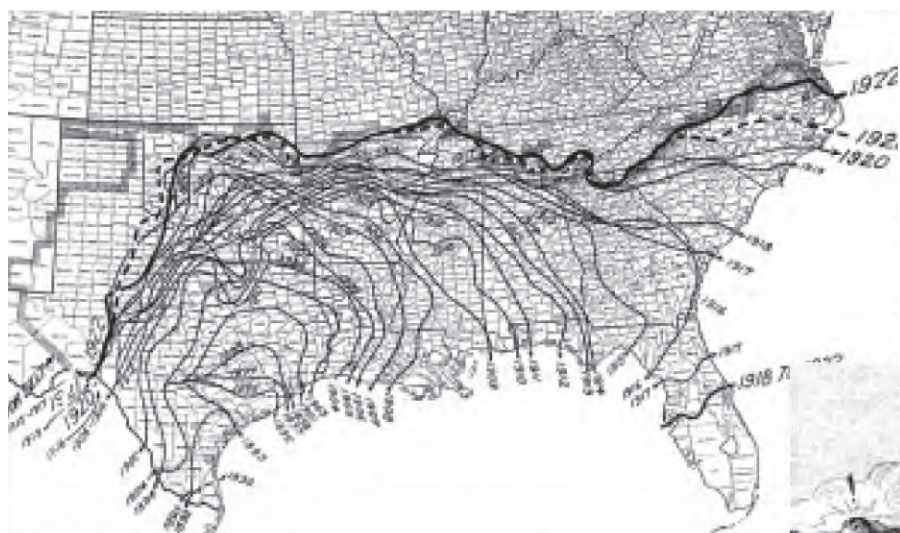




Cotton Production and the Boll Weevil in Georgia:

History, Cost of Control, and Benefits of Eradication



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**Reviewed by
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Abstract

Georgia's history and cotton production have been inseparably woven together since 1733, when the colony was founded and cotton was first planted in Trustee's Garden, near Savannah. The success of the Southeast Boll Weevil Eradication Program has played a major role in the recent revival of Georgia's cotton industry. The boll weevil first appeared in Thomasville in 1915, and cotton production began declining rapidly, from a historical high of 2.8 million bales in 1914 to 600,000 bales in 1923. Aerial applications of calcium arsenate dust began in the early 1920s. This helped increase yields somewhat, but the industry never really recovered, and overall production continued declining steadily for another 60 years. In 1983 Georgia produced only 112,000 bales on 115,000 harvested acres. The active treatment and trapping phase of the eradication program began in 1987 and was completed in 1990. Since then, cotton production has increased dramatically each year. Average yield has increased from 482 pounds per acre in the pre-eradication period (1971 to 1986) to 733 pounds per acre in the post-eradication period (1991 to 1995). Acreage has increased from an average of 228,000 to 770,000, and average gross crop revenues have increased from \$70 million to \$400 million per year. Net crop revenues (gross revenues less insect pest management costs and amount of damage) have increased from \$187 to \$451 per acre. In 1995 2.0 million bales were produced on 1.5 million harvested acres (59% more than in 1994 and the largest yield since 1919), with total revenues of about \$720 million (the highest in Georgia's history).

Along with these economic benefits, the remarkable success of the eradication program has led to a significant decrease in insecticide use in Georgia cotton, and to substantial environmental benefits to growers and residents of the State. The average number of insecticide treatments have decreased from 14.4 per acre in the pre-eradication period to 5.4 per acre in the post-eradication period. In most cases, the materials used are more specific, and the amount of active ingredient applied during each treatment has been reduced from pounds per acre to a few ounces per acre. Also, a severe outbreak of the normally non-economic beet armyworm, *Spodoptera exigua* (Hubner), occurred between 1987 and 1989 following repeated aerial applications of guthion and malathion. This outbreak was followed by a rapid decline in beet armyworm densities immediately after the treatment phase was completed. This event provided a dramatic contrast between disruption of a formally minor pest caused by repeated insecticide applications versus effective biological control of the same pest by its natural enemies, in this case, the braconid parasitoid *Cotesia marginiventris* Cresson. The dual successes of the Southeast Boll Weevil Eradication Program and subsequent resumption of beet armyworm control by *Cotesia* helped generate renewed and widespread interest in biological control principals and provided a foundation for efforts to develop an economically and environmentally sustainable pest management program in Georgia cotton.

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Part I: History of Cotton Production and the Boll Weevil

Introduction to Part I

It would be difficult to exaggerate the importance of cotton in Georgia's social and economic history, or to exaggerate the boll weevil's impact on cotton production in Georgia and the South. Truly, the stories of cotton production and the boll weevil have become inseparably woven together into the fabric of Georgia's past and present history. This section provides a brief summary of the early history of cotton production around the world, followed by a chronological review of the history of cotton production in Georgia from 1733, when cotton was first planted in Trustee's Garden, until the present time. Part I also provides a brief summary of the early history of the boll weevil in the Cotton Belt, followed by a detailed review of the boll weevil in Georgia, from August 1915, when it was first found in Thomas County, until the present day.

The Early History of Cotton

As far as we know, cotton cultivation began at least 5000 years ago in India (Prentice 1972; Frisbie et al. 1989). Cotton cloth dating back to about 2500 B.C. has been found in Peruvian ruins and in Arizona pueblos, and cotton cloth dating back to 500 B.C. has also been found in the Upper Nile area of modern Sudan (Brown and Ware 1958). In ca. 425 B.C., Herodotus described wild trees in India, "the fruit of which is a wool exceeding in beauty and goodness that of sheep . . . the Indians make their clothes of this tree wool." Nearchus, an admiral in the army of Alexander the Great, wrote in ca. 327 B.C. of "trees in India that bear, as it were, bunches of wool" (Brown and Ware 1958). Theophrastus stated in ca. 287 B.C. that the Indians "set plants that resemble the dog rose in plains arranged in rows so as to look like vines at a distance" (Brown and Ware 1958). Cotton bolls dated to 900 A.D. were found with Mayan artifacts in a cave in Oaxaca, Mexico (Warner and Smith 1968). In the 1200s, Marco Polo observed that the inhabitants of Madras, India, produced "the finest and most beautiful cottons that are to be found in any part of the world," while another anonymous writer said that "when (their) muslin is laid on the grass to bleach and dew has fallen on it, it is no longer discernible" (Brown and Ware 1958).

Although early explorers reported finding wild cotton growing in the lowlands of the Meschachebe (Mississippi) River and its many tributaries (Donnell 1872), 1620 is generally regarded as the birth of cotton culture in America, when seeds imported from the West Indies were first planted in the Jamestown Colony (Anonymous 1975). A tract called "A Declaration of the State of Virginia," published in England in 1620, mentions "cotton wool" as one of the commodities of that colony (Donnell 1872).

The Early History of Cotton in Georgia

Georgia's social and economic history and the production of cotton have been knitted together since 1733, when Georgia (named after King George II of England) was established as a British colony under the direction of James Edward Oglethorpe (Bass 1993), and cotton was first planted in Trustees Garden, Savannah, with seed sent by Philip Miller of Chelsea, England (Donnell 1872). The first sample of 'Georgia cotton' was sent to England in 1741 (Donnell 1872; Linder 1954). Two years later, despite Oglethorpe's objections, the use of slave labor was legalized (Anonymous 1930), and by 1749 commercial cotton production in Georgia began increasing rapidly (Linder 1954; figure 1). Opening up the slavery market in America instituted the development of a complex international business system, with finished cotton products shipped abroad from English ports, followed by transportation of slaves from West Africa to North (and South) America, then shipment of baled cotton from the cotton states back to England for commercial finishing. By 1790, there were 697,000 slaves in America, located mostly in the Cotton Belt. This number grew to 2,000,000 by 1830, with 980,000 in the South, then to 3,200,000 in 1850, with 1,900,000 in the cotton states (Donnell 1872). Basically, cotton became the primary raw material that fueled the Industrial Revolution, which began in the cotton factories of Manchester, England and eventually spread far abroad (Prentice 1972).

In 1778 'Sea Island' cotton, a high quality, long-staple variety similar to the modern 'Pima' variety, was first grown commercially by Alexander Bisset with seed sent from the Bahamas to Georgia Governor Tatnall, James Spalding, and Bisset at the Sea Island Plantation on St. Simon's Island. Remnants of some of the buildings and part of the main carriage road, which is lined on both sides with huge old oak trees, can still be seen at the Sea Island golf course (Donnell 1872; Linder 1954). Incidentally, the term "Upland cotton" was derived from cotton grown in the interior areas (Uplands) of Georgia and South Carolina, where a majority of the American cotton acreage was located, vs. the "Lowland" or coastal areas where 'Sea Island' cotton was grown (Anonymous 1930). By 1786 cotton production and the homespun spinning and weaving movement had become so well established and widespread throughout the South that Thomas Jefferson wrote: "The four southern-most States make a great deal of cotton. Their poor are almost entirely clothed in it in winter and summer" (Linder 1954). In 1791 the United States produced the equivalent of 4000 bales of cotton, of which 3000 were grown in South Carolina, and 1000 in Georgia (figure 1). During this initial period of growth, half of the cotton produced in America was exported to England, while the remainder was manufactured into cloth, ropes, canvas, etc., in factories located almost entirely in the South (Linder 1954).

The Cotton Gin

Cotton production in America and the commercial use of cotton throughout the world changed forever in March of 1793 when Eli Whitney, a Massachusetts teacher-inventor, fashioned his own version of a cotton gin while teaching at the Mulberry Plantation, the home of General Nathaniel Greene's widow, near Savannah, Georgia (Donnell 1872; Linder 1954). A patent for the gin, signed by President George Washington, was granted to Whitney in 1796 (Thomas 1929). Whitney's cotton gin did the work of 50 people, and practically overnight it became economically feasible to grow the tight-seed, long-staple "Upland" cotton on a commercial scale. Whitney, "the South's great Benefactor," died with great honor in New Haven, Connecticut, in January 1825 (Anonymous 1930).

Cotton production in Georgia increased rapidly from 1000 bales in 1791 to 21,000 bales in 1796, or 21% of the total U.S. production (Donnell 1872). By 1800 America, with Georgia as a major contributor, had established her long dominance of the world cotton market, which, except for the period during the War Between the States, continued unabated into the 1960s (Prentice 1972).

By the early 1800s the Industrial Revolution was spreading rapidly into the South. In 1811 the first cotton mill in Georgia, called the Bolton Factory, was built on Upton Creek in Wilkes County, nine miles southeast of Washington, where the first cotton gins were also manufactured commercially (Watkins 1904; Linder 1954). Cotton production in the South continued to increase, but it was not until 1825 that movement within the cotton trade was regularly recorded and published (Donnell 1872). When the first national census was taken in 1840, cotton was included as one of the 37 main commodities surveyed (Trelogan 1969). As stated in the first "Report of the Commissioner of Patents" in 1848, however:

The cotton crop, though one of great importance, embracing as it does the interest of so many States, is yet one respecting which, at this early period, it is exceedingly difficult to form very accurate conclusions. Even those who reside in the midst of the great depots of the product do not agree respecting the quantity that may eventually be included in the gathering for the year . . . doubtless there are many small proprietors who raise a small quantity each for his own family use, which, when multiplied, form a very considerable aggregate which should also have a place in the general estimate of the crop (Anonymous 1849).

Yet, up to the year 1850, no census had ever been taken, either by any state legislature, or by the federal government, of the acreage specifically devoted to the cotton crop (Anonymous 1850a). Marketing and production records were also in general disarray:

The cotton grown in one State being often sent to market in another, there are no reliable data to determine the quantity grown in any State . . . nor can one in ten of those that make it their staple crop answer the question "How much does it cost to grow a pound of cotton?" (Anonymous 1850b).

Overall growth of cotton production in Georgia between 1825 and 1860 averaged about ten percent per year (Anonymous 1851; figure 1). Southwest Georgia was now referred to as the "the great cotton region of the South, and, perhaps, the best in the whole southern U.S." (Howard 1867). A sustained increase in cotton production in the South between 1840 and 1860 was a major contributing factor in America's tremendous population growth (1.7 million new immigrants arrived from 1840 to 1850; 6.2 million arrived between 1850 and 1860; Trelogan 1969). By 1849 cotton had the greatest export value of any agricultural commodity in the United States; cotton also paid for nearly two-thirds of all the imports coming into the country. Domestic cotton prices at that time averaged between six and seven cents per pound (Anonymous 1850b; Philips 1850; figure 2), while export prices were about 60% higher (Anonymous 1851). By 1850 the United States had become the world's largest producer (85% of the world's crop), exporter, consumer, and manufacturer of cotton products, exceeding even Great Britain's industry, which had long been the dominant force in the international cotton market. Meanwhile, the American homespun industry was still thriving, and although there were

still no trustworthy statistics showing the domestic consumption of cotton in the southern states during the first half of the past century (19th), it is quite certain that practically the entire slave population, as well as the poorer classes of whites, continue to be clothed with homespun cotton (Watkins 1904).

This is also the period when Levi Strauss began marketing his famous cotton jeans.

The first studies that attempted to document the cost of producing cotton and describe the methods of cultivating cotton were published by Solon Robinson and M. W. Philips, respectively, in the 1849 "Report to the Commissioner of Patents" (Anonymous 1850b; Philips 1850). There were still no agricultural colleges in the country at that time, but the demand for improvement of agricultural methods through scientific research and education was gaining widespread momentum and public support (Anonymous 1911a). In 1854, T. Glover was appointed as the first government entomologist under the office of the Commissioner of Patents; cotton insects were mentioned in the first and second reports he filed in 1854 and 1855 (Parenica 1978). On May 15, 1862, Congress established the United States Department of Agriculture, separating it from the Office of the Commissioner of Patents (Trelogan 1969). During the same year Congress also passed the Land Grant College Act, and approved the Morrill Bill, which established federal support for agricultural schools, including the University of Georgia's College of Agriculture in Athens (Anonymous 1911a).

The Civil War Period

The War Between the States ended on April 9, 1865 (Anonymous 1956). Total cotton production in Georgia in 1860 was 584,000 bales; virtually none was produced for commercial purposes during the war, and by 1866 cotton production had climbed back to 300,000 bales (Howard 1867; figure 1). Overall, Georgia lost 66% of its developed resources during the great conflict, and post-war farming practices were in the midst of monumental changes as former slaves were emancipated. Prior to the war there were more than 1000 plantations in Georgia at least 1000 acres in size, but now farm size was based on the area a man could manage by his own labors, with the assistance of his family or contracted labor. In addition,

The plantations (farms) of the country were in a rough and dilapidated condition generally; stock, mules and horses for plow-teams were scarce, as was also grain to feed them . . . most of the seed was old and imperfect from neglect during the war . . . and the laborers generally disinclined to do full work (Cloud 1867).

To help in the recovery of cotton production in the South, Joseph B. Lyman wrote a detailed account in the 1866 "Report to the Commissioner of Agriculture" on how to select a cotton farm, and how to cultivate, harvest, and market the crop. He emphasized the importance of preserving the soil and maintaining its fertility by adding fertilizer (manure), and by practicing three-year rotation farming with cotton followed by corn, then rye or oats. He also mentioned that in some parts of Georgia cotton had been cultivated (without rotation) for 50 years or more (Lyman 1867).

The USDA aided in the post-war recovery effort by emphasizing the importance of accurate record keeping and by maintaining reliable production statistics. In 1866, the

total U.S. cotton crop was correctly estimated at 1.75 million bales, providing evidence of the “reliability attainable under the present statistical system” (Anonymous 1867). This was quite a contrast to the disorganized state of affairs that existed through the 1850s (Anonymous 1849).

In 1860, one year prior to the Civil War, America held 80% of the market share in England. This fell to less than 2% during the height of the war, then climbed back up to 62% by 1876 (Anonymous 1877). The shortage of cotton from America caused a severe economic depression in England. Taking advantage of the opportunity,

Ten nations tried when the South was plunged in war to organize and steal the cotton industry from our soil. With all the genius and energy of England, Russia (Ukraine), India and Brazil behind it the movement failed, and confessing the failure they bowed to the South’s exclusive and permanent supremacy. Following the war, cotton once again become “the mainstay of eleven States and twenty million people” in the South (Anonymous 1909; Newell and Paulsen 1908).

There is no portion of the world occupied by civilized nations, and probably no equal extent of the earth’s surface, so peculiarly suited to cotton culture as the States of the Gulf Coast, which virtually gives the monopoly of cotton production to the United States. The price, as index of quality, tells the story of India’s inability to compete with the United States (Anonymous 1877).

For example, the price of export cotton from the U.S. during this recovery period (1872–1876) averaged 8.22 pence per pound versus 6.04 pence per pound from India, a 27% higher value (Anonymous 1877). G. W. Gift wrote as early as 1867, however, that

If the production of cotton is to be continued, it must be under some system which will secure an adequate return for the capital invested in the enterprise, . . . which is not possible under the present routine. Cotton is now cultivated under a very slovenly system, if it can (even) be called a system. No manures are used, the first plowing scarcely exceeds two inches in depth, and the later cultivation is often delayed at the critical time until the crop is materially injured by being crowded by grass (Gift 1868).

Georgia Enters the Modern Era

By an Act of Congress in 1878, Professor C. V. Riley was appointed as chief entomologist of the Department of Agriculture. He immediately began work on cotton insects. In the same year J. H. Comstock published the first USDA cotton research report entitled “Report on Cotton Insects” (Parencia 1978). The U.S. Entomological Commission was established in 1880 under the direction of the Department of the Interior. C. V. Riley was given responsibility for cotton research (Parencia 1978). The first million-bale harvest in Georgia’s history also occurred in 1880 (Talmadge 1928; figure 1). On March 2, 1887, the U.S. Congress passed the Hatch Act, signed by President Cleveland, which appropriated the sum of \$15,000 annually to each of the states and territories in the Union for the establishment and support of an agricultural experiment station (Anonymous 1888). On February 18, 1888, the Trustees of the University of Georgia (UGA) established the Experiment Station at Rock College, near Athens, as a department of the State College of Agri-

culture and Mechanical Arts, appointing a director, chemist, assistant chemist, and a meteorologist (Anonymous 1888). In early June the Georgia State Legislature endorsed the Hatch Act, and on June 14, 1888, the Governor issued an executive order verifying Georgia's assent to the terms of the Hatch Act and authorizing the treasurer of the College of Agriculture and Mechanical Arts to receive federal funds that had been retroactively available since July 1887 (Anonymous 1888; Bass 1993). On December 29, 1888, after some controversy, the State Legislature voted to relocate the "Station" to the Bates Farm, near Griffin, and by the summer of 1889 the new Station began operating (Bass 1993).

Cotton became a major part of UGA's research program as soon as the Georgia Experiment Station (GES) was permanently relocated to Griffin. In 1891 the station published its first cotton bulletin (number 11) dealing with "various tests," and followed this with a second cotton bulletin (number 16) in 1892, also dealing with various tests (Anonymous 1895). In 1895 the station director set a goal of producing a minimum of one-half bale of cotton per acre, using "simple, common-sense farming methods." Continued emphasis was also placed on ensuring optimum productivity by maintaining soil health and quality (Anonymous 1895). In 1895 the GES also published bulletins 24 and 27, both dealing with cotton varieties and fertilizer and cultural practices (Anonymous 1895). The Georgia State Board of Entomology (GSBE) was established in 1898 with a special appropriation of \$2500, making it a separate agency from the State Department of Agriculture. The GSBE was also authorized to hire an entomologist to act as inspector for the GSBE (Worsham 1912). In 1900 the Georgia General Assembly increased the annual GSBE appropriation to \$5000 (Worsham 1912).

The Boll Weevil—Early History

The boll weevil (*Anthonomus grandis* Boheman) has a long association with cultivated cotton. A single adult female dating from ca. 900 A.D. was found entangled in a cotton boll in a cave in the Oaxaca Valley, Mexico, in the mid-1960s (Warner and Smith 1968). The boll weevil was first described by Boheman in 1843 from four specimens received from Vera Cruz, Mexico (Parenica 1978), but, at that time, its food plant remained unknown (Worsham 1914). In 1862, a boll weevil infestation reportedly caused the abandonment of cotton cultivation in Monclova, Mexico (Howard 1897). In 1885, the first scientifically verified record of boll weevil damage to cotton was reported in a note by C. V. Riley, chief entomologist for the USDA, from specimens sent to the department by Dr. Edward Palmer from Monclova, northern Mexico (Worsham 1914; Parenica 1978). The boll weevil first appeared in the United States in 1892 near Brownsville, Texas (Parenica 1978). The USDA sent C. H. T. Townsend to south Texas in 1894, where he found several counties that had been infested with the boll weevil since at least 1892. He recommended the destruction of cotton stalks to kill the overwintering boll weevil adults and the establishment of a non-cotton (quarantine) zone to prevent its future spread. These recommendations were not adopted, and by 1895 the boll weevil had spread as far north as San Antonio and as far east as Wharton, Texas (Parenica 1978). Townsend also reported that the boll weevil was likely to advance at the rate of 65 miles north and east per year. In 1897 L. O. Howard authored a report summarizing the investigations of 1896 and 1897, entitled "Insects Affecting the Cotton Plant" (Howard 1897), which included a detailed description of the Mexican cotton boll weevil biology, and a short history, with map, of its movement from

southern Texas eastward into Louisiana. Control methods suggested by Howard included early planting, clean cultivation, and stalk destruction, just as prescribed by Townsend in 1894. These reports were published in English, Spanish, and German (Adkisson 1968). In 1901 the USDA published Farmer's Bulletin 130, one of the first reports recommending use of molasses to attract the boll weevil to arsenical poison (two ounces of arsenic boiled in water until dissolved then mixed into 46 gallons of water plus two gallons of cane or sorghum molasses) (Mally 1901).

In 1903 W. D. Hunter wrote that "The work of the Division of Entomology for several years has demonstrated that there is not even a remote probability that the boll weevil will ever be exterminated." His control recommendations included stalk destruction, early planting, use of early maturing varieties, thorough cultivation, row spacing of at least four feet, and the use of fertilizer to help produce an earlier crop (Hunter 1904b). "One of the best planned and most extensive investigations of all time" by entomologists in the USDA Bureau of Entomology also began in 1903. Their subsequent discoveries

gave great hope and courage to the farmers and at the same time gradually brought about much better and more diversified methods of farming in areas affected by the boll weevil. The thoroughness of the USDA investigation helped promote progress in agriculture greatly in the way of progress by serving as a great example and inspiration to other entomologists to plan and carry out their investigations with greater care (Marlatt 1940).

In 1903 the first congressional research appropriation, \$20,000, was made to W. D. Hunter and three other USDA entomologists, to conduct large-scale experiments of cultural methods to control the boll weevil on a total of 558 acres of cotton, including 200 acres around Calvert, in the Brazos Valley, plus 100 acres near Austin, and another 156 acres in Wharton and Victoria, in south Texas, where a field research laboratory was established. These farm-based demonstration projects became known as the Farmer's Cooperative Demonstration Work of the Bureau of Plant Industry and, later, as the Extension Service of the USDA. Dr. Hunter stated that they had conducted the most extensive investigation of the life history of a single insect yet published (Hunter 1903; Anonymous 1904; Hunter 1904c; Parencia 1978). In 1903 the first international attempt to control boll weevil by biological control occurred, in this case, with the mite *Pediculoides ventricosus*, which was reared in Cuernavaca, Mexico, and transported to Texas. It failed to control the boll weevil in Texas, apparently because of the difference in climate (Anonymous 1904; Hunter 1904c). E. A. Schwarz was also assigned to work in Cuba in 1903 (with hopes that research conducted in a more tropical climate would be relevant to parts of the Cotton Belt; Worsham 1912).

By this time, the outlook was rather bleak, for it seemed clear to many that "The boll weevil is undoubtedly the most serious menace that the cotton planters of the South have ever been compelled to face; indeed it is doubtful if any other insect ever caused such grave fears for an agricultural industry" (Hunter 1904c; Worsham 1912). Potential losses over the entire Cotton Belt are estimated at \$250 million (about 50% of the entire value of the crop), based on the fact that Texas growers lost \$15 million in 1903 (53% of their crop; Hunter 1904b; Parencia 1978). Stalk destruction (plowing under) in the fall, early planting, regular cultivation, planting of good varieties, and proper spacing were the main recommendations coming forth from this project (Worsham 1912). The newly adopted

Georgia Quarantine laws, passed on August 28 1903, prohibited importation of any living Mexican boll weevil or any cotton bolls, squares, plants, or seed containing the adult, pupal, larval, or egg stage of the Mexican boll weevil.

No cotton seed grown in the states of Texas or Louisiana shall be shipped into Georgia without a certificate signed by a duly authorized state or government entomologist stating that said cotton seed has been fumigated in such manner as to kill any Boll Weevil adults, larva or pupa which may be contained therein (Hunter 1904b).

By 1904 the weevil was still only in Texas, but it had progressed 500 miles north from its original point of entry near Brownsville (Hunter 1904b; Hunter 1905; Redding 1905). Total losses throughout the Cotton Belt were set at \$15 million in 1903, \$22 million in 1904, and \$88 million in 1909 (Worsham 1916). Congress appropriated \$250,000 to enable to Secretary of Agriculture to meet the boll weevil emergency. Of this amount, \$100,000 was allotted to the Bureau of Entomology and the remainder to The Bureau of Plant Protection. Incidentally, the boll weevil crisis prompted the Louisiana State Legislature to establish the Crop Pest Commission of Louisiana (Parencia 1978). A similar response was seen in several other Cotton States, including Georgia. The first Georgia State Board of Entomology publication on history of control and biology of the boll weevil was written by Wilmon Newell, Georgia State Entomologist and Secretary of the Board, GSBE. (His name was destined to become prominent in the history of boll weevil research and entomology) (Newell 1904; Newell 1908; Newell and Paulsen 1908; Parencia 1978). Newell's report included a copy of the new Act of the General Assembly of the State of Georgia of August 15, 1904, prohibiting importation, etc., of boll weevils or materials containing the boll weevil; this was an expanded version of the August 28, 1903, publication (Newell 1904). In 1904 the GSBE appropriation was increased to \$10,000, partly to increase boll weevil work (Newell 1904), and the first publication on the importance of controlling the boll weevil in the ginning operation appeared (Hunter 1904a). Initial research attempts to use Paris Green instead of previously recommended cultural practices for boll weevil control were shown to be absolutely futile; the tests were conducted to counter extensive use of Paris Green by Texas farmers, who falsely assumed that early season kills of boll weevils would be adequate (Hunter 1904d). By 1908 the boll weevil crossed the Mississippi River; half of the cotton-producing acreage in the South was now affected, and early destruction of cotton stalks remained the primary recommendation (Hinds 1908).

In 1908 several papers on boll weevil control appeared in the very first volume of the *Journal of Economic Entomology* (Hinds 1908; Newell 1908; Newell and Paulsen 1908; Pierce 1908). In 1908 Wilmon Newell conceived the idea of dusting cotton plants with a formulation of powdered lead arsenate (versus spraying them with liquid insecticides). Until then, the only available form of arsenate was a paste which was mixed with water and applied as a spray. The first powdered formulation of lead arsenate was prepared for Newell by Grasselli Chemical Company for use in cage tests in 1908 (Parencia 1978). In the same year Newell presented the first written proposal to defoliate cotton plants in the fall to arrest the boll weevil's life cycle. He also published the results of his experiments with at least ten different insecticides (Newell and Paulsen 1908), and reported the first observation of a Carabid beetle predator of the boll weevil (Newell 1908). In 1908 Pierce

published his observations on the effect of predation by fire ants and control by six beneficial parasite species (20% and 10% mortality, respectively) (Pierce 1908). One year later, the Georgia State Agricultural Society again urged Georgia farmers to diversify, stating that “our trouble since the war has been the craze of our people for cotton production to the exclusion of food crops (Anonymous 1909).

By 1911 the boll weevil had advanced to central Alabama, and what is still the largest cotton crop in Georgia’s history was harvested (2.8 million bales produced on 4.9 million acres) (figures 1, 3, and 4) (Floyd and Treanor 1944). The same year the USDA published the first of what became a long series of similar Farmers’ Bulletins on the boll weevil problem, complete with maps showing the advances of the boll weevil across the Cotton Belt and with specific references for reducing its damage (Hunter 1911; Hunter 1912; Hunter 1917; Hunter and Coad 1922; Hunter and Coad 1923; Folsom 1932). Destruction of cotton stalks, preferably by October 10, was still a major part of boll weevil control, and the V-shaped cotton stalk cutter was considered the most effective and preferred approach (Anonymous 1911b). Use of early maturing varieties in combination with fertilizers to further hasten crop maturity was also strongly recommended (Anonymous 1911c). In 1912 the Georgia Quarantine laws were expanded to include shipments from Texas, Louisiana, Mississippi, Arkansas, Oklahoma, and Alabama as the boll weevil moved into central Alabama (Hunter 1912; Worsham 1912).

In 1914 land devoted to cotton production in Georgia peaked at 5.2 million acres (Floyd and Treanor 1944). Simultaneously, the boll weevil had advanced to a point in Alabama only six miles west of the Early County border (in the extreme southwest corner of Georgia). From this point, the story of cotton production and the story of the boll weevil merge together and become tightly blended into the fabric of Georgia’s history. The continued growth and prosperity of Georgia’s cotton industry and the voracious appetite of the boll weevil were now about to collide head-on. In 1914, E. L. Worsham, Georgia State Entomologist, published GSBE Bulletin 39, “The Mexican Cotton Boll Weevil,” stating that “The purpose of this bulletin is to sound a warning to the cotton growers of Georgia.” By the fall of 1914, crop losses suffered in more westerly states were averaging about 60% (Worsham 1914), and the “dreaded enemy of cotton, the Mexican Cotton Boll Weevil,” was found within two miles of the Georgia border (Worsham 1915).

The Boll Weevil in Georgia—Control Before World War II

The boll weevil was first observed in Georgia in Thomasville (Thomas County) on August 25, 1915. By the first killing frost on November 16, it had appeared in 40 counties, covering an area of 86,000 square miles (Worsham 1916). In 1915, one of the first detailed observations on hibernation and life history of the boll weevil was published by B. R. Coad (1915). His initial report laid the foundation for the subsequent development of the diapause control method by Brazzel and Newsom (1959) which became the cornerstone for a successful boll weevil eradication program in Georgia and much of the Cotton Belt seventy years later. That same year, GSBE published its first report proposing the use of plant breeding as a management tool against the boll weevil (Worsham 1915). That recommendation laid the foundation for a plant-breeding program that has provided Georgia farmers with tremendous benefits over the years. In 1916 the Georgia Extension Service published its first report summarizing new methods for cotton production under boll

weevil conditions. Recommended methods included crop rotation, cultivation methods, fertilization, improved varieties, better seed, an earlier planting date, picking up dropped bolls by hand, timely harvesting, destruction of cotton stalks, and burning of plant debris (Rast 1916). The USDA also published bulletin 382 with a special reference to picking up fallen squares and picking weevils off the plants by hand (Coad 1916), and a new insecticide, calcium arsenate, was compared for the first time with lead arsenate in field tests (Parencia 1978).

By 1917, every cotton-producing county in Georgia reported the boll weevil (Hunter 1917), and cotton production had fallen by 30% (2.82 million bales vs. 1.96 million bales) (figure 1) (Anonymous 1917; Floyd and Treanor 1944). The GSBE published a circular entitled "How to Grow Cotton in Spite of the Boll Weevil," which included a suggestion that growers offer their workers a reward for spotting weevils and for collecting them (there are many stories from people who grew up on farms in Georgia about collecting weevils for one penny each). The concluding summary included a strong encouragement to farmers, which was intended to counter fears that cotton would be lost as a major money crop (Worsham 1917). In 1917 the GSBE also began experiments with a modified peach tree duster for controlling the boll weevil on cotton, but it was initiated too late in the season for industry use (Warren 1920).

In 1918 the USDA published a complete summary of biological observations and boll weevil control experiments conducted between 1913 and 1917 that used arsenical dust compounds in fields located near the Delta Boll Weevil Laboratory in Tullulah, Louisiana. The results were remarkable, especially in light of the fact that earlier efforts to poison the boll weevil were largely unsuccessful. Yields in one experiment averaged 55 pounds per acre in the untreated fields versus 500 pounds per acre in the treated fields; yields in another experiment averaged 900 pounds in the untreated fields versus 1700 pounds in the treated fields (Coad 1918). At the same time, one of the first large-scale boll weevil control "extension" trials conducted with cooperating growers took place in Arkansas (Coad 1918). The GSBE published an updated version of the Boll Weevil Quarantine Regulations and revised the quarantine boundaries (Worsham 1918), and conducted its first calcium arsenic dusting experiments (based on USDA results) in Valdosta, but the experiments were interrupted and no definitive results were obtained. An intensive breeding program to develop new cotton varieties resistant to the ravages of the boll weevil was also initiated by the GSBE (Lewis and McLendon 1919).

By the end of 1919, the boll weevil was distributed across the entire Cotton Belt, from south Texas through the Carolinas (Anonymous 1920; Newell and Bynum 1920). Total losses from "the most destructive cotton insect at present in Georgia" were estimated at \$40 million in 1919 (Campbell 1919). Ironically, market disruption and concurrent high demand of cotton caused by World War I pushed prices and revenues to a historical high (figures 2 and 5). Recommendations for boll weevil control were still based on use of early varieties, high fertilization, hand picking of early weevils, picking up infested squares once a week for four to five weeks, and early plowing of the stalks (Lewis 1919). Plowing of cotton stalks with the Thompson Stalk Bender (or "even with a hoe, if nothing else is available") was also strongly advised (Oliver 1919). The GSBE conducted several field demonstrations for boll weevil control in cooperation with local county agents and local farmers in 1919, using calcium arsenate dust at rates and application methods that were

based on USDA recommendations. A total of three million pounds of calcium arsenate dust was applied throughout the South in 1919 (Ward 1920; Parencia 1978).

In 1920, “. . . some sections in south Georgia had losses from the boll weevil of 50 to 75 percent of the crop. Dusting cotton for the control of the boll weevil is not as yet a general practice by the cotton growers of Georgia” (Lewis 1920). Nonetheless, the Georgia Senate passed the first legislative act to regulate “registration, branding, inspection, analysis and sale of calcium arsenate, lead arsenate, and dust mixtures containing sulfur, lead arsenate and lime, and other insecticides and fungicides commonly used on cotton.” The act set minimum standards for sale, distribution, and packaging of dusting compounds. For example, calcium arsenate could be not less than 40% arsenic pentoxide, with a density of not less than 80 or more than 100 cubic inches per pound (Brown and Wilson 1922). This legislation was necessary because by 1920 more than 30 companies were marketing calcium arsenate in Georgia, and quality varied widely. Some mixtures were phytotoxic, while some were not sufficiently toxic to kill the boll weevil (Parencia 1978). Ten million pounds of calcium arsenate per year were now being used for cotton dusting throughout the South (Coad 1920). The first entomological research at the Coastal Plain Experiment Station (CPES), in Tifton, Georgia, was conducted in 1920 by Director S. H. Starr, who treated cotton plants growing in his variety trials with calcium arsenate for boll weevil control (Bass 1993). The USDA published a detailed summary of how to dust with calcium arsenate (apply once every four days; raise a cloud of dust, then let it settle; apply at night if possible). It also published the first complete description of newly developed dusting machinery (Coad 1920; Johnson and Coad 1920). Experiments showed that maximum benefits occurred within three days of application of calcium arsenate; thereafter, efficacy fell off rapidly through the seventh day, indicating that applications should be made at least weekly (Newell and Bynum 1920). The first reports of calcium arsenate dusting trials conducted by the Georgia Extension Service (from experiments in Cordele, Ashburn, Americus and Valdosta) were published in 1920 (Lewis 1920; Ward 1920).

The cotton industry was experiencing a severe depression in 1921 as crop losses from the boll weevil continued and producers in other countries began competing on the world market. Georgia crop losses were 45%, the highest suffered in the entire Cotton Belt (Isely and Baerg 1924). R. R. Childs, of the Georgia Extension Service, wrote that “Good yields can be obtained under weevil conditions, but not by the practices prevailing in the past.” He emphasized the use of rotation and cover crops, just as Joseph P. Lyman had done in 1866 (Lyman, 1867; Childs 1921). The USDA conducted detailed biology experiments in south-central Georgia cotton fields and adjoining areas of north-central Florida that included further observations on boll weevil hibernation behavior (Smith 1921), and UGA’s Extension Service published “Some Important Factors Effecting the Economic Production of Cotton.” It included a very clear admonition to “encourage research on a basis commensurate with the importance of the interests involved. This we assuredly have not done up to the present time.” The boll weevil “has disturbed our economic situation more than any other single factor since the conclusion of the Civil War; it is a pest of as great a magnitude as any which afflicted the Egyptians in the olden days” (Soule 1921). The GSBE published the results of further calcium arsenate dusting experiments conducted in Thomasville, Valdosta, and Baxley, along with detailed recommendations for rates and application methods (Warren and Williams 1921).

At this point in history, mechanized farming practices—i.e., the use of tractors and mechanical sprayers—were rapidly gaining momentum (Childs 1921). Agriculture was now poised on the verge of another period of dramatic transition and rapid change. The first great transition began in 1793 with the invention of Eli Whitney's cotton gin. This was followed seventy years later by the Civil War and the abolition of slavery, and now, fifty-five years after the end of the war, with the transition from man, mule, and horse power, to tractor (mechanical) power.

Another new development occurred in 1922 which would have far-reaching benefits for agriculture:

The cotton boll weevil is now found in all cotton producing States. During the summer experiments made in cooperation with the Air Service of the War Department give hope that the use of airplanes for the distribution of poisons may not only reduce the cost (of hand- or ground dusting) but extend the use of such poisons generally in the communities (Hinds 1926).

These experiments were conducted at the USDA Delta Laboratory in Tallulah, Louisiana, under the direction of B. R. Coad (Hinds 1926a). Otherwise, boll weevil control measures recommended by the USDA were still essentially the same as they were in 1916 (Hunter and Coad 1922). In Georgia, a complete summary of dusting experiments, together with recommendations for the coming season, were published by GSBE. Farmers were advised to treat every 4–6 days (nine to ten times per season) with calcium arsenate dust (Warren and Williams 1922). This treatment program cost about \$5.50 per acre per year (Bass 1993). Meanwhile, the Association of Southern Agricultural Workers (ASAW) voted to appoint the Cotton Council to help remedy a recognized lack of uniformity in the methods of experimentation and recommendations by various agencies. The following standard recommendation was adopted:

For the boll weevil, one presquare poisoning may be applied if it appears there are numerous overwintering weevils present. This should be given just as squares begin to form. Then apply the regular series of three or more dust applications of calcium arsenate at 4 or 5-day intervals, beginning when an average of approximately one-tenth of the squares show weevil punctures. Dusting should be continued as needed to keep this infestation low until a full crop is set and matured beyond the probability of further weevil injury (Parenica 1978).

In 1923, the USDA published the second, updated description of dusting methods with new machinery, stating in the introduction that “for successful dusting a time interval of hardly more than four days between poison applications has been found necessary as a general rule” (Johnson et al. 1923). The boll weevil now dominated the activities of the GSBE, which was also distributing calcium arsenate to farmers at cost (Warren and Williams 1922; Williams 1923). A warning was published by the USDA that companies vigorously promoting proprietary preparations and equipment were exploiting farmers and that many useless or impractical devices were being sold to them (Hunter and Coad 1923).

In 1924, the first Georgia publication promoting aerial spraying for boll weevil control was published. The first public demonstrations of aerial spraying were held at Athens on August 26 and at Cordele (Crisp County) on August 28, 1924; they were attended by 10,000 and 4000 people, respectively (Post 1924). One airplane could dust 750 to 1000

acres per day, even when the fields were too wet to treat by ground equipment. Much of the early work on aerial spraying was done by the USDA, but later (in 1931) the Bureau of Entomology discontinued its work and sold its airplanes, since the treatment method was now well established commercially (Post 1924; Parencia 1978). The overall yield losses from the boll weevil for the entire South during the period from 1921 to 1925 were estimated at 17.3% (\$18.7 million), with a peak crop loss in 1921 of 30% (\$23.4 million; Thomas 1929; Coad 1930). These figures do not include the additional costs of treating for the boll weevil during the growing season.

In 1926, a massive cooperative effort between federal and state entomologists, the UGA Extension Service, the Army Air Service, and private industry began in Georgia and in other states throughout the Cotton Belt. The widespread use of airplanes for dusting cotton for boll weevil control constituted the most striking advance in control efforts since the pest first appeared in Texas in 1894 (Hinds 1926a), and predictions were made that airplanes would become an important method of boll weevil control in the near future (Hinds 1926b). Some new observations on the boll weevil's spring emergence behavior were presented by D. Isely in 1926, which led to more precise spot treatments. These observations would be used 40 years later in the development of the pheromone trapping component of the eradication program (Isely 1926). Additional important observations on boll weevil life history and reproductive behavior were made by Gehauf (1926). By 1926, more than 1000 new insecticides had been tested in comparisons to calcium arsenate. Fifty of the new compounds equaled or surpassed the toxicity of calcium arsenate, but the use of arsenate dust was so commonplace and widely accepted by growers (Mills 1926) that the Association of Southern Agricultural Workers continued to recommend that its use as a dust, or in special cases as a syrup mixture, be strictly adhered to for the time being (Walker and Mills 1926).

In 1927, as it had been since the invention of the cotton gin, cotton remained the number one cash crop in Georgia, exceeding the value of all the other crops grown in the state (Talmadge 1928). 'Acala' cotton was "discovered" in a small field in Acala, Mexico, in 1927 by USDA personnel who were searching for varieties of cotton that showed resistance to boll weevil (Cook and Doyle 1927). This high-yielding, long-staple variety is now grown extensively in the western United States. Its discovery is just one of a number of benefits that have emerged since the boll weevil invasion began (see appendix).

The year 1929 marked the 25th anniversary of the beginning of farm demonstration (extension) work in the U.S., a movement that began with the specific purpose of helping farmers produce a good crop of cotton in the parts of Texas infested with the boll weevil. "The boll weevil was one of the initial factors which produced the impulse for laying the foundation of extension work" (Anonymous 1904; Hunter 1904c; Thomas 1929; Parencia 1978).

By 1930, most growers had incorporated dusting and fall plowing into their general farming practices, but overall production and revenues continued to decline as soil fertility diminished in areas where cotton was grown on marginal land, or where it was still grown year after year without rotation, and as other countries continued increasing their share of the world market. Harvested cotton acreage in Georgia had already declined 35% in 15 years, from 5.2 million acres in 1914 to 3.4 million in 1930 (figure 3), and total production had fallen from 2.8 million bales to 1.7 million (40%) during the same 15-year period.

Meanwhile, yield remained constant at about one-half bale per acre (figure 4). Early season boll weevil treatments were now widely recommended, with

one or two applications, four to six days apart, of one pound of calcium arsenate, one gallon of fresh molasses, and one gallon of water, daubed on the buds with a home-made burlap mop just before squaring time, (which) will kill most of the weevils that have survived the winter. If a good job is done at this time a crop of cotton may often be produced without the use of additional poison (Westbrook 1931).

By 1934, boll weevil damage had exceeded \$200 million per year across the Cotton Belt (Folsom 1932), and cotton acreage in Georgia had dropped to just 45% of the total farmed in 1910–1914; this was the greatest decline experienced in any of the Cotton States. Fertilization, use of improved varieties, thinning, proper cultivation, turning under stalks, and daubing the buds at squaring with a molasses-arsenic treatment plus three or four applications of dust were still the recommended methods to ensure optimum production. The new one-variety program also began to gain momentum in Georgia during the 1934 season (Childs and Westbrook 1934).

The boll weevil was actually credited with giving rise to the science of entomology in 1935, at least in the South:

Prior to the coming of the boll weevil and the establishment of the agricultural experiment stations there was very little interest in entomological work in the South. The advent of the boll weevil was responsible for a beginning in bringing the attention of the public to a realization of the importance of the influence of insects in the agricultural and economic development of the South (Bilsing 1935).

This was quite a contrast to the first USDA demonstration trials in Texas in 1903, where Dr. Hunter had to enter into contracts with the growers, promising to reimburse them if they did not produce a greater yield under his recommendations than with their customary methods. In 1935 the USDA assigned Dr. P. M. Gilmer and Mr. P. A. Glick to the CPES Agronomy Department to work on the boll weevil problem (Bass 1993). The USDA also sent Dr. Seaman A. Knapp to Texas to demonstrate further the benefits of implementing the results of scientific research. This demonstration program led to passage of the Smith-Lever Bill in 1914, making the establishment of our modern system of county agricultural agents possible. “The forced change in the production of cotton due to the advent of the boll weevil resulted in the reorganization of our system of agriculture; indirectly to diversified farming, and in a well organized system of imparting scientific information to a large part of the agricultural population of the South” (Bilsing 1935; Caesar 1940).

In 1936 experiments on boll weevil control in ‘Sea Island’ cotton began in Tifton, Georgia, with the intention of reviving the ‘Sea Island’ cotton industry, but results showed that it could not be grown economically in the Coastal Plain because of its low yield and attractiveness to the boll weevil (Parencia 1978). The Georgia one-variety cotton program now included 15,194 farmers in 134 organized communities around the state that together produced 103,000 bales of cotton and received \$1.5 million more for their improved variety cotton than they would have from the ordinary, older varieties (Anonymous 1936).

In 1939, cotton was still the number one crop in Georgia, but it no longer had a greater value than all the other crops in the state. Treatment recommendations remained similar to those of earlier years; i.e., either to mop the cotton with an arsenic-molasses syrup or dust with 1.5 to two pounds of calcium arsenate by hand or apply a mixture of five pounds of calcium arsenate (with an optional one-fourth pound of Paris Green), one to two gallons of syrup, and 48 to 49 gallons of water, at the rate of 25 gallons of water per acre with a mule-drawn spray machine (Westbrook 1931). Picking up infested bolls that had dropped from the plants, and plowing up stalks as soon as the cotton was picked were also strongly encouraged as part of an overall boll weevil control program (Westbrook 1939). The year 1939 was also the first time that Georgia cotton growers participated in a widescale spring treatment program to help reduce the boll weevil population prior to its late summer migration period (Westbrook 1939).

Georgia farmers applied 1.5 million pounds of calcium arsenate dust for boll weevil control in 1940; growers who treated averaged 62 pounds of lint per acre more than growers who did not treat. The one-variety cotton program continued gaining popularity, especially since 51% of the cotton now had a staple length averaging one inch or longer, compared to less than 4% averaging one inch or longer in 1931 (Westbrook 1939). The one-variety movement now included 29,421 farmers in 195 organized communities, producing 239,178 bales of cotton on 386,600 acres of land. Growers received \$2,980,000 more for their improved variety cotton than they would have received with the ordinary varieties. The average yield was 310 pounds per acre in the improved fields versus 250 pounds per acre in the regular fields (Anonymous 1940). Georgia farmers were first encouraged to follow an economic threshold (marking the earliest beginnings of cotton Integrated Pest Management [IPM] in 1940). For example, it was recommended that four to six pounds of arsenical dust be applied on a weekly basis, once the number of punctured bolls surpassed ten percent. Detailed instructions on how to make counts in the field and how to verify weevil damage were also provided (Anonymous 1941).

In 1944 cotton was still the number one crop in Georgia, and the earlier economic losses suffered from a drop in cotton production were gradually being replaced by increased production of other crops such as peanuts (Floyd and Treanor 1944). Farming in America and the South was once again poised for another period of rapid change as it entered the post World War II chemical pesticide era.

The Boll Weevil in Georgia—The Post-War Pesticide Era

In 1945 the boll weevil remained the number one pest of cotton in Georgia. E. C. Westbrook wrote in the Experiment Station publication, "Modernizing Cotton Production," that "Cotton production methods are on the eve of drastic and far-reaching changes. We are now at the beginning of an extensive shift to mechanized production of cotton and other crops. Cotton farmers are faced with the immediate necessity of greatly reducing cost of production." He also mentioned the immanent advent of "Power-take-off-driven dusting machines" (Westbrook 1945). Treatment recommendations for arsenical syrup prior to squaring and for dusting during the main growing season remained essentially the same as those developed in 1940 (Anonymous 1941).

In 1946, Dr. P. M. Gilmer accepted a split appointment as head of the new University of Georgia Department of Entomology at the CPES and USDA researcher. He worked on control of cotton insects, including the boll weevil, with the new insecticides benzene hexachloride (BHC) and chlorinated camphene (Bass 1993). Calcium arsenate was still the only poison used by farmers in Georgia in 1947 for boll weevil control, and virtually all the cotton acreage was still harvested by hand (Fullilove and Elrod 1950a). In 1948 the first full-time UGA entomologist, Mr. Loy Morgan, began working with USDA personnel at the CPES, with an initial research emphasis on boll weevil control in cotton using DDT, toxaphene and BHC (Anonymous 1975; Bass 1993). Seed cotton yield in the first toxaphene-treated plots averaged 1943 pounds per acre, versus 1457 pounds per acre for calcium arsenate-treated plots (Bass 1993). In the same year the USDA began conducting the very first early season, large-scale community boll weevil control experiments, using 20% toxaphene dust, on 1050 acres of cotton in Wharton County, Texas. The experiment resulted in an average yield of 448 pounds per acre versus 310 pounds per acre in the untreated fields. K. P. Ewing and C. R. Parencia wrote that "Large-scale community experiments of this kind should be conducted in many cotton-producing areas during several seasons to determine where and under what conditions the early-season application of insecticides is profitable" (Ewing and Parencia 1949a).

In 1949 the CPES published its first recommendation for either 1) 3% gamma isomer BHC plus 5% DDT (the "3-5 Mixture") in 40% sulfur dust or any other suitable neutral or slightly acid diluent at 10 pounds per acre, 2) Chlorinated camphene (Toxaphene) at 20% camphene plus 5% DDT in 40% sulfur dust or any other suitable neutral or slightly acid diluent at 10 to 15 pounds per acre, or 3) Calcium arsenate combined with 1% nicotine or 1% rotenone at 7 to 10 pounds per acre (Anonymous 1949; Anonymous 1950a). The USDA continued the second year of a large-scale experiment in Wharton and Waco, Texas, on 1400 acres. One of the treatments included the 3-5 Mixture in 40% sulfur dust. Yield averaged 415 pounds per acre in treated fields versus 178 pounds per acre in the untreated fields (Ewing and Parencia 1949b). Also, 1949 saw the introduction of a low-volume spray method for applying chlorinated hydrocarbon (CHC) insecticides such as DDT (Parencia 1959). This new application method allowed growers to treat a larger area in a much shorter period of time. It also set the stage for a revolution in pest management practices and created a new branch of entomological research (i.e., efficacy evaluations).

The Georgia Experiment Station published the first comprehensive report describing cotton farming practices and input costs in four distinct farming regions in Georgia in 1950. The results showed that the consistency and quality of boll weevil pest management practices varied widely within the four regions, especially within the main production areas located in the south-central and southwestern parts of Georgia (Fullilove and Elrod 1950a, 1950b, 1950c; Glasgow and Fullilove 1950). Yield still averaged about one-half bale per acre, as it had for more than 100 years, and total cotton acreage continued to decline because of the boll weevil, poor yields, and additional pressures brought on by increased competition from synthetic fibers such as rayon (Westbrook et al. 1950). The boll weevil remained in its secure position as the major cotton pest in Georgia and the Cotton Belt. In fact, C. M. Beckham and M. Dupree of the Georgia Experiment Station reported that "the boll weevil population is considered greater than in any previous year in history, with counts as high as 3,900 weevils per acre in some fields. This was probably due to the previous mild winter" (Beckham and Dupree 1951). In other words, after fighting against

the boll weevil for 25 years with calcium arsenate dusts and cultural practices, the problem in 1950 was worse than ever. Beckham and Dupree also presented results from eight new field trials, where applications were made with the newly developed, low-volume, tractor-mounted, six-row applicator, operated at 60 pounds per square inch (psi) with improved disk-type nozzles. Materials tested in the trials included two pounds of toxaphene, two pounds of toxaphene plus 0.5 pounds of DDT, 0.4 pounds of BHC plus 0.5 pounds of DDT, 0.25 pounds of aldrin plus 0.5 pounds of DDT, and 0.15 pounds of dieldrin plus 0.5 pounds of DDT (Beckham and Dupree 1950). Yield in treated fields was significantly higher than in the check plots, but a comparison with standard calcium arsenate dust treatments was not made. The Extension Service of UGA published the first edition of the "Georgia Agricultural Handbook" (Anonymous 1950b), which included the same recommendations for boll weevil control as outlined in 1949 (Anonymous 1949; Anonymous 1950a). Later in 1950 a new recommendation of 10 pounds of 20% technical toxaphene dust per acre was also distributed to cotton growers (Westbrook et al. 1950). The Georgia legislature passed a new Economic Poisons Act (EPA) on February 17, 1950, which was designed to be enforced jointly by the Commissioner of Agriculture and the Director of Entomology. Its purpose was to regulate the distribution, sale, and transportation of a rapidly growing number of new insecticides and spray application devices (Alden 1953).

In 1950, the USDA presented a report summarizing the results of 50 years of research to the Committee on Agriculture of the House of Representatives of the eighty-first Congress. The report stated that "Agriculture has made more progress in the United States in the last 75 years than in the previous 75 centuries elsewhere in the world. This period of great advancement (largely prompted by the boll weevil) coincides with the history of research in the USDA and the State agricultural experiment stations" (Anonymous 1950c). The federal government had spent a total of \$3,207,897 on boll weevil research during the 58 years (1892–1950) since the boll weevil first appeared in the U.S. In comparison, conservative estimates placed losses caused by the boll weevil at \$200,000,000 each year during the same 50-year period (Anonymous 1950c). The USDA conducted the third and final year of a large-scale, early season insecticide test on 3084 acres near Wharton, Texas, and 3602 acres near Waco, Texas. Yield averaged 474 pounds per acre in the treated fields versus 270 pounds per acre in the untreated fields (Ewing and Parenica 1950).

In 1951, the Georgia Experiment Station published the results of its first test with emulsifiable concentrate sprays applied with a tractor-mounted, low pressure (50–55 psi), low gallon sprayer equipped with hollow cone nozzle tips (three gallons per minute output). Six applications of toxaphene and DDT, aldrin and DDT, or dieldrin and DDT were applied. Effectiveness of all of the compounds for controlling the boll weevil was similar to calcium arsenate (Beckham and Dupree 1951). The first tests documenting degradation of DDT treatments after three days were also published in 1951. Results of these tests led to the recommendation of a seven-day spray schedule, which, as it turned out, served to hasten the development of resistance to DDT by the boll weevil. This test was also the first to evaluate the effectiveness of an organophosphate (OP) compound, EPN-300, with calcium arsenate. It was by far the most effective material tested, suggesting that the mode of action of this new class of compounds may be different than the mode of action of chlorinated hydrocarbons such as DDT (Rainwater and Gaines 1951). In 1951 a fourth

treatment of 2.5% aldrin plus 5% DDT at 10 pounds per acre was also added to the three existing treatment recommendations listed above (Westbrook 1951; Anonymous 1949; Anonymous 1950a; Westbrook et al. 1950).

By 1953, there were 3259 brands of economic poisons and application devices from 439 companies registered under the 1950 Georgia Economic Poisons Act (Westbrook 1951).

Boll weevil resistance to chlorinated hydrocarbons (CHCs) was first reported in Louisiana in 1954, with 65% of the weevils tested showing some degree of resistance (Dunn 1964). Ninety-eight percent of the insecticides sold in 1954 were CHCs; by 1958 only 34% of the insecticides sold were CHCs. Concurrently, OPs became available in 1956, accounting for 20% of the total insecticides sold, and for 55% of the insecticides sold in the next two years. During this transition period, pest control costs at the Delta Laboratory in Tallulah, Louisiana, increased to a high of \$60 per acre in the early to mid-1950s, then decreased to \$38 per acre in 1957, and to \$20 per acre by 1962. Average yield between 1957 and 1962 increased from 558 to 745 pounds per acre (Rainwater 1962; Smith et al. 1964). Boll weevil resistance to toxaphene and dieldrin was first reported in Texas in 1956 (Parencia 1959; Parencia and Cowan 1960), followed by more widespread resistance to toxaphene and dieldrin by 1958. At the same time, improved control was observed with Sevin, guthion, and malathion (Parencia and Cowan 1960), and in 1958 the Georgia Extension Service added endrin, guthion, heptachlor, malathion and parathion to its list of recommended materials for boll weevil control (Anonymous 1958).

The Boll Weevil in Georgia—Beginning of the Eradication Era

In 1959 J. R. Brazzel and L. D. Newsom published their now-famous paper that clearly outlined the winter diapause behavior of the boll weevil (Brazzel and Newsom 1959), expanding on a concept that was first suggested by B. R. Coad (1915). Brazzel's work set the stage for the eventual development of the Boll Weevil Eradication Program. Brazzel also published the results of his first diapause control insecticide treatment trial in 1959. He found that late fall season methyl parathion treatments significantly reduced the overwintering boll weevil population. His results clearly showed that properly timed fall insecticide applications combined with cultural practices (stalk plowing) effectively reduced overwintering boll weevil populations (Brazzel 1959).

In 1960 Brazzel published additional details on boll weevil reproductive biology, diapause, and insecticide resistance that brought him closer to the formation of his diapause treatment paradigm (Brazzel and Hightower 1960). Brazzel showed that four insecticide applications in the fall reduced boll weevil populations by 90% the following spring—from 8800 to 935 diapausing adults per acre in 1959 (Brazzel et al. 1961; Knipling 1971). E. F. Knipling believed that significantly better control (i.e., reducing the remaining 935 diapausing adults per acre to just 25) could be achieved by increasing the number of fall treatments from four to seven (Knipling 1971; Anonymous 1979). This approach was called the reproduction-diapause control spray schedule. Also, Knipling calculated that pheromone traps would capture 88.5% of the surviving boll weevil adults emerging from diapause in the spring if they were set out at the rate of 10 per acre (Knipling 1971;

Parencia 1978). One year later the Georgia Extension Service added Sevin to its list of recommended materials for boll weevil control (Anonymous 1961).

Knipling's calculations were confirmed in the Texas High Plains pilot suppression program which began in 1964 and continued through 1967. A cumulative total of over 1.1 million acres was treated at least four times with malathion applied as an Ultra-Low-Volume (ULV) spray. This pioneering program was considered a success, and ultimately reduced the overwintering boll weevil population by 99% (Adkisson 1968; Knipling 1968). Economic benefits from the entire program were calculated at \$273 million versus an overall input cost of \$17 million, for a final net cost:benefit ratio of 16:1 (Carlson et al. 1989; Frisbie et al. 1989).

In 1968, the second comprehensive report describing cotton farming practices and input costs in Georgia was published in a joint UGA Extension-USDA report. It stated that from 10 to 14 treatments per acre were being applied by self-propelled sprayers, plus an additional three to four by airplane, for control of boll weevil and other pests in Georgia (Martin 1968). In the same year work on the isolation, identification, and synthesis of the boll weevil male sex pheromone began (Tumlinson et al. 1968). In 1970, USDA researchers working along the Mexico-Texas border discovered male boll weevils in traps at least 45 miles from the nearest cotton. This discovery formed the basis for the development of minimum exclusion zones in the eradication programs. It also coincided with ongoing research in the development and effective use of boll weevil sex- and aggregation-pheromones as part of a widescale eradication program (Davich et al. 1970; Knipling 1971). This key project was successfully completed in 1971 (Hardee 1972; Tumlinson et al. 1971). The first suggestion to use sex-pheromone baited traps to trap emerging boll weevils and pinpoint high density areas of boll weevil activity as part an overall eradication program was made in 1971 (Knipling 1971), and the first diapause control program in Alabama began the same year. It included 650 farmers with 11,200 acres of cotton in three counties. The treatment was 0.25 pound per acre of guthion applied as a ULV spray with five Pawnee 235 airplanes (Ledbetter 1971).

In July of 1971 the Pilot Boll Weevil Eradication Experiment (PBWEE) began in south Mississippi and in adjoining areas of Louisiana and Alabama (Parencia 1978; Perkins 1980). This experiment was completed on August 10, 1973, one season sooner than originally planned. Funding was provided by USDA-ARS (\$1 million), CSRS (\$500,000), and Cotton Incorporated (\$500,000). Five in-season applications of azinphos-methyl were made, followed by 13 applications for reproductive-diapause control. This approach was based on the pioneering work by Brazzel and by Knipling (Brazzel and Newsom 1959; Brazzel 1959; Brazzel and Hightower 1960; Knipling 1971; Anonymous 1979). Pheromone traps in the spring indicated a significant reduction of overwintering population, as Knipling had predicted. It was also discovered (by accident) that a single untreated acre of cotton provided a source of infestation for at least 1800 surrounding acres. The principles of a coordinated management program became very clear in the Mississippi trial program. The favorable results of the PBWEE indicated that elimination of the boll weevil from the continental U.S. was technologically and operationally feasible, if an entire geographical region was covered. Final plans for a National Program to Eliminate the Boll Weevil from the United States were then prepared by a technical committee and presented to a special study committee on December 4, 1973, which in turn forwarded the final

recommendations to the Secretary of Agriculture on December 12, 1973. The Secretary had already been instructed in the Agricultural Act of 1973 to carry out an eradication program for the boll weevil if it was feasible to do so. Not everyone, however, on the three different boll weevil review committees that now existed agreed that eradication using the fall diapause insecticide treatment approach was really possible, and a dramatic period of intense behind-the-scenes arguing erupted within the entomological community. The various committee reports included conflicting opinions and disagreements. In summary, the argument was whether biology or chemicals would ultimately prevail against the boll weevil. One school, following the Integrated Pest Management (IPM) approach, believed that complete eradication of the boll weevil was not supported by the results of the Mississippi Pilot Program, while another school, following the Total Population Management (TPM) approach, believed that the results of the Pilot Program demonstrated that eradication was possible. The debate went to Congress and was finally resolved in 1977, when, after several high-level meetings with Secretary of Agriculture Earl Butz, various Congressmen, and President Ford, the decision was made to initiate the Trial Boll Weevil Eradication Program (TBWEP) in 1978 in North Carolina (Parencia 1978). In the end, the PBWEE and TBWEP were the most complex experiments ever designed under the TPM paradigm, and, as it turned out, rather ironically, they prepared the way for eventual implementation and widespread adoption of the IPM approach to pest management in cotton (Perkins 1980).

A concurrent review on eradication-suppression of emerging, overwintering boll weevil populations was published by USDA researchers in Florence, South Carolina, in 1972. Their IPM approach, based on behavior, biology, chemical control, and use of pheromones, included this statement:

Integrated control of the type described could be used to totally suppress the emerging overwintered boll weevil populations in an areawide program, since aerial applications of foliar insecticides are possible on a strict schedule. Then it may be possible, with present knowledge, materials, and techniques, to eradicate the boll weevil with a program consisting of systemic insecticides, conventional insecticides, and boll weevil-pheromone traps (Taft et al. 1972).

In the same year, D. D. Hardee published the first complete review of boll weevil sex-pheromone research (Hardee 1972). His paper outlined all of the published research that led to the development and use of Grandlure (the boll weevil sex-pheromone) and included the following statement: "The boll weevil is the most costly insect in the history of American agriculture." Hardee based his statement on a phrase that appeared as early as 1964, referring to the boll weevil as the "\$10 billion insect" (Dunn 1964; Mitlin and Mitlin 1968), and on estimates made in 1950 that boll weevil losses had averaged at least \$200 million per year for 50 years (Anonymous 1950c).

Losses in cotton production due to the boll weevil were estimated in 1972 to average from \$200 to \$300 million annually, with an additional \$50–70 million spent each year to prevent further losses (Knipling 1971; Perkins 1980). It was also estimated that one-third of all insecticides used for agricultural purposes in the United States were applied to cotton for boll weevil control (Perkins 1980). Data from another survey covering 1971 to 1978 indicated that this proportion may have been closer to 53% of all agricultural chemicals (Ridgway et al. 1983). Even with the different estimates, there is no doubt that

for at least twenty years after World War II, cotton received more insecticide treatments than any other crop, and that the boll weevil was the primary target.

Hardee also included one of the first definitive statements describing what became known as the “pesticide treadmill” in the introduction to his review of pheromone research in 1972. He wrote:

The extensive use of insecticides for control of boll weevil not only may cause a serious problem of environmental pollution but often causes a drastic reduction of natural biological agents that otherwise would hold other agricultural pests in check. The adverse effect on natural insect parasites often leads to a subsequent increase in populations of such insects as the tobacco budworm and the (cotton) bollworm. This, in turn, may result in increased crop losses and increased intensive use of insecticides to protect the cotton crop (Hardee 1972).

His observations were clearly born out the same year, when, after years of debate and controversy, DDT and some related organochlorine compounds were totally banned from use in American agriculture. Applications of OPs, especially methyl parathion, immediately increased. This was followed by a decline in yield and acreage, plus several years of dramatic fluctuations in budworm, bollworm, and armyworm populations as their natural enemies were being decimated by increasingly frequent insecticide applications (figures 1, 6, 7, 8).

In 1978, the Trial Boll Weevil Eradication Program began in North Carolina. The five-year program was dramatically successful, leading to improved yield, significantly lower pest management costs, and an increase in the acreage planted in cotton. These successes also provided the momentum to begin serious efforts to expand boll weevil eradication in other parts of the Cotton Belt (Ganyard et al. 1981; Keller 1981). Overall economic benefits were calculated at \$112 per acre (Carlson et al. 1989; Frisbie et al. 1989; Szmedra et al. 1991). In the same year a large-scale, early season test was also conducted in Chowan County, North Carolina, using Dimilin, an Insect Growth Regulator (IGR). The boll weevil was treated with 0.3 pounds of Dimilin in 2.5 gallons of Sun Oil 7N with a Stearman PT17 cropduster on a seven-day treatment schedule, with a total of ten treatments. Results showed greater than 90% reduction of subsequent F3 reproduction over the conventionally treated fields. Yield increases in Dimilin treated fields averaged 808 pounds of seed cotton per acre, versus 523 pounds per acre in untreated fields (Ganyard et al. 1978). An Optimum Pest Management Trial also began in the Panola-Pontotoc area of Mississippi in 1978. This cooperative effort resulted in reducing the number of treatments from a high of 18 in 1971 to 3.3, 3.4, and 3.0 applications in 1978 1979, and 1980, respectively. Yield increased an average of 84 pounds per acre during the trial, or 34 pounds per acre over the 10-year average, and total cotton acreage increased from 32,075 to 39,000 (18%) during the course of the trial (Ridgway et al. 1983).

The 1980 USDA insecticide recommendations for boll weevil control included aldicarb, azinphos-methyl, carbaryl, EPN, EPN plus methyl parathion, malathion alone, malathion plus methyl parathion, methyl parathion plus methomyl, monocrotophos, toxaphene alone, and toxaphene plus methyl parathion, all applied “on foliage at 3 to 7 day intervals until controlled” (Anonymous 1980). During this time, Georgia cotton growers were applying an average of 14.4 treatments per acre (figure 6 and table 1).

In 1985, cotton was still regarded as the most important textile fiber in the world, accounting for 50% of the world's total fiber production. China, the Soviet Union (Ukraine and Khazakstan), Egypt, and the U.S. accounted for more than 90% of the world's production (Starbird et al. 1987).

By 1986 the Grandlure-baited boll weevil traps had become an "essential component of any control program." Indeed, 400,000 traps and 2,750,000 dispensers containing 10 mg. of Grandlure were used in the North Carolina program in 1985 (Dickerson 1986). The pheromone traps were used successfully for a variety of purposes, such as a capture-control method, or to attract and trap male weevils emerging from diapause in the spring, or as a tool for monitoring population trends and specific sites of weevil activity during the growing season (Cate 1988; Leonhardt et al. 1988).

In 1987, following the publication of several earlier economic studies by Fullilove and Elrod (1950a, 1950b, 1950c), Glasgow and Fullilove (1950), and Martin et al. (1968), an updated analysis of costs and returns for cotton production in Midville, Georgia was published. This study showed that cotton, on a per-acre basis, was still the most profitable and stable commodity produced in the central region of the state, and that insecticide costs averaged 13.3% of the annual operating budget (Perry and Saunders 1987).

Eradication of the Boll Weevil in Georgia

Despite the dramatic success of the eradication program in North Carolina, the first referendum to assess Georgia growers for the purpose of initiating the Southeast Boll Weevil Eradication Program failed to pass (Planer 1988). The second Georgia referendum passed in November 1986 (Planer 1988; Anonymous 1991; see Appendix B) after being promoted as an essential part of a larger Beltwide Eradication Program. The fall diapause treatment phase of the eradication program began in September 1987. An average of 8.4 treatments per acre with 16 ounces of guthion were applied to 287,500 acres of cotton during the first season. Ninety-five percent of the planned treatments were applied by the first killing frost on November 12. The first two of the eight treatments per acre were applied five days apart; then treatments were applied in seven-day intervals through October, then in 10-day intervals through mid-November, and, finally, in 14-day intervals through December (Planer 1988; Brazzel 1989). The pheromone trapping phase of the eradication program began in April 1988, with an average of one trap per acre placed on all 346,548 acres of cotton involved. Problems with fish kills associated with the aerial application of guthion near ponds resulted in a change to less-toxic malathion for the diapause treatments in the autumn of 1988. An average of 9.1 applications per acre using 16 ounces of malathion were applied in the fall of 1988, followed again by placing one pheromone trap per acre on 259,438 acres the next spring. In the autumn of 1989 an average of 12.4 treatments using 16 ounces of malathion per acre were applied, again followed by placing one pheromone trap per acre on 349,929 acres in the spring of 1990. The average number of treatments applied in the autumn of 1990 declined to 2.7 per acre, and the trapping ratio in the spring of 1991 was reduced to one trap per every one, five, or 10 acres, depending on the status of the eradication program in the area. In 1991 only 0.66 fall diapause applications per acre of malathion were applied, and the trapping program the following spring continued on a variable-acre basis as it had in 1991. Malathion treatments continued to decline each year, with an average of 0.47, 0.27, 0.02,

and 0.01 applications per acre between 1992 and 1995 (table 2). Plans for the 1996 season are to continue the Eradication Program on a maintenance basis, with traps set at one per every eight to 10 acres, and to apply spot treatments whenever necessary.

A detailed discussion and analysis of overall pest management costs, boll weevil pest management costs and the economic and environmental benefits of the Southeast Boll Weevil Eradication Program in Georgia are presented in Part II of this bulletin.

Part II: Economic and Environmental Benefits of Eradication

Introduction to Part II

Part II reviews overall insect pest management costs (primarily insecticides and application costs) and amount of damage to cotton in Georgia from 1971 through 1995. It also highlights the economic and environmental benefits of the Southeast Boll Weevil Eradication Program (SEBWEP) during the same period of time. For easier comparison, the graphs and tables referred to in Part II are divided into three sections, covering 1) 1971 to 1986, the pre-SEBWEP era; 2) 1987 to 1990, the SEBWEP era; and 3) 1991 to 1994, the post-SEBWEP era.

Amount of Boll Weevil and Other Insect Pest Treatment Costs

Although detailed annual records of insect pest management treatment costs for boll weevil and other pests in Georgia cotton were not available until 1971, we know that between 1938 and 1947 growers usually mopped the plants once or twice with a cloth dipped in a calcium arsenate syrup mixture early in the season, then applied three or four more treatments of calcium arsenate dust (Fullilove and Elrod 1950a, 1950b, 1950c). Very little detailed information on pest management costs in Georgia during the 1950s is available, but it is well established that at least 30% of all the agricultural insecticides applied during that period were being used in cotton dust (Brazzel et al. 1961; Knipling 1971; Perkins 1980; Ridgway 1983). Meanwhile, annual costs continued increasing as primary cotton pests developed resistance and outbreaks of secondary pests (e.g., plant bugs, thrips, and mites) became increasingly common. We also know that during the middle 1960s from 13 to 18 treatments of broad spectrum insecticides (primarily OPs) per acre were being applied, primarily for boll weevil, bollworm, budworm and armyworm control (Smith et al. 1964), and that pest control costs in Georgia averaged \$20 per acre, or 16% of the total production budget of \$125 per acre (Martin et al. 1968). This was similar to the number of treatments that were being applied during the 1970s and through the mid-1980s (figure 6). Studies conducted at the Midville Branch Station in 1987 (part of the pre-SEBWEP era) showed that insect pest management costs averaged \$56 per acre—13.3% of the annual operating budget (Perry and Saunders 1987)—versus \$27 per acre (6.3% of the annual budget) in 1994 (part of the post-SEBWEP era), a reduction of 53% (Midville Station 1994 Preliminary Production Budget; currently unpublished).

A detailed summary of all insect pest management costs and damage for each year from 1971 through 1995 is provided in tables 3, 4, 5, and 6. All pest management data presented in those tables are derived from “Summary of Economic Losses Due to Insect Damage and Costs of Control in Georgia,” published annually by the University of Georgia College of Agriculture and Environmental Sciences Experiment Station (Suber and Todd 1980; Todd and Suber 1980; Suber et al. 1981a, 1981b; Suber et al. 1982; Suber et al. 1983; Suber et al. 1984; Suber et al. 1985; Douce and Suber 1985; Douce and Suber 1986; Douce and Suber 1988a, 1988b; Douce and McPherson 1989; Douce and McPherson 1991; Douce and McPherson 1992; Douce and McPherson 1993; McPherson and Douce 1993; Lambert and Herzog 1995). Additional production and acreage data are derived from “Georgia Agricultural Facts: 1984 Edition” (Anonymous 1984), and from the

1995 and 1996 Cotton Production Guide (Crawford 1995; Brown 1996). Finally, the 1994 and 1995 economic loss and pest control data used in tables 3, 4, 5, and 6 have been compiled by UGA Extension, but are currently unpublished.

Overall cotton insect pest management costs in Georgia during the pre-SEBWEP period averaged \$68 per acre, versus \$140 during the SEBWEP period, and \$48 in the post-SEBWEP period, or 22%, 33%, and 9% of the gross crop revenues, respectively (table 1). Overall pest management costs in the post-SEBWEP period are 30% less than costs during the pre-SEBWEP period.

Amount of Boll Weevil and Other Insect Pest Damage

Cotton production in Georgia peaked in 1911, with 2,900,000 bales produced on nearly five million acres (figures 1 and 2). After the boll weevil appeared in 1915, cotton production declined precipitously, falling to just 600,000 bales by 1923, or just 20% of the pre-weevil production. Although the introduction of standardized methods of applying calcium arsenate dust, followed by the introduction of newly designed spray application equipment and aerial spraying, helped the cotton industry recover some of its losses during the 1930s, cotton production generally began a long period of decline that culminated in 1978 and 1983, when 111,000 and 112,000 bales, respectively, were produced on just 115,000 acres. Even the introduction of DDT in the early 1950s, followed by OPs in the mid-1950s and 1960s, failed to bring about a strong recovery of cotton production. By the early 1950s, other crops, such as peanuts, tobacco, and vegetables, began replacing cotton as the state's principal crop, and by the mid-1980s many considered cotton in Georgia to be dead.

Overall pest damage in the pre-SEBWEP era averaged \$56 per acre, versus \$64 during the SEBWEP era, and \$18 in the post-SEBWEP era (table 1), or 15%, 13%, and 3% of gross crop revenues, respectively. Overall amount of damage in the post-SEBWEP era is 68% less than damage during the pre-SEBWEP era.

In summary, total pest management costs combined with the overall amount of damage in the Pre-SEBWEP period averaged \$125 per acre, versus \$204 during the SEBWEP period, and \$66 in the Post-SEBWEP period, or 37%, 46%, and 12% of gross crop revenues, respectively (table 1). Combined pest management costs and amount of damage in the post-SEBWEP period are 53% less than in the pre-SEBWEP period.

Benefits of Eradication: Economic

An economic analysis by Szmedra et al. (1991) of several boll weevil eradication programs conducted across the Cotton Belt offered the following conclusion:

Results indicate that a Boll Weevil Eradication program is economically attractive at virtually any cost share (providing it is followed) with high IPM. Positive cash flow results (even) when growers finance 100 percent of the program, (and they) can expect higher returns than from a comparable strategy without eradication in effect, due to fewer insect control applications and thus lower control costs (and reduced damage). The results of this study indicate that boll weevil eradication is

a significant step towards improving the grower's financial situation as well as limiting the number of pesticide (treatments).

This has proven to be the case in the Boll Weevil Eradication Program in Georgia. The number of treatments have been reduced from an average of 14.4 per acre in the Pre-Eradication era to 5.4 in the post-Eradication era, while cost of treatments in the same two periods has dropped from \$125 per acre to \$66 per acre (figure 6 and table 1). Pest management costs in Georgia are now the lowest in the Cotton Belt. Concurrently, yield has increased from 482 to 733 pounds per acre, and harvested acres have increased from 228,000 to 770,000 (tables 1, 3, 4, 5, 6). Total crop value has increased from an average of \$69 million to \$399 million. The gross value of cotton has increased from \$312 to \$517 per acre, while net crop value (gross crop value less insect pest management costs and amount of damage) has increased from \$187 to \$451 per acre (table 1).

The total cost of the eradication program in Georgia from its beginning in 1987 through the 1995 season has been \$99.3 million. The state of Georgia made a one-time contribution of \$3 million in 1990 (3.0%), and the federal government has contributed a total of \$27.7 million (27.9%). Grower assessments have accounted for \$68.6 million (69.1%) of the total program cost. Assessments in 1987 began at \$10 per acre; this amount was raised to \$35 per acre in 1988, 1989, and 1990, then reduced to \$20 in 1991, \$18 in 1992, \$10 in 1993, \$6.50 in 1994, and \$5.50 in 1995 (table 2). In 1995 \$3.43 of the \$5.50 grower assessment fee went to the Southeast Eradication Foundation; the remaining \$2.07 was used to establish, for the first time, a contingency fund for Georgia cotton growers. Total crop values in the five-year, post-SEBWEP era have averaged \$399 million per year, versus \$69 million in the pre-SEBWEP era (figure 7 and table 1), a difference of \$330 million annually, or about \$1.7 billion overall. The net benefit, after deducting the \$99.3 million total cost of the program, is \$1.6 billion, plus an additional benefit of about \$60 per acre (\$46 million annually) in reduced pest management costs. Compounded economic benefits to the Georgia economy during the post-SEBWEP era, using traditional "cotton dollar turnover" rates of five to seven, range between \$4 and \$5 billion annually (Brown 1996).

Benefits of Eradication: Environmental

For more than 80 years, cotton pest management in the Cotton Belt was based primarily on multiple insecticide treatments. In 1971 approximately 73 million pounds of insecticide active ingredient (Ridgway 1983) were applied to 11.5 million acres of harvested cotton (Anonymous 1993), an equivalent of 6.3 pounds per acre. By 1992 the amount of insecticide active ingredient used had dropped to 20 million pounds (Gianessi and Anderson 1995), on 11.1 million acres of harvested cotton (Anonymous 1993), an equivalent of 1.8 pounds per acre. Reasons for this reduction include completion of boll weevil eradication programs in several states, widespread efforts to implement IPM in cotton, development of threshold-based treatments, and wider use of synthetic pyrethroids, which are used at extremely low rates of active ingredient per acre.

Now, for the first time in Georgia's history, cotton insect pest management can be built on a solid foundation of biology and sustainability. One of the most immediate environmental benefits derived from the eradication program in Georgia has been an approximate

60% reduction in the number of insecticide applications (figure 6). This substantial reduction of insecticide use allows beneficial insects to build up to more effective populations, which in turn helps establish long-term stability and sustainability in the cotton agro-ecosystem. The establishment of enhanced stability leads to a general trend of fewer and fewer insecticide treatments, ultimately facilitating the expression of another kind of “treadmill”; that is, a benign, long-term, sustainable biological cycle.

The Beet Armyworm, Bollworm, and Budworm Connection

The beet armyworm (BAW), *Spodoptera exigua* (Hubner), provides a good illustration of disruption of biological control by insecticides versus long-term, sustainable biological control by beneficial arthropods, especially the braconid parasitoid *Cotesia marginiventris* Cresson. In the years 1988–1990 an outbreak of *Spodoptera* occurred in Georgia when repeated treatments of guthion (in the fall of 1987) and malathion were applied during the “active treatment phase” of the eradication program. BAW cost of control plus damage (see tables 3 through 6) averaged 1.9% of total crop value during the 16-year, pre-eradication era. This amount increased fivefold to 9.9% during the active phase, then declined quickly to 0.8% once the active phase of the program was completed (figure 8). Closer study of BAW biodynamics before, during, and after the eradication program indicates that disruption of natural enemies, such as *Cotesia*, by broad-spectrum insecticides was probably a key factor in the dramatic outbreak of this normally sporadic and minor cotton pest (Ruberson et al. 1994). Also, bollworm, *Helicoverpa zea* (Boddie), and budworm, *Heliothis virescens* (F.), cost of control plus damage averaged 26.1% of total the crop value during the pre-eradication era. This amount declined to 11.4% during the active phase, then declined further to 7.1% in the post-eradication period (figure 8). During the same period, average treatments declined from 14.4 per year to 5.4 per year (figure 6). Clearly, there is a correlation between the use of insecticides and worm densities. It is likely that average worm densities and subsequent crop damage will remain at lower levels in the post-eradication period as Georgia’s cotton agro-ecosystem continues to gain stability, treatment thresholds are re-defined, and the annual number of insecticide treatments declines.

Conclusion

The success of the Southeast Boll Weevil Eradication Program has played a major part in the revival of Georgia’s cotton industry, just as eradication programs have done in the Carolinas and other parts of the Cotton Belt. In 1994 Georgia produced 1.5 million bales of cotton on 875,000 harvested acres, with revenues of more than \$575 million that surpassed peanuts in total value for the first time in forty years. In 1995 2.0 million bales were produced on 1.49 million harvested acres (59% more than in 1994), the largest yield since 1919, with total revenues of about \$720 million (the highest for cotton in Georgia’s history). Total cotton acreage has increased from a pre-eradication average of 228,000 to a post-eradication average of 770,000.

Georgia agriculture has experienced several dramatic transitions since 1733, when the colony was founded and cotton was first planted in Trustee’s Garden, Savannah. Notable historical events impacting cotton production include the invention of Eli Whitney’s cotton

gin in 1793, the end of the War Between the States and emancipation in 1865, the first million-bale year in 1880, the first appearance of the boll weevil near Thomasville in 1915, and the simultaneous transition from horse- and mule-drawn plows to tractor power. This was followed by the “pesticide era,” which began in the mid-1940s, and by completion of the active treatment phase of the Boll Weevil Eradication Program in 1990. Georgia is now in the midst of another dramatic transition period. The dual successes of the Southeast Boll Weevil Eradication Program and the subsequent reestablishment of effective beet armyworm control by parasitoids such as *Cotesia marginiventris* have generated renewed support and widespread interest in IPM, biological control, and development of more sustainable insect pest management methods. Looking ahead, the biology and behavior of the beneficial-pest species complex in Georgia cotton needs further attention. Changes in the structure and balance of the existing beneficial-pest complex are likely, and some formerly secondary pests (e.g., plant bugs or stink bugs) may eventually emerge as primary pests. All of our current treatment thresholds need to be revised, since they were developed when the boll weevil was still the primary pest and are now obsolete. Also, invasion by an exotic pest species is always possible. These points all help emphasize the necessity of a thorough biology-based understanding of the insect complex in Georgia cotton.

Just before the eradication program began, cotton production and acreage in Georgia were at their lowest points since the War Between the States ended. Input costs were economically prohibitive, yields were falling, and revenues were at their lowest point in a hundred years. Cotton was just not profitable to grow, and its future looked pretty bleak. In 1985, growers voted on a referendum to eradicate the boll weevil, but it failed. A year later, in the fall of 1986, it passed, and the active treatment phase of the eradication program began the following September. The rest is now history, but it is important to point out that a combination of other economic and agronomic factors helped make the recent increase in cotton production in Georgia possible. First, a successful industry-driven program to expand the use of cotton, and a subsequent increase in domestic and worldwide demand, helped push cotton prices up at a very opportune time. During the same period, cotton acreage in the western U.S. began declining, providing an opportunity for expansion in the Southeast, and a few countries overseas experienced poor harvests. In the agronomic arena, the introduction of improved varieties and fertilization practices, better nutritional analysis, increased use of irrigation, and more effective use of herbicides have all played a role in the phenomenal revival of cotton. All these economic and agronomic factors have added stability to the industry, helped drive the financing of new gins and equipment, etc., and further opened the market to Georgia cotton growers. It is virtually impossible, however, to analyze these factors separately from the success of the eradication program, or to determine precisely how, or in what proportion, they have contributed to this historical period of expansion. It is also impossible to determine where cotton in Georgia would be now, even with the success of the eradication program, if these factors were not part of the equation. On the other hand, there is little doubt that Georgia cotton growers could never realize the true benefits of any of the economic or agronomic factors listed above if the boll weevil were still present. Perhaps the clearest correlation of this is seen in the 63% reduction in post- vs. pre-eradication insecticide treatments (5.4 vs. 14.4 per acre), along with a 30% reduction in pest management costs and 68% reduction in crop damage.

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Appendices

Appendix A

Beneficial Developments Associated with the Boll Weevil Invasion

- 1) “One of the best planned and most extensive investigations of all time” was initiated in 1903 by entomologists in the USDA Bureau of Entomology. Their subsequent discoveries “gave great hope and courage to the farmers and gradually brought about much better and more diversified methods of farming in the affected areas. The thoroughness of their investigation also helped greatly in the way of progress by serving as a great example and inspiration to other entomologists to plan and carry out their investigations with greater care” (Marlatt 1940).
- 2) W. D. Hunter also stated in 1903 that the USDA had “conducted the most extensive investigation of the life history of a single insect yet published” (Parencia 1978), setting a standard for entomological and agricultural research.
- 3) The first Congressional research appropriation of \$20,000 was made in 1903 to W. D. Hunter and three other USDA entomologists to conduct large-scale experiments on cultural methods for controlling the boll weevil, and to establish a field research laboratory. Their farm-based demonstration projects became known as the Farmer’s Cooperative Demonstration Work of the Bureau of Plant Industry and, later, as the Extension Service of the USDA (Anonymous 1904; Hunter 1904c; Parencia 1978).
- 4) One of the first international cooperative attempts to control an insect pest with biological control, in this case, with the predatory mite *Pediculoides ventricosus*, began in 1903. *P. ventricosus* was reared in Cuernavaca, Mexico, and transported to Texas, for release. The experiment was not successful USDA (Anonymous 1904; Hunter 1904c).
- 5) The first Georgia Quarantine laws were passed on August 28, 1903. These statutes prohibited importation into the state of any living Mexican Boll Weevil or any cotton bolls, squares, plants, or seed containing the adult, pupal, larval or egg stage of the weevil. “No cotton seed grown in the States of Texas or Louisiana shall be shipped into Georgia without a certificate signed by a duly authorized State or Government entomologist stating that said cotton seed has been fumigated in such manner as to kill any Boll Weevil adults, larva or pupa which may be contained therein (Hunter 1904b).
- 6) In 1904, the boll weevil crisis prompted the Louisiana State Legislature to establish the Crop Pest Commission (Parencia 1978). A similar response occurred in several other Cotton States, including Georgia.
- 7) In 1920, the Georgia Senate passed the first Legislative Act to regulate “registration, branding, inspection, analysis and sale of . . . insecticides and fungicides commonly used on cotton.” The Act set minimum standards for sale, distribution, and packaging of dusting compounds and agricultural chemicals (Brown and Wilson 1922).
- 8) Another new development which would have far-reaching benefits for agriculture occurred in 1922. “The cotton boll weevil is now found in all cotton producing States.

During the summer experiments made in cooperation with the Air Service of the War Department give hope that the use of airplanes for the distribution of poisons may not only reduce the cost (of hand- or ground dusting) but extend the use of such poisons generally in the communities (Anonymous 1922). These experiments were conducted at the USDA Delta Laboratory in Tallulah, Louisiana, under the direction of B. R. Coad (Hinds 1926b).

- 9) The Association of Southern Agricultural Workers (ASAW) voted in 1922 to establish the Cotton Council, in order to help remedy a recognized lack of uniformity in the methods of experimentation and recommendations by various agencies (Parencia 1978).
- 10) A massive cooperative effort between Federal and State entomologists, the UGA Extension Division, the Army Air Service, and private industry to control the boll weevil with aerial spraying began in 1926. The widespread use of airplanes for the dusting of cotton boll weevil control constituted the most striking advance step in weevil control work since it first appeared in Texas in 1894 (Hinds 1926b), and further predictions were made that the airplane would become an important method of control in the near future (Hinds 1926a).
- 11) Acala cotton was “discovered” in 1927 in a small field in Acala, Mexico, by USDA personnel who were searching for varieties of cotton that showed resistance to boll weevil (Cook and Doyle 1927). This high-yielding, long-staple variety has been grown extensively in the western United States.
- 12) The year 1929 marked the 25th anniversary of the beginning of farm demonstration (extension) work in the U.S., a movement which started with a single effort to help farmers produce a good crop of cotton in boll weevil-infested Texas. “The boll weevil was one of the initial factors which produced the impulse for laying the foundation of extension work” (Thomas 1929; see Anonymous 1904; Hunter 1904c; Parencia 1978).
- 13) In 1935, the boll weevil was actually credited with giving rise to the science of entomology, at least in the South. “Prior to the coming of the boll weevil and the establishment of the agricultural experiment stations there was very little interest in entomological work in the South. The advent of the boll weevil was responsible for a beginning in bringing the attention of the public to a realization of the importance of the influence of insects in the agricultural and economic development of the South” (Bilsing 1935).
- 14) The USDA sent Dr. Seaman A. Knapp to Texas in 1935 to further demonstrate the benefits of implementing the results of scientific research. This program led to the establishment of the Smith-Lever Bill, which established our modern system of County Agricultural Agents. “The forced change in the production of cotton due to the advent of the boll weevil resulted in the reorganization of our system of agriculture; indirectly to diversified farming, and in a well organized system of imparting scientific information to a large part of the agricultural population of the South” (Bilsing 1935; Caesar 1940).

- 15) The first full-time UGA entomologist, Mr. Loy Morgan, began working with USDA personnel in 1948 at the Coastal Plain Experiment Station, with an initial research emphasis on boll weevil control in cotton using DDT, toxaphene, and BHC (Anonymous 1975; Bass 1993).
- 16) The year 1949 saw the introduction of the low-volume spray method of applying insecticides, in this case, chlorinated hydrocarbon (CHC) insecticides such as DDT (Parencia 1959). This new application method allowed growers to treat a larger amount of acreage in a much shorter period of time. It also set the stage for a revolution in pesticide application methods and created a new branch of entomological research.
- 17) In 1968, Jim Tumlinson et al. began the process of isolating, identifying and synthesizing the boll weevil male sex pheromone. This project was successfully completed in 1971 (Hardee 1972). It was one of the first examples of the use of pheromones as part of an IPM program in agriculture.

Appendix B

Principle agencies involved in bringing the Boll Weevil Eradication Program to Georgia:

Georgia Department of Agriculture

Commissioner Tommy Irvin

Senate Agriculture Committee

House of Representatives Committee on Agriculture & Consumer Services

Georgia Cotton Commission

Georgia Farm Bureau

University of Georgia Extension

University of Georgia, Department of Entomology

USDA-APHIS

Boll Weevil Eradication Foundation of Georgia

Southeast Boll Weevil Eradication Program, Incorporated

Tommy Irvin, Georgia Commissioner of Agriculture, began advocating eradication of the boll weevil in the late 1970s, while observing initial successes in Virginia and North Carolina. He spoke before the State Legislature in 1984, promoting the eradication program and pledging strong support on behalf of the Georgia Department of Agriculture. He utilized his dual roles of Commissioner and President of NASDA (National Association of State Departments of Agriculture) to encourage widespread grower support of the program, ensuring passage of the second grower mandate in 1986. He maintains an active interest in managing the financial interests of the eradication program to this day.

During the same period, Senator Sam McGill served as Chairman of the Senate Agriculture Committee and Representative Henry Reaves served as Chairman of the House of Representatives Committee on Agriculture and Consumer Services. Both provided major support in securing passage of the final legislation authorizing the eradication program, as did Representative Newt Hudson, whose district was in the central portion of the proposed eradication zone. Ron Conley was Assistant Commissioner during this time; he played a key role in developing the legislature that provided for the program. Dr. Don Canerday in the Department of Entomology at the University of Georgia also lent strong initial support. Jim Bridges managed initial collection of grower assessments. Tom Kowalski was appointed by the Commissioner to direct the eradication program in 1986, after the second grower initiative passed, and the necessary legislation was in place. He remains a member of the Georgia BWEF Board, and also serves as a member of the Southeast Foundation Board (North Carolina, South Carolina, Virginia, Georgia, Florida, Alabama, and now parts of Tennessee and Mississippi). Both Billy Sanders and Bobby Webster have also served on the Southeast Foundation Board since its inception.

The first Board members of the Boll Weevil Eradication Foundation of Georgia included Bobby Webster, Chairman; Johnny Paul DeLoach, Wavell Robinson, Marvin Ruark, Chauncey Taylor, Charles Williams, Tom Kowalski, Georgia Department of

Agriculture; and Dr. Bill Lambert, University of Georgia Extension Service, serving as advisor. Johnny Paul DeLoach became Executive Director of the Southeast Foundation Board in 1988, providing leadership in Georgia and 21 southern Alabama counties. He was succeeded on the Georgia Foundation Board by Billy Sanders. In 1990 Chauncey Taylor was succeeded by Ronald Lovell, who represented northwest Georgia for the first time. The six grower Board members are elected by cotton growers within their respective districts. The Georgia Farm Bureau organized the elections and played an instrumental role in the early development of grower support and education.

Members of the Georgia Cotton Commission, along with Dr. Gary Herzog, Dr. Bill Lambert, and Dr. Johnny Crawford, all with the University of Georgia, and Fred Planer, with USDA, were involved in promoting the program and helped educate growers in public meetings organized jointly by the Department of Agriculture and the UGA County Extension Service.

G. L. Arflin is currently Officer in Charge of the eradication program in Georgia, with offices in Louisville, Quitman, and Unadilla.



Figure 1. Total number of 480 lb. bales harvested in Georgia: 1791-1995.



Figure 2. Price per pound of Georgia cotton: 1866–1995.



Figure 3. Total acres of cotton harvested in Georgia: 1866–1995.

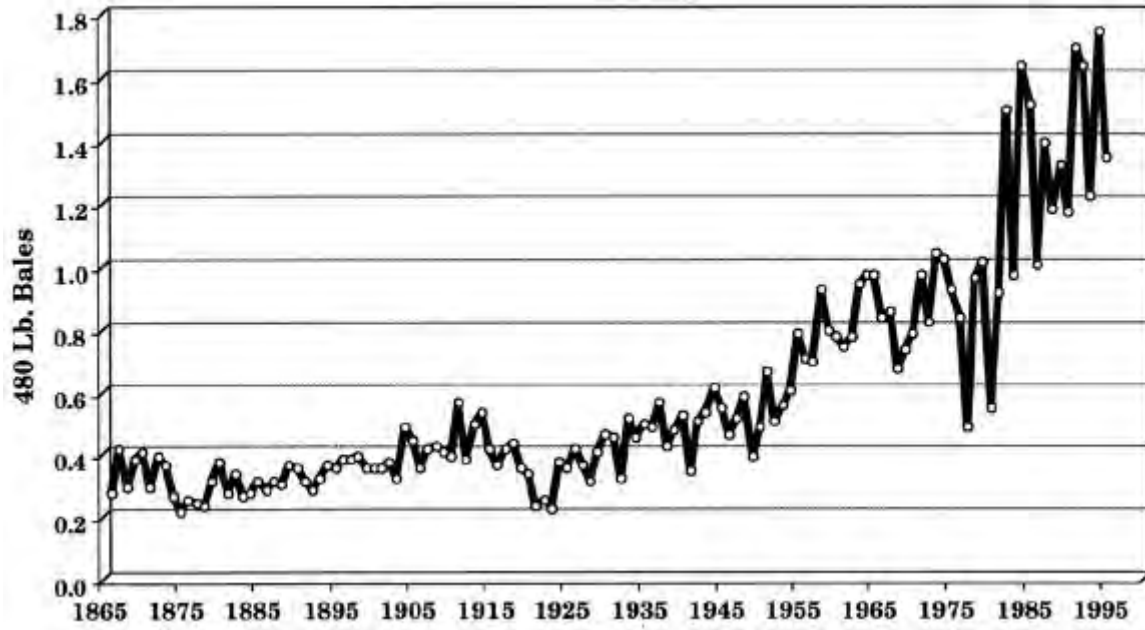


Figure 4. Total bales of cotton harvested per acre in Georgia: 1866–1995.

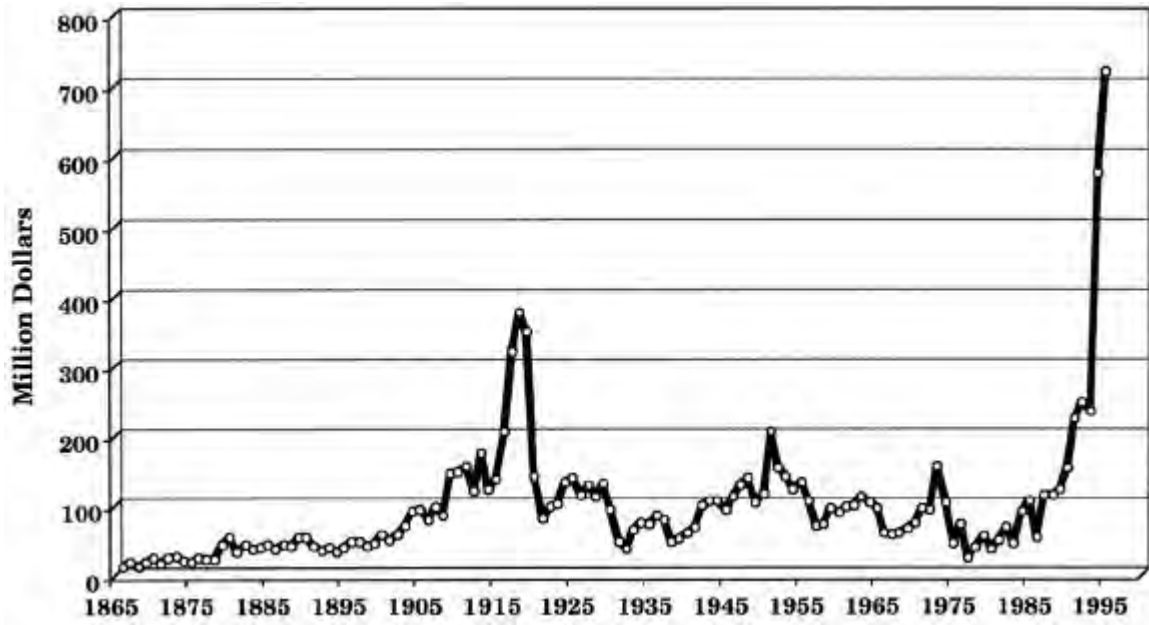


Figure 5. Total value (lint and seed) of Georgia cotton: 1866–1995.

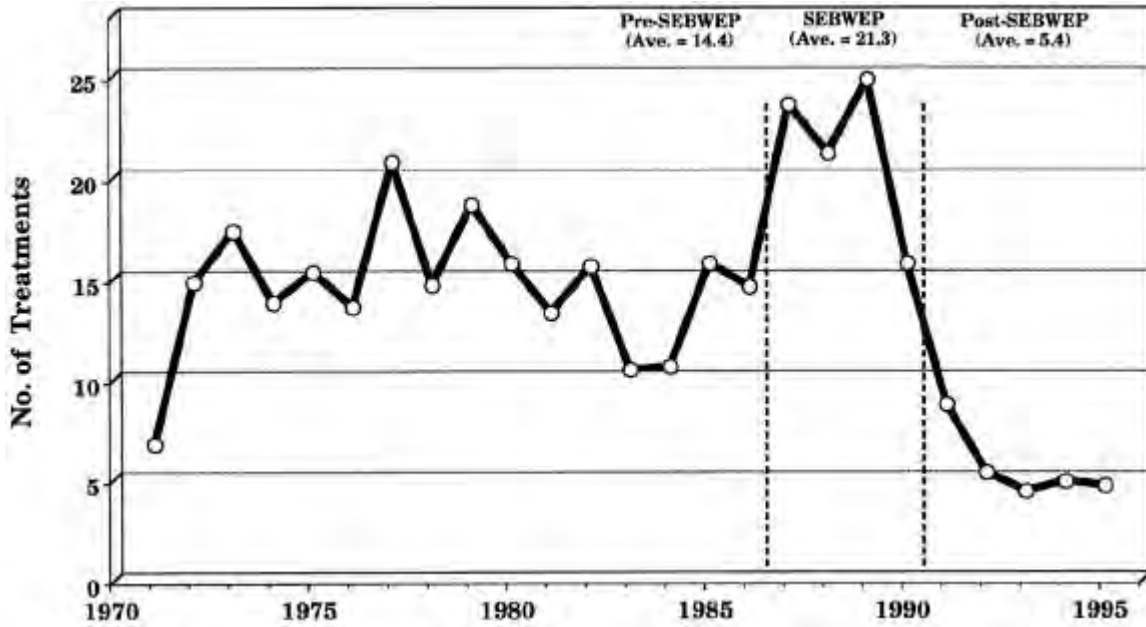


Figure 6. Number of treatments for all pests in Georgia cotton: 1971-1995.

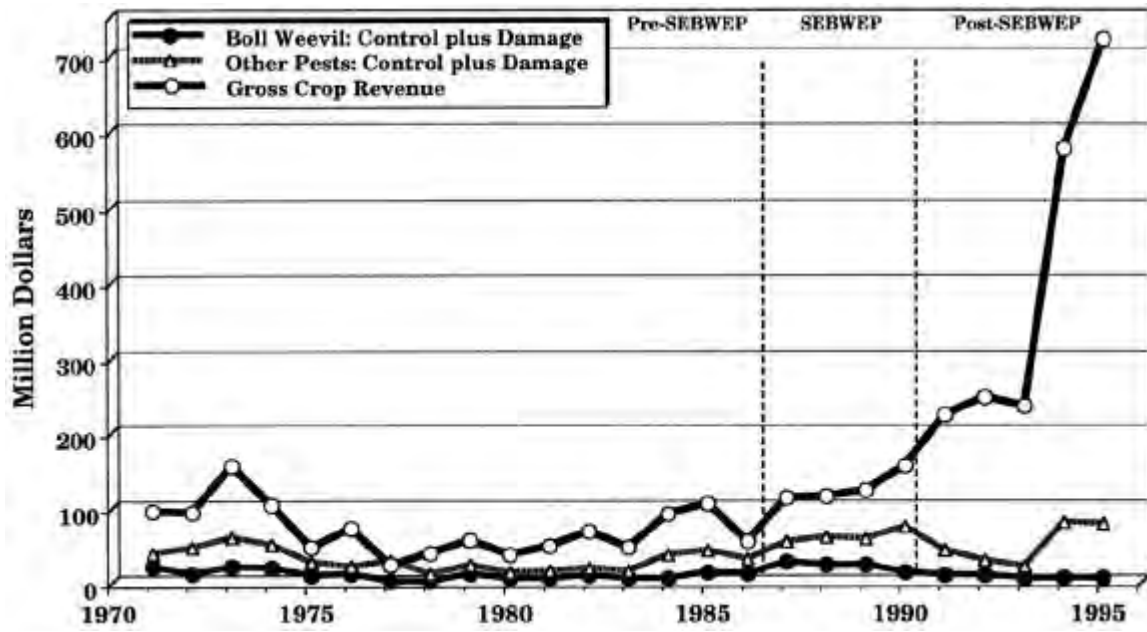


Figure 7. Cost of control plus amount of damage by the boll weevil and other pests* vs. gross crop revenue in Georgia cotton: 1971-1995.

*Tobacco Budworm, Cotton Bollworm, Beet & Fall Armyworms, Thrips, Aphids, Mites, Soy & Cabbage Loopers, and Whiteflies.

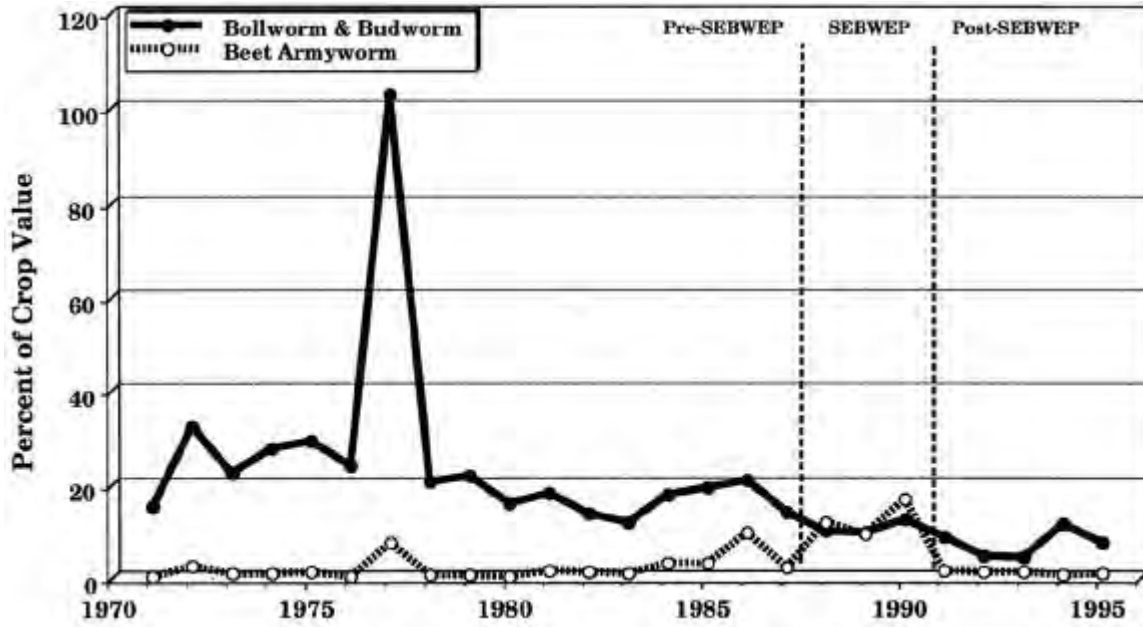


Figure 8. Bollworm, budworm, and beet armyworm cost of control plus damage as percent of gross crop revenue in Georgia cotton: 1971-1995.

Table 1. Summary of Insect Control Costs, Economics, Yield, and Acreage in Georgia Cotton: 1971–1995

	<i>Boll Weevil</i>				<i>Other Pests^a</i>			
	Treatments per Acre	Treatment Cost/Acre	Damage to Crop	Combined Amount/Acre	Treatments per Acre	Treatment Cost/Acre	Damage to Crop	Combined Amount/ Acre
Pre-SEBWEP ^b	4.9	\$17	\$17	\$34	9.5	\$51	\$39	\$91
SEBWEP	8.1	\$64	\$8	\$72	13.2	\$76	\$56	\$132
Post-SEBWEP	0.3	\$10	\$0	\$10	5.1	\$38	\$18	\$56
	<i>Boll Weevil and Other Pests Combined</i>				<i>Economics, Yield, and Acreage</i>			
	Treatments per Acre	Treatment Cost/Acre	Damage to Crop	Combined Amount/Acre	Gross Value per Acre	Net Value per Acre	Yield per Acre (lb.)	Harvested Acres
Pre-SEBWEP	14.4	\$68	\$56	\$125	\$312	\$187	482	228,000
SEBWEP	21.3	\$140	\$64	\$204	\$429	\$225	604	293,000
Post-SEBWEP	5.4	\$48	\$18	\$66	\$517	\$451	733	770,000

a. Tobacco Budworm, Cotton Bollworm, Beet & Fall Armyworms, Thrips, Aphids, Mites, Soy & Cabbage Loopers, Whiteflies, and Plant bugs.

b. Southeast Boll Weevil Eradication Program: Pre-SEBWEP covers the period from 1971–1986; SEBWEP 1987–1990; and Post-SEBWEP 1991–1995.

Table 2. Boll Weevil Control Costs and Amount of Damage in Georgia Cotton: 1971–1995^a

Year	No. of Treatments per Acre	Cost of Control (Million \$)	Damage to Crop (Million \$)	Control & Damage (Million \$)	Cost of Control/ Acre (\$)	Amount of Damage/ Acre (\$)	Control & Damage/ Acre (\$)	Total Harvested Ac. (1,000)	Grower Assessment per Acre	Total Grower Assessment	Number of Traps per Acre
Pre-SEBWEP^b											
1971	2.3	\$7.0	\$13.0	\$20.0	\$18	\$34	\$52	385	N/A	N/A	N/A
1972	5.0	\$6.0	\$4.0	\$10.0	\$14	\$9	\$23	430	N/A	N/A	N/A
1973	6.1	\$10.0	\$10.1	\$20.1	\$27	\$27	\$54	375	N/A	N/A	N/A
1974	4.6	\$10.2	\$8.2	\$18.4	\$25	\$20	\$45	410	N/A	N/A	N/A
1975	5.2	\$4.5	\$4.0	\$8.5	\$28	\$25	\$53	160	N/A	N/A	N/A
1976	4.6	\$10.4	\$0.0	\$10.4	\$4	\$0	\$4	240	N/A	N/A	N/A
1977	0.1	\$0.0	\$0.0	\$0.0	\$0	\$0	\$0	170	N/A	N/A	N/A
1978	3.2	\$0.4	\$0.1	\$0.5	\$4	\$1	\$5	115	N/A	N/A	N/A
1979	7.7	\$4.2	\$5.1	\$9.3	\$28	\$34	\$62	150	N/A	N/A	N/A
1980	7.2	\$3.0	\$0.3	\$3.3	\$19	\$2	\$20	160	N/A	N/A	N/A
1981	5.5	\$2.8	\$1.4	\$4.2	\$16	\$8	\$24	175	N/A	N/A	N/A
1982	6.7	\$3.2	\$4.6	\$7.8	\$20	\$29	\$49	158	N/A	N/A	N/A
1983	5.3	\$2.2	\$2.0	\$4.2	\$19	\$17	\$36	115	N/A	N/A	N/A
1984	2.4	\$1.4	\$1.7	\$3.1	\$8	\$10	\$18	172	N/A	N/A	N/A
1985	5.7	\$5.3	\$7.2	\$12.5	\$22	\$29	\$51	245	N/A	N/A	N/A
1986	6.2	\$4.9	\$4.9	\$9.8	\$25	\$25	\$50	195	N/A	N/A	N/A
Average	4.9	\$4.7	\$4.2	\$8.9	\$17	\$17	\$34	228	N/A	N/A	N/A
SEBWEP											
1987	8.3	\$16.9	\$8.2	\$25.1	\$69	\$34	\$102	245	\$10	\$2,875,000	1 to 1
1988	9.1	\$21.8	\$0.0	\$21.8	\$69	\$0	\$69	315	\$35	\$12,129,180	1 to 1
1989	12.4	\$22.1	\$0.0	\$22.1	\$85	\$0	\$85	260	\$35	\$9,080,330	1 to 1
1990	2.7	\$11.9	\$0.0	\$11.9	\$34	\$0	\$34	350	\$35	\$12,247,515	1 to 1
Average	8.1	\$18.2	\$2.1	\$20.2	\$64	\$8	\$73	293	\$29	\$9,083,006	
Post-SEBWEP											
1991	0.7	\$8.3	\$0.0	\$8.3	\$19	\$0	\$19	427	\$20	\$8,223,140	Variable ^d
1992	0.5	\$7.9	\$0.0	\$7.9	\$17	\$0	\$17	456	\$18	\$8,227,764	Variable ^d
1993	0.3	\$3.2	\$0.0	\$3.2	\$5	\$0	\$5	600	\$10	\$5,959,150	Variable ^d
1994	0.02	\$3.1	\$0.0	\$3.1	\$4	\$0	\$4	875	\$6.50	\$5,687,500	Variable ^d
1995 ^c	0.01	\$4.2	\$0.0	\$4.2	\$3	\$0	\$3	1490	\$5.50	\$5,145,000	Variable ^d
Average	0.3	\$5.3	\$0.0	\$5.3	\$10	\$0	\$10	770	\$12	\$6,648,511	

a. All data provided by South East Boll Weevil Eradication Foundation, Montgomery, AL, or derived from UGA Extension Publications.

b. Southeast Boll Weevil Eradication Program: Pre-SEBWEP covers the period from 1971–1986; SEBWEP 1987–1990; and Post-SEBWEP 1991–1995.

c. The Grower Assessment in 1995 was \$5.50; \$3.43 went to the Foundation; the remaining \$2.07 went to the GA Commission as a contingency fund.

d. Variable: Either 1 trap per acre, 1 trap per 5 acres, or 1 trap per 10 acres, depending on eradication status.

Table 3. Overall Insect Control Costs and Amount of Damage in Georgia Cotton: 1971–1977^a

Year	1971	1972	1973	1974	1975	1976	1977
No. of Harvested Acres	385,000	430,000	375,000	410,000	160,000	240,000	170,000
Total 480 Lb. Bales	374,000	354,000	390,000	419,000	148,000	199,000	82,000
Average Yield per Acre	466	395	499	490	443	398	232
Average Price per Lb. ^b	\$0.48	\$0.50	\$0.75	\$0.42	\$0.56	\$0.67	\$0.52
Gross Revenue per Acre	\$242.60	\$210.86	\$410.68	\$248.99	\$274.19	\$294.20	\$130.25
Gross Crop Revenue	\$93,400,000	\$90,670,000	\$154,006,000	\$102,086,000	\$43,871,000	\$70,607,000	\$22,143,000
Insect Control Cost^c							
Boll Weevil	\$7,000,000	\$6,000,000	\$10,000,000	\$10,250,000	\$4,480,000	\$1,037,000	\$11,000
Tobacco Budworm	\$0	\$16,000,000	\$15,500,000	\$11,480,000	\$4,800,000	\$6,772,000	\$7,245,000
Cotton Bollworm	\$5,000,000	\$4,000,000	\$4,001,000	\$3,690,000	\$1,600,000	\$6,772,000	\$10,485,000
Beet & Fall Armyworm	\$0	\$1,500,000	\$800,000	\$440,000	\$150,000	\$25,000	\$711,000
Thrips	\$50,000	\$300,000	\$300,000	\$330,000	\$280,000	\$672,000	\$652,000
Cotton Aphid	\$75,000	\$20,000	\$50,000	\$40,000	\$11,000	\$42,000	\$0
Spider Mites	\$200,000	\$2,200,000	\$1,100,000	\$330,000	\$120,000	\$38,000	\$207,000
Soy & Cabbage Looper	\$0	\$0	\$0	\$0	\$0	\$0	\$28,000
Whiteflies	\$0	\$0	\$0	\$0	\$90,000	\$19,000	\$14,000
Plant Bugs	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Total Cost of Control	\$12,325,000	\$30,020,000	\$31,751,000	\$26,560,000	\$11,531,000	\$15,377,000	\$19,353,000
Total Cost per Acre	\$32.01	\$69.81	\$84.67	\$64.78	\$72.07	\$64.07	\$113.84
% (of Gross Crop Revenue)	13.2	33.1	20.6	26.0	26.3	21.8	87.4
No. of Treatments per Acre	7.6	16.6	20.2	15.4	17.2	15.3	20.7
Average Cost/Treatment ^d	\$4.20	\$4.20	\$4.20	\$4.20	\$4.20	\$4.20	\$5.50
Amount of Damage^e							
Boll Weevil	\$13,000,000	\$4,000,000	\$10,125,000	\$8,154,000	\$4,026,000	\$0	\$0
Tobacco Budworm	\$0	\$8,000,000	\$11,968,000	\$9,820,000	\$4,830,000	\$1,892,000	\$2,777,000
Cotton Bollworm	\$10,000,000	\$2,000,000	\$4,500,000	\$4,826,000	\$2,416,000	\$1,258,000	\$3,710,000
Beet & Fall Armyworm	\$0	\$500,000	\$187,000	\$48,000	\$277,000	\$64,000	\$872,000
Thrips	\$200,000	\$75,000	\$15,000	\$6,000	\$10,000	\$127,000	\$0
Cotton Aphid	\$75,000	\$75,000	\$3,000	\$1,000	\$1,000	\$0	\$0
Spider Mites	\$1,000,000	\$950,000	\$562,000	\$60,000	\$25,000	\$38,000	\$0
Soy & Cabbage Looper	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Whiteflies	\$0	\$0	\$0	\$0	\$1,515,000	\$64,000	\$0
Plant Bugs	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Total Damage Amount	\$24,275,000	\$15,600,000	\$27,360,000	\$22,915,000	\$13,100,000	\$3,443,000	\$7,359,000
Total Damage per Acre	\$63.05	\$36.28	\$72.96	\$55.89	\$81.88	\$14.35	\$43.29
% (of Total Crop Value) ^e	20.6	14.7	15.1	18.3	23.0	4.6	24.9

a. Yield, Acreage, and Economic data for 1971–1981 derived from Georgia Ag. Facts, 1984 Edition, pg. 7; data for 1982–1995 derived from the 1996 Cotton Planting Guide, pg. 1.

b. Price per Pound data for 1971–1985 derived from Georgia Ag. Facts, 1984 Edition, pg. 7; data for 1986–1993 derived from Georgia Ag. Facts, 1994 Edition, pg. 3.

c. Insect Control Cost and Amount of Damage data for 1971–1995 derived from *Summary of Losses from Insect Damage and Cost of Control in Georgia*, published annually by UGA's Agricultural Experiment Stations; 1994–1995 data currently unpublished.

d. Actual data for 1971–1976 unavailable; calculations based on average treatment cost of \$4.74 for 10-year period, 1977–1986.

e. "Total Crop Value" was derived by dividing "Amount of Damage" by "Gross Crop Revenue" plus "Amount of Damage."

Table 4. Overall Insect Control Costs and Amount of Damage in Georgia Cotton: 1978–1984^a

Year	1978	1979	1980	1981	1982	1983	1984
No. of Harvested Acres	115,000	150,000	160,000	175,000	158,000	115,000	172,000
Total 480 Lb. Bales	111,000	152,000	86,000	159,000	235,000	112,000	281,000
Average Yield per Acre	463	486	258	436	714	467	781
Average Price per Lb. ^b	\$0.60	\$0.66	\$0.78	\$0.54	\$0.57	\$0.67	\$0.59
Gross Revenue per Acre	\$318.17	\$356.39	\$224.42	\$271.18	\$416.35	\$381.42	\$518.85
Gross Crop Revenue	\$36,590,000	\$53,459,000	\$35,907,000	\$47,456,000	\$65,784,000	\$43,863,000	\$89,242,000
Insect Control Cost^c							
Boll Weevil	\$405,000	\$4,204,000	\$2,989,000	\$2,829,000	\$3,150,000	\$2,174,000	\$1,445,000
Tobacco Budworm	\$4,063,000	\$4,111,000	\$2,493,000	\$4,193,000	\$3,903,000	\$1,316,000	\$4,025,000
Cotton Bollworm	\$2,214,000	\$3,460,000	\$1,571,000	\$1,786,000	\$2,570,000	\$822,000	\$3,019,000
Beet & Fall Armyworm	\$17,000	\$37,000	\$0	\$374,000	\$261,000	\$53,000	\$132,000
Thrips	\$294,000	\$394,000	\$480,000	\$561,000	\$415,000	\$713,000	\$743,000
Cotton Aphid	\$0	\$0	\$0	\$0	\$0	\$0	\$172,000
Spider Mites	\$24,000	\$94,000	\$864,000	\$266,000	\$45,000	\$854,000	\$71,000
Soy & Cabbage Looper	\$3,000	\$0	\$0	\$0	\$0	\$0	\$0
Whiteflies	\$2,000	\$0	\$0	\$0	\$0	\$0	\$0
Plant Bugs	\$16,000	\$84,000	\$113,000	\$92,000	\$142,000	\$46,000	\$275,000
Total Cost of Control	\$7,038,000	\$12,384,000	\$8,510,000	\$10,101,000	\$10,486,000	\$5,978,000	\$9,882,000
Total Cost per Acre	\$61.20	\$82.56	\$53.19	\$57.72	\$66.37	\$51.98	\$57.45
% (of Gross Crop Revenue)	19.2	23.2	23.7	21.3	15.9	13.6	11.1
No. of Treatments per Acre	14.6	18.6	15.7	13.2	15.5	10.4	10.5
Average Cost/Treatment ^d	\$4.19	\$4.44	\$3.39	\$4.37	\$4.28	\$5.00	\$5.47
Amount of Damage^e							
Boll Weevil	\$131,000	\$5,075,000	\$260,000	\$1,411,000	\$4,578,000	\$1,983,000	\$1,693,000
Tobacco Budworm	\$1,142,000	\$2,036,000	\$1,545,000	\$937,000	\$1,307,000	\$2,212,000	\$5,455,000
Cotton Bollworm	\$0	\$2,217,000	\$0	\$1,546,000	\$1,018,000	\$925,000	\$4,044,000
Beet & Fall Armyworm	\$106,000	\$158,000	\$0	\$149,000	\$413,000	\$154,000	\$2,445,000
Thrips	\$0	\$0	\$16,000	\$0	\$69,000	\$540,000	\$71,000
Cotton Aphid	\$0	\$0	\$0	\$0	\$0	\$0	\$3,527,000
Spider Mites	\$0	\$0	\$144,000	\$18,000	\$0	\$1,190,000	\$0
Soy & Cabbage Looper	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Whiteflies	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Plant Bugs	\$571,000	\$339,000	\$244,000	\$10,000	\$69,000	\$661,000	\$8,464,000
Total Damage Amount	\$1,950,000	\$9,825,000	\$2,209,000	\$4,071,000	\$7,454,000	\$7,665,000	\$25,699,000
Total Damage per Acre	\$16.96	\$65.50	\$13.81	\$23.26	\$47.18	\$66.65	\$149.41
% (of Total Crop Value) ^e	5.1	15.5	5.8	7.9	10.2	14.9	22.4

a. Yield, Acreage, and Economic data for 1971–1981 derived from Georgia Ag. Facts, 1984 Edition, pg. 7; data for 1982–1995 derived from the 1996 Cotton Planting Guide, pg. 1.

b. Price per Pound data for 1971–1985 derived from Georgia Ag. Facts, 1984 Edition, pg. 7; data for 1986–1993 derived from Georgia Ag. Facts, 1994 Edition, pg. 3.

c. Insect Control Cost and Amount of Damage data for 1971–1995 derived from *Summary of Losses from Insect Damage and Cost of Control in Georgia*, published annually by UGA's Agricultural Experiment Stations; 1994–1995 data currently unpublished.

d. Actual data for 1971–1976 unavailable; calculations based on average treatment cost of \$4.74 for 10-year period, 1977–1986.

e. "Total Crop Value" was derived by dividing "Amount of Damage" by "Gross Crop Revenue" plus "Amount of Damage."

Table 5. Overall Insect Control Costs and Amount of Damage in Georgia Cotton: 1985–1991^a

Year	1985	1986	1987	1988	1989	1990	1991
No. of Harvested Acres	245,000	195,000	245,000	315,000	260,000	350,000	427,000
Total 480 Lb. Bales	370,000	185,000	338,000	370,000	342,000	405,000	722,000
Average Yield per Acre	725	455	662	564	634	555	812
Average Price per Lb. ^b	\$0.58	\$0.58	\$0.62	\$0.55	\$0.65	\$0.69	\$0.60
Gross Revenue per Acre	\$421.95	\$266.79	\$455.54	\$354.83	\$466.85	\$437.02	\$520.76
Gross Crop Revenue	\$103,378,000	\$52,025,000	\$111,608,000	\$111,773,000	\$121,382,000	\$152,957,000	\$222,366,000
Insect Control Cost^c							
Boll Weevil	\$5,307,000	\$4,860,000	\$16,860,000	\$21,750,000	\$22,100,000	\$11,900,000	\$8,300,000
Tobacco Budworm	\$5,988,000	\$4,212,000	\$6,350,000	\$4,465,000	\$4,114,000	\$6,859,000	\$8,509,000
Cotton Bollworm	\$6,243,000	\$2,486,000	\$3,241,000	\$2,977,000	\$3,399,000	\$4,722,000	\$5,673,000
Beet & Fall Armyworm	\$985,000	\$1,584,000	\$849,000	\$9,086,000	\$6,344,000	\$15,975,000	\$1,683,000
Thrips	\$2,044,000	\$1,148,000	\$1,248,000	\$3,990,000	\$2,324,000	\$3,142,000	\$3,076,000
Cotton Aphid	\$531,000	\$219,000	\$1,072,000	\$3,528,000	\$1,697,000	\$2,204,000	\$669,000
Spider Mites	\$61,000	\$38,000	\$64,000	\$71,000	\$225,000	\$439,000	\$0
Soy & Cabbage Looper	\$0	\$0	\$0	\$0	\$868,000	\$0	\$3,570,000
Whiteflies	\$0	\$0	\$0	\$0	\$0	\$976,000	\$2,352,000
Plant Bugs	\$221,000	\$295,000	\$427,000	\$55,000	\$105,000	\$114,000	\$260,000
Total Cost of Control	\$21,380,000	\$14,842,000	\$30,111,000	\$45,922,000	\$41,176,000	\$46,331,000	\$34,092,000
Total Cost per Acre	\$87.27	\$76.11	\$122.90	\$145.78	\$158.37	\$132.37	\$79.84
% (of Gross Crop Revenue)	20.7	28.5	27.0	41.1	33.9	30.3	15.3
No. of Treatments per Acre	15.7	14.5	23.5	21.1	24.7	15.7	8.6
Average Cost/Treatment ^d	\$5.56	\$5.25	\$5.23	\$6.91	\$6.41	\$8.43	\$9.28
Amount of Damage^e							
Boll Weevil	\$7,224,000	\$4,901,000	\$8,232,000	\$0	\$0	\$0	\$0
Tobacco Budworm	\$3,214,000	\$1,734,000	\$3,346,000	\$1,718,000	\$1,092,000	\$3,551,000	\$2,313,000
Cotton Bollworm	\$4,628,000	\$2,495,000	\$2,819,000	\$1,718,000	\$2,853,000	\$3,644,000	\$2,313,000
Beet & Fall Armyworm	\$1,843,000	\$3,428,000	\$1,242,000	\$4,009,000	\$4,613,000	\$9,924,000	\$906,000
Thrips	\$523,000	\$48,000	\$687,000	\$859,000	\$618,000	\$149,000	\$241,000
Cotton Aphid	\$52,000	\$1,048,000	\$1,747,000	\$2,978,000	\$4,066,000	\$4,032,000	\$0
Spider Mites	\$120,000	\$90,000	\$57,000	\$0	\$303,000	\$853,000	\$0
Soy & Cabbage Looper	\$0	\$0	\$0	\$0	\$1,554,000	\$0	\$1,430,000
Whiteflies	\$0	\$0	\$0	\$0	\$0	\$3,101,000	\$477,000
Plant Bugs	\$1,068,000	\$900,000	\$3,666,000	\$573,000	\$607,000	\$0	\$0
Total Damage Amount	\$18,672,000	\$14,644,000	\$21,796,000	\$11,855,000	\$15,706,000	\$25,254,000	\$7,680,000
Total Damage per Acre	\$76.21	\$75.10	\$88.96	\$37.63	\$60.41	\$72.15	\$17.99
% (of Total Crop Value) ^e	15.3	22.0	16.3	9.6	11.5	14.2	3.3

a. Yield, Acreage, and Economic data for 1971–1981 derived from Georgia Ag. Facts, 1984 Edition, pg. 7; data for 1982–1995 derived from the 1996 Cotton Planting Guide, pg. 1.

b. Price per Pound data for 1971–1985 derived from Georgia Ag. Facts, 1984 Edition, pg. 7; data for 1986–1993 derived from Georgia Ag. Facts, 1994 Edition, pg. 3.

c. Insect Control Cost and Amount of Damage data for 1971–1995 derived from *Summary of Losses from Insect Damage and Cost of Control in Georgia*, published annually by UGA's Agricultural Experiment Stations; 1994–1995 data currently unpublished.

d. Actual data for 1971–1976 unavailable; calculations based on average treatment cost of \$4.74 for 10-year period, 1977–1986.

e. "Total Crop Value" was derived by dividing "Amount of Damage" by "Gross Crop Revenue" plus "Amount of Damage."

Table 6. Overall Insect Control Costs and Amount of Damage in Georgia Cotton: 1992–1995^a

Year	1992	1993	1994	1995
No. of Harvested Acres	456,000	600,000	875,000	1,490,000
Total 480 Lb. Bales	744,000	733,000	1,480,000	1,970,000
Average Yield per Acre	783	586	839	635
Average Price per Lb. ^b	\$0.56	\$0.60	\$0.72	\$0.75
Gross Revenue per Acre	\$537.34	\$387.61	\$657.24	\$476.25
Gross Crop Revenue	\$245,029,000	\$232,565,000	\$575,088,000	\$709,612,500
Insect Control Cost^c				
Boll Weevil	\$7,900,000	\$3,200,000	\$3,100,000	\$4,185,000
Tobacco Budworm	\$2,849,000	\$5,174,000	\$14,168,000	\$6,951,218
Cotton Bollworm	\$3,798,000	\$3,308,000	\$12,600,000	\$36,493,897
Beet & Fall Armyworm	\$937,000	\$1,053,000	\$551,250	\$2,589,000
Thrips	\$4,569,000	\$4,590,000	\$5,197,500	\$500,000
Cotton Aphid	\$175,000	\$218,000	\$582,750	\$2,600,000
Spider Mites	\$0	\$0	\$0	\$525,000
Soy & Cabbage Looper	\$181,000	\$271,000	\$105,000	\$4,050,000
Whiteflies	\$394,000	\$375,000	\$170,625	\$60,000
Plant Bugs	\$160,000	\$0	\$0	\$1,800,000
Total Cost of Control	\$20,963,000	\$18,189,000	\$36,475,125	\$59,754,115
Total Cost per Acre	\$45.97	\$30.32	\$41.69	\$40.10
% (of Gross Crop Revenue)	8.6	7.8	6.3	8.4
No. of Treatments per Acre	5.2	4.3	4.8	4.6
Average Cost/Treatment ^d	\$8.84	\$7.05	\$8.78	\$8.74
Amount of Damage^c				
Boll Weevil	\$0	\$0	\$0	\$0
Tobacco Budworm	\$1,810,000	\$372,000	\$28,119,924	\$5,882,940
Cotton Bollworm	\$1,810,000	\$581,000	\$12,030,696	\$1,120,560
Beet & Fall Armyworm	\$1,460,000	\$737,000	\$1,902,852	\$1,796,760
Thrips	\$0	\$0	\$0	\$0
Cotton Aphid	\$226,000	\$0	\$0	\$3,361,680
Spider Mites	\$0	\$0	\$0	\$0
Soy & Cabbage Looper	\$228,000	\$135,000	\$52,857	\$0
Whiteflies	\$0	\$0	\$0	\$162,300
Plant Bugs	\$208,000	\$0	\$0	\$2,550,240
Total Damage Amount	\$5,742,000	\$1,825,000	\$42,106,329	\$16,845,120
Total Damage per Acre	\$12.59	\$3.04	\$48.12	\$11.31
% (of Total Crop Value) ^e	2.3	0.8	6.8	2.3

a. Yield, Acreage, and Economic data for 1971–1981 derived from Georgia Ag. Facts, 1984 Edition, pg. 7; data for 1982–1995 derived from the 1996 Cotton Planting Guide, pg. 1.

b. Price per Pound data for 1971–1985 derived from Georgia Ag. Facts, 1984 Edition, pg. 7; data for 1986–1993 derived from Georgia Ag. Facts, 1994 Edition, pg. 3.

c. Insect Control Cost and Amount of Damage data for 1971–1995 derived from *Summary of Losses from Insect Damage and Cost of Control in Georgia*, published annually by UGA's Agricultural Experiment Stations; 1994–1995 data currently unpublished.

d. Actual data for 1971–1976 unavailable; calculations based on average treatment cost of \$4.74 for 10-year period, 1977–1986.

e. "Total Crop Value" was derived by dividing "Amount of Damage" by "Gross Crop Revenue" plus "Amount of Damage."

Conversion Table

U.S. Abbr.	Unit	Approximate Metric Equivalent
Length		
mi	mile	1.609 kilometers
yd	yard	0.9144 meters
ft or ' in or "	foot inch	30.48 centimeters 2.54 centimeters
Area		
sq mi or mi ²	square mile	2.59 square kilometers
acre	acre	0.405 hectares or 4047 square meters
sq ft or ft ²	square foot	0.093 square meters
Volume/Capacity		
gal	gallon	3.785 liters
qt	quart	0.946 liters
pt	pint	0.473 liters
fl oz	fluid ounce	29.573 milliliters or 28.416 cubic centimeters
bu	bushel	35.238 liters
cu ft or ft ³	cubic foot	0.028 cubic meters
Mass/Weight		
ton	ton	0.907 metric ton
lb	pound	0.453 kilogram
oz	ounce	28.349 grams
Metric Abbr.	Unit	Approximate U.S. Equivalent
Length		
km	kilometer	0.62 mile
m	meter	39.37 inches or 1.09 yards
cm	centimeter	0.39 inch
mm	millimeter	0.04 inch
Area		
ha	hectare	2.47 acres
Volume/Capacity		
liter	liter	61.02 cubic inches or 1.057 quarts
ml	milliliter	0.06 cubic inch or 0.034 fluid ounce
cc	cubic centimeter	0.061 cubic inch or 0.035 fluid ounce
Mass/Weight		
MT	metric ton	1.1 tons
kg	kilogram	2.205 pounds
g	gram	0.035 ounce
mg	milligram	3.5 × 10 ⁻⁵ ounce

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