerable reduction should be expected. Where no insecticides are applied for boll weevil control there will be more opportunities to utilize beneficial arthropods to control bollworm/tobacco budworm and other cotton insect pests. This could provide further avenues for reducing insecticide use. Reducing our dependence on chemical insecticides is certainly a worthwhile goal from an economic as well as an environmental point of view.

Entomologists involved in cotton insect pest management have learned the rules well by observing infestations in the field year after year. Many have been involved in the development of economic thresholds for the different insect pests. Eradication of the boll weevil, however, will change some of the rules and alter some of the economic thresholds that have become so familiar to us. It is possible that certain secondary insect pests will attain more economic importance—others may become less important.

Following eradication of the boll weevil the responsibility of re-evaluating cotton insect pest management systems will fall on the shoulders of state and federal entomologists as well as consultants and others in the private sector. The potential for developing innovative approaches to assist farmers in managing insect pest problems in cotton is great.