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ONE HUNDRED TWENTY YEARS OF RESEARCH ON COTTON INSECTS IN THE UNITED STATES

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ONE HUNDRED TWENTY YEARS OF RESEARCH ON COTTON INSECTS IN THE UNITED STATES

By C. R. Parencia, Jr., *research entomologist*

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PREFACE

This handbook summarizes research information developed on cotton insects and their control largely by researchers in the Agricultural Research Service and its predecessor organizations and in the State agricultural experiment stations. It gives results of early and current research on cotton insects and their control for growers, processors, research and extension personnel, and others interested in the production of cotton.

CONTENTS

ONE HUNDRED TWENTY YEARS OF RESEARCH ON COTTON INSECTS IN THE UNITED STATES

C. R. PARENCIA, Jr., *ARS research entomologist*[1]

In the United States problems with cotton insects did not begin in 1892 with the introduction of the boll weevil, *Anthonomus grandis* Boheman. The early colonists cultivated cotton and had problems with cotton insects. T. Glover, the first Government entomologist under the Commissioner of Patents, mentions cotton insects in his first and second reports for 1854 and 1855.

Pursuant to an Act of Congress, Professor C. V. Riley, appointed entomologist of the Department of Agriculture in 1878, started a special investigation of cotton insects. Professor J. H. Comstock continued this investigation and in 1879 published a large, practical volume on the cotton leafworm, *Alabama argillacea* (Hübner), and the bollworm, *Heliothis zea* (Boddie), entitled "Report on Cotton Insects."

The investigations on cotton insects were transferred to the U.S. Entomological Commission under the Department of the Interior and assigned to C. V. Riley. In 1885, Riley published another large volume on the cotton leafworm and bollworm as the "Fourth Report of the U.S. Entomological Commission." Both Comstock's and Riley's reports had large editions and contained much useful information on the occurrence of outbreaks, methods of control, and spraying machines.

These two insects continued to be important pests of cotton until the boll weevil reached the United States. Many references to the cotton leafworm and other insects affecting cotton are found in the early entomological publications. Since the boll weevil entered Texas about 1892, it has been the most important pest of cotton, receiving most of the attention focused on insects attacking cotton.

Some results of boll weevil investigations, also, have been helpful in the development of control measures for other insects. Of particular importance have been the development of calcium arsenate and organic insecticides, the improvements in ground application equipment, and the development of applying calcium arsenate in a dust formulation and later other insecticides in dust, as well as in spray formulations, by aircraft.

With the advent of the organic insecticides in the mid-1940's, tremendous improvements were made in the control of all cotton insects. However, as the boll weevil built up resistance to the organochlorine insecticides in the mid-1950's and other species developed resistance to various insecticides, the need for alternate methods of control became apparent. Budget constraints, however, permitted research only on solving immediate problems. As more money became available for research, basic research and development of alternatives to conventional insecticides for control of insect pests that attack cotton were emphasized.

In the 1960's research was expedited on the boll weevil, resulting in a Pilot Boll Weevil Eradication Experiment in South Mississippi and in adjoining areas of Louisiana and Alabama, which began in July 1971 and terminated in August 1973. Results indicated that eliminating the boll weevil from the continental United States was technologically and operationally feasible, and plans were submitted to the Secretary of Agriculture on December 12, 1973.

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Though much progress has been made, new problems are continually arising and the need for more effective and economical control of most cotton insects continues.

This handbook consists of a brief discussion of progress made in research on the various cotton insects. The first section covers the period 1854 to 1940 and lists cotton insects and research achievements about each of them. The last section lists areas of research about all insects attacking cotton from 1941 to 1974. The outstanding research findings reported by authors of Federal and State agencies[2] are summarized here, including some unpublished observations.

The author is indebted for much of the early information to an unpublished manuscript, entitled "Report on the Accomplishments of the Work on Cotton Insects Investigations of the Bureau of Entomology and Plant Quarantine and Preceding Organizations of the United States Department of Agriculture from 1954 to 1938." This manuscript was found in the Waco, Tex., Cotton Insects Laboratory files.

RESEARCH 1854 TO 1940

Boll Weevil

The boll weevil (*Anthonomus grandis* Boheman) was described by Boheman in 1843 from specimens received from Vera Cruz, Mexico, and was recorded by Suffrian in 1871 as occurring in Cuba. Its food plant was not known, and the first association of this species with cotton was a note by C. V. Riley in 1885 stating that the boll weevil had been reared from cotton bolls sent to the Department by Dr. Edward Palmer from near Monclova, Mexico, where it was causing serious damage. In the mid-1960's archeologists working in Oaxaca, 150 miles south of Mexico City, found cotton bolls on the floor of a cave once inhabited by Zapotec Indians. An adult boll weevil was discovered in a lock of one boll. The carbon-14 dating process established beyond doubt that the weevil was alive about 900 A.D. making it at least 1,000 years old.

The first report of the occurrence of the boll weevil in the United States was received in the Department of Agriculture in the fall of 1894 from Brownsville, Tex. The Division of Entomology immediately dispatched C. H. T. Townsend to Texas. He found several counties infested with the boll weevil causing serious damage to cotton since 1892. His report, published in March 1895, dealt with the area infested and the life history and habits of the boll weevil that were previously unknown. He concluded his report with recommendations for the destruction of cotton stalks to kill the overwintering weevils and the establishment of a noncotton zone to prevent further spread. The Department reported the seriousness of the pest to the Governor of Texas and urged immediate legislation to permit quarantine and remedial work. These recommendations were not adopted, and in 1895 the boll weevil had spread as far north as San Antonio and as far east as Wharton, Tex.

The Division of Entomology continued its investigations, and in 1896 and 1897 L. O. Howard published the results. These publications and many earlier ones on the boll weevil were published in English, Spanish, and German for the benefit of the large foreign population of Texas. Townsend was stationed in Mexico in 1897 to study the parasites and diseases of the boll weevil, but he found none that appeared promising to control the insect.

The boll weevil was a newly introduced pest causing almost total loss of the crops in the infested areas and rapidly spreading to new territory. Therefore, to meet the demand for immediate information, the Department issued frequent publications on this subject matter. L. O. Howard in 1896 first suggested the importance of early planting and clean cultivation as control measures. These recommendations were based on his knowledge of the habits and life history of the weevil. Marlatt and Townsend in 1896 experimented in poisoning the boll weevil by spraying with paris green and sweetened poisons. Howard reported these results in

[2] See References, p. 70.

1898. Because results indicated that the weevil could not be controlled by poisons then available, special emphasis in most of the early work was placed on other methods of control and on the economic phases of the problem.

The year 1898 was important in the history of the boll weevil in several ways. The season was favorable for the development of the boll weevil and it spread rapidly, causing serious damage over a large area.

The first of a long series of boll weevil conventions attended by many cottongrowers, merchants, and bankers was held on October 12, 1898, in Victoria, Tex. The Legislature of Texas appointed a State entomologist to investigate means of controlling the pest. At the end of the 1898 season, the Division of Entomology discontinued its work in Texas.

The boll weevil continued to spread, however. In 1901 when it became evident that other States were threatened, Congress appropriated money for the first boll weevil investigations to discover means of preventing its spread. From 1901 until his death in 1925, W. D. Hunter was in charge of this work. In addition to other work, Hunter inaugurated cooperative work on eight farms in 1901 to demonstrate the cultural methods controlling the weevil that had been recommended by the Division of Entomology. These farm demonstrations of boll weevil control developed into the Farmers' Cooperative Demonstration Work of the Bureau of Plant Industry and, later, into the present Extension Service of the Department.

The work was expanded in 1902, and a laboratory was established at Victoria, Tex., to obtain much needed information on the life history, habits, and hibernation of the boll weevil. So much attention was devoted to the immediate economic phases of the problem that detailed studies of the insect had not been possible up to that time. The results of the first 2 years' work were published by Hunter and Hinds in 1904, and Howard in his letter of transmittal stated it was the most complete treatise on the life history of a single insect species published.

Development.—The boll weevil has four stages in its life cycle—egg, larva, pupa, and adult. Under favorable conditions, it completes the cycle in 2½ to 3 weeks. High temperatures and humidity result in faster development, while low temperatures slow it down. As many as seven generations may develop in a year in the extreme southern part of the Cotton Belt. The adult boll weevil is one-eighth to one-third inch long. It ranges in color from tan to dark gray, or sometimes to dark brown.

Starting in the spring, the female lays eggs singly in cotton squares (flower buds). When the boll weevil population is high and a shortage of squares exists, two or more eggs may be laid in one square. Late in the season, eggs are laid both in squares and in young bolls.

Eggs hatch in 3 to 5 days. The larvae feed 7 to 12 days inside the squares or bolls. The pupal stage lasts 3 to 5 days. Adults cut their way out of the squares or bolls. After feeding 3 to 7 days and mating, females begin laying eggs. This cycle is repeated until the cotton plants are killed by cold weather (fig. 1).

Adult boll weevils hibernate in surface woods trash and along ditchbanks near cottonfields and in trash and litter around gins and farm buildings. In the spring they return to the cottonfields.

Jaws at the end of an adult weevil's snout enable it to eat into a square or boll. Both males and females make feeding punctures. Females make egg punctures, which are deeper than feeding punctures, in which they lay eggs.

Both kinds of punctures cause damage. After a square is egg punctured, the bracts around it flare, the square turns yellow, and after a few days, usually drops to the ground.

Many punctured small bolls drop to the ground, but punctured large ones usually remain on the plants. If the large bolls have egg punctures, however, they will be damaged by the weevils developing in the locks where the eggs were laid. Weevil-infested locks produce little, if any, cotton, and the quality of that produced is inferior.

Early research.—Congress in 1904, after becoming aware of the great damage inflicted by the boll weevil, appropriated $250,000 to enable the Secretary of Agriculture to meet the boll weevil emergency. Of this amount, $100,000 was allotted to the then Bureau of Entomology and the rest to the then Bureau of Plant Industry. Much of the money was used to expand the demonstration work in newly infested areas,

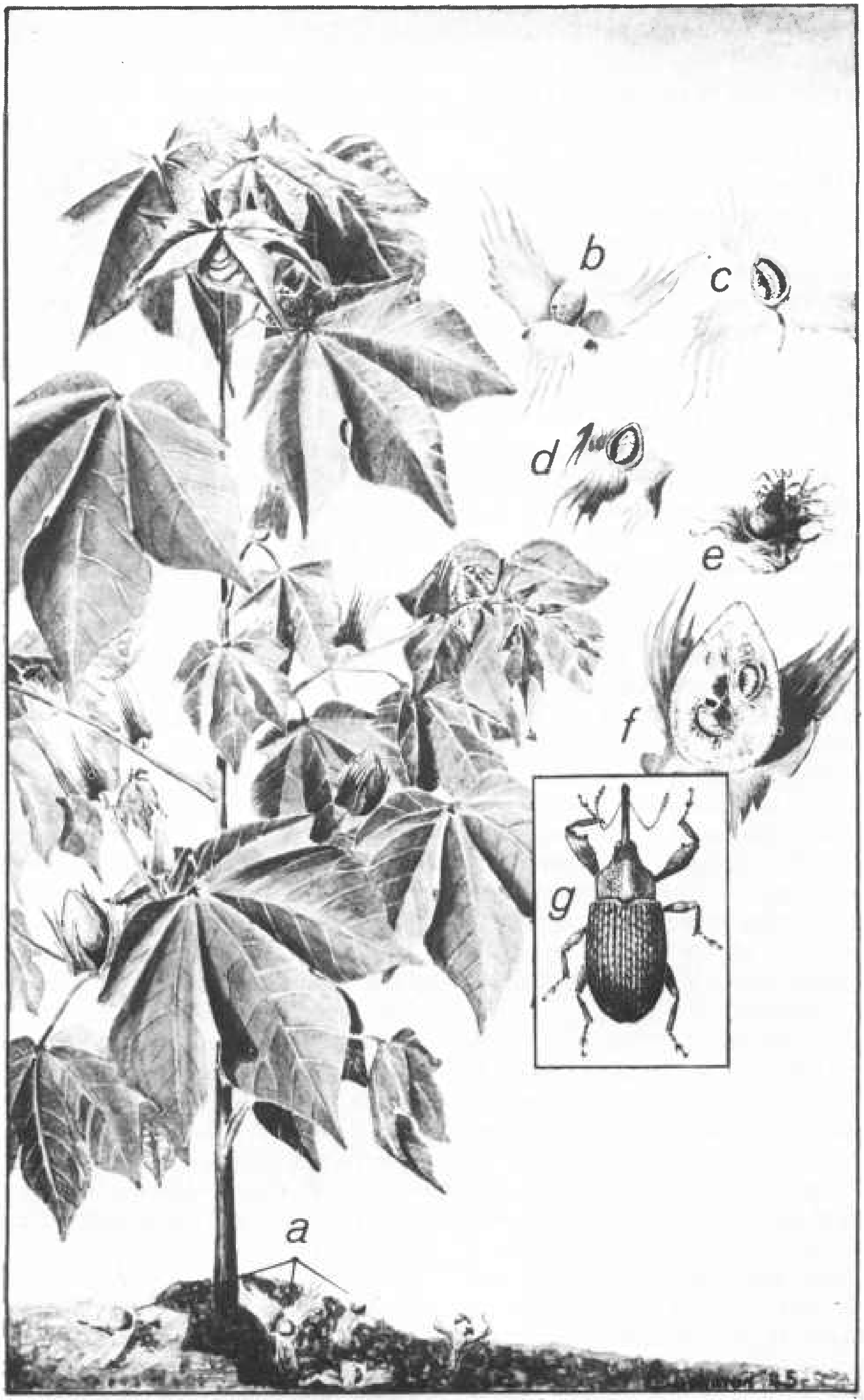

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Figure 1.—Cotton plant showing (a) punctured squares on ground; (b) square showing egg puncture; (c) larva in square; (d) pupa in square; (e) adult emerging from square; (f) larva and pupa in boll; (g) adult. (Punctured squares on ground about one-fourth actual size; adult about 6 times actual size. Other stages actual size.)

testing control recommendations on a large scale, and experimenting with insecticides. The weevil had spread to Louisiana in the previous year, and a special session of the Louisiana Legislature, called in 1904, established the Crop Pest Commission of Louisiana. This commission made many contributions toward controlling the pest.

Early in 1905 the boll weevil laboratory was moved from Victoria to Dallas, Tex. Many farmers' bulletins, circulars, and articles for farm papers containing information of practical value to farmers were published in 1904 and 1905 and distributed in large numbers. A comprehensive publication by Hunter and Hinds in 1906 brought together the more fundamental information that had been accumulated on life history, dissemination, and natural and artificial control of the boll weevil.

The State of Texas offered a reward of $50,000 for an effective control for the boll weevil, and numerous remedies and devices were proposed. The Bureau of Entomology tested all remedies that were submitted and reported the results to the originator. Although these tests required a great deal of time, they were of immense aid to farmers in reducing the amount of money spent for ineffective concoctions and devices, as not a single new method of any value resulted.

Extensive tests with paris green showed that some weevils could be killed, but under field conditions the benefits were too slight to recommend its use. A satisfactory method of fumigating cottonseed by vaporizing carbon bisulphide was developed so that seed could be moved from infested territory. Numerous machines and traps for controlling the weevils were tested, also. Government entomologists studied the relation of temperature and climate to damage, dissemination, and areas where the weevil would become a pest. Results of biological studies indicated that the boll weevil could infest most of the Cotton Belt.

With the apparent ineffectiveness of insecticidal and other direct methods of control, emphasis was placed by the Bureau of Entomology on "cultural methods," which included various modifications of the cropping system that studies of the pest indicated might be useful in avoiding damage. The most important cultural methods developed for reducing boll weevil damage were the early maturity of the crop before the weevils become abundant by selecting an early maturing variety, planting early, fertilizing and cultivating properly, and destroying stalks as early as possible in the fall. Early destruction of stalks in the fall prevented the large, late season increase in weevil populations, thus reducing the numbers that entered hibernation sites and survived the winter.

Other investigations were also started. Studies were made on the abundance and distribution of some 50 species of native parasites and predators of the boll weevil, but efforts to increase their usefulness were unsuccessful.

Estimates from many sources of the damage caused by the boll weevil during this period varied greatly. The most reliable estimates placed the losses in newly infested areas at about 50 percent of the crop, but after a few years growers were able to reduce this considerably by adopting the recommended cultural control practices. About one-third of the acreage planted to cotton in Texas was then infested, and the loss to the 1904 crop was conservatively estimated by the cotton industry at $22 million.

The boll weevil crossed the Mississippi River into Mississippi in 1907. All cotton-growing States had previously enacted quarantines against the introduction of infested material, and the spread was almost entirely by natural dispersal. Only a few isolated infestations became established at any distance ahead of the general line of advance, with most of these being eradicated. It was then generally accepted that the boll weevil would continue to spread over the Cotton Belt, and growers became concerned as the weevil entered the large plantations in the Mississippi Delta.

The spread of the boll weevil year by year was of paramount interest to the people in the line of advance. The most severe damage was usually caused during the first few years before the infestation became stabilized and growers learned the best methods of growing cotton in the presence of weevils. One great service of the Bureau of Entomology was in determining the limits of infestation each season. Maps and articles giving this information were widely distributed each fall that greatly assisted farmers, businessmen, State authorities, ginners, and many others in planning for the next season. This service was rendered from the beginning of the investigations in 1904 in south Texas until the weevils reached Virginia in 1922.

The advance varied from 40 to 160 miles a year, although in several instances adverse winter conditions caused a reduction in the infested areas. Spread was more rapid to the north and northeast during the early years, and then faster to the east as unfavorable climatic conditions were reached in western Texas and Oklahoma. The semiarid areas with high summer and low winter temperatures are unfavorable for weevil development and survival, and infestation have never become established in the High Plains of Texas, New Mexico, Arizona, and California. A suppression program to prevent the establishment of infestations on the High Plains has been underway, however, because the boll weevil was found able to survive the winter above the caprock. By 1922 the boll weevil had spread over North Carolina and into Virginia, thus covering over 600,000 square miles of territory since its entry into the United States 30 years previously (fig. 2). About 85 percent of the cotton in the United States was produced in the infested territory, and the rapid expansion of cotton production to the West was partly due to the absence of the boll weevil in that area.

As the boll weevil continued to spread to new areas, it became more and more apparent that the "boll weevil problem" was a series of problems and that investigations should be conducted under different climatic, ecological, and agricultural conditions. Consequently, in 1909 the laboratory moved from Dallas, Tex., to Tallulah, La., until it closed on June 30, 1973.

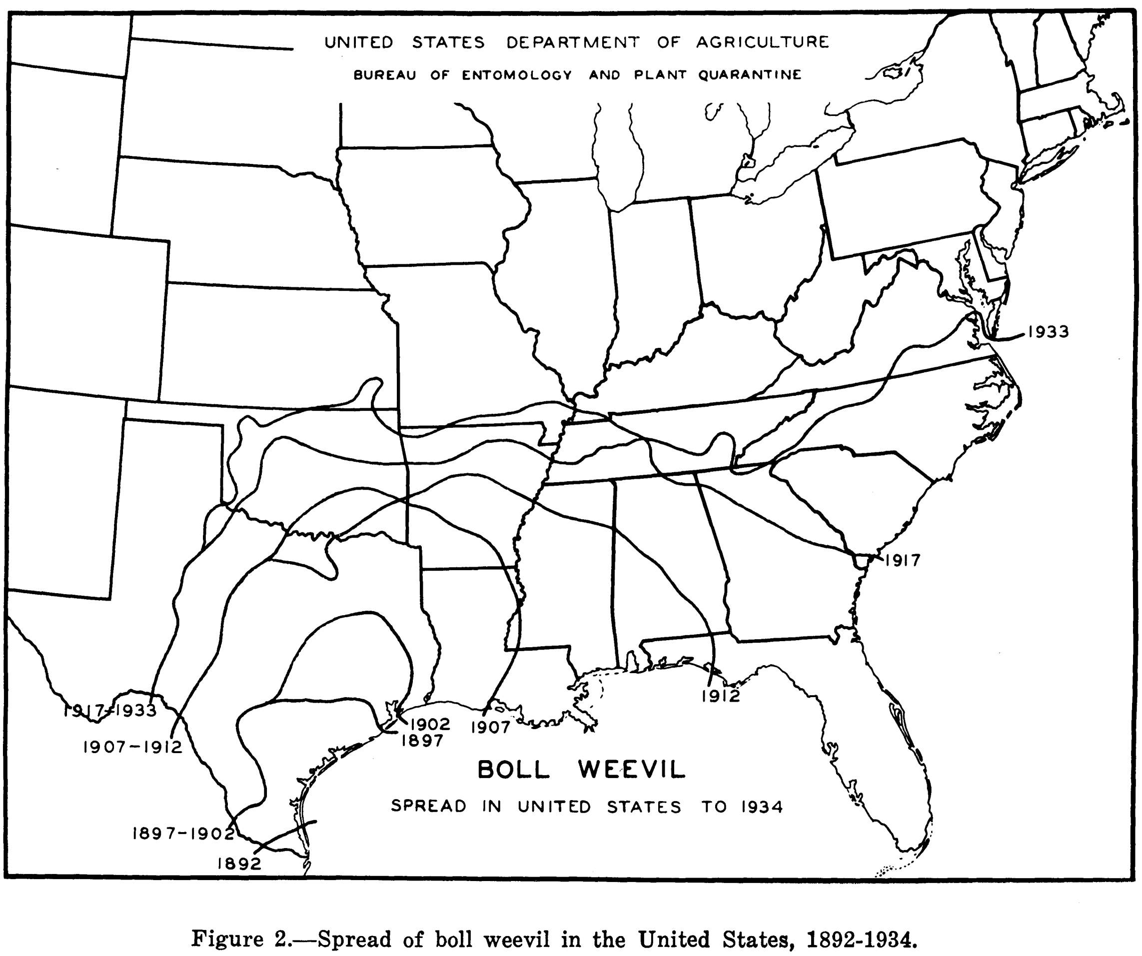

Figure 2.—Spread of boll weevil in the United States, 1892-1934.

This location was selected because it was near the southern edge of the Delta section where the boll weevil was expected to cause as much damage as anywhere in the South. The soils were fertile and with the abundant rainfall plants normally continued to produce cotton until late in the season. Large areas of dense forests afforded good hibernation quarters, and with comparatively mild winters heavy infestations were the general rule.

The policy of investigating the boll weevil "on the spot" was followed throughout the work and additional laboratories were established by the Bureau of Entomology in Mississippi, Florida, South Carolina, Oklahoma, and Georgia. As the weevil spread to new areas, work also moved to these areas. Information on habits, damage, and control measures best adapted to different local conditions fully justified this procedure. The State agricultural experiment stations, particularly Texas, Oklahoma, Alabama, Arkansas, Florida, and South Carolina, did a great deal of work on the boll weevil, but the Tallulah laboratory was the leader in these investigations.

The many phases of the boll weevil investigations and the interest in this insect are indicated by bibliographies compiled by Bishopp in 1911 (*7*), Dunn in 1964 (*25*), and Mitlin in 1968 (*74*), all of which contain titles or abstracts of important papers by both Federal and State entomologists.

Research for the first few years at the Tallulah laboratory continued somewhat along the same lines as the previous work in Texas. Whether the cultural methods that had given good results in Texas would be effective under the ecological and farming conditions of the Delta had to be determined. Every phase of the control methods then in use was based on biological facts, and life history studies had a direct economic bearing on the boll weevil problem. Consequently, biological studies were made at Tallulah from 1910 to 1915. In 1913 another series of biological studies, also, were made at Victoria, Tex., to check those made 10 years previously. Because of the shorter developmental periods, the same number of generations (7) were produced at Tallulah as at Victoria, although the breeding season at Tallulah was more than a month shorter.

The discovery of the Thurberia weevil, *Anthonomus grandis* var. *thurberia* Pierce, a close relative of the boll weevil, in the "wild cotton" of Arizona led to further studies on the host plants of the boll weevil. In experiments conducted at Victoria, the boll weevil developed in *Hibiscus syriacus*, a common ornamental shrub, and fed and partially developed on two other species of native Malvaceous plants under cage conditions. This was the first record of rearing the boll weevil on plants other than cotton.

A method of control consisting of collection of weevils and infested squares was thoroughly tested in the Mississippi Delta in 1915 and 1916. Considerable reduction in damage and fair increases in yield resulted from this practice, but it was impractical because of the great amount of labor and expense involved.

Research with insecticides.—Although the Bureau of Entomology had been concentrating its efforts on cultural control based on biological data, research had also started on use of insecticides as a control measure. In addition to the Bureau's work, the Louisiana Crop Pest Commission began conducting tests with paris green in 1905. A certain amount of control was obtained, but paris green seemed to have some adverse physiological effect on the plants and increases in yield were not commensurate with the reduction in weevil infestation. Arsenate of lead was coming into general use as a substitute for paris green for use on fruit trees, but this insecticide was then made only as a paste and could be used only as a spray. Since spraying was considered impractical for cotton, Wilmon Newell conceived the idea of making lead arsenate as a powder that could be dusted on cotton for boll weevil control.

The first powdered lead arsenate was prepared for Newell by the Grasselli Chemical Company in 1908 and was used in cage tests against the weevil in that season. Field tests conducted in 1908 and 1909 showed considerable increases in yield and profits from dusting with lead arsenate under some conditions. Emphasis was placed on the value of dusting early in the season and forcing the dust inside the bracts of the squares and into the terminal buds of the plants where it would be ingested by the weevils while feeding on the external tissues. Dusting was recommended as a useful supplementary measure to cultural methods. The results were the most successful that had been obtained to that date with insecticides, arousing considerable public interest as well as stimulating renewed interest in insecticides by the Bureau of Entomology. Results from subsequent tests of dusting with lead arsenate were erratic, and the method was neither recommended nor used extensively by growers. In 1916, however, tests with tri-plumbic arsenate of lead dust resulted in good gains in yield when applied late into the season.

In 1916, the new insecticide, calcium arsenate, was first compared in field tests against the boll weevil with di-plumbic arsenate of lead. Calcium arsenate in a dust formulation was being made by a few manufacturers but was a comparatively unknown insecticide. Its physical properties were poor, having a density of about 40 cubic inches per pound, and when applied it did not form a good dust cloud for plant coverage. Excessive quantities of water-soluble arsenic often made it phytotoxic. Considerable experimenting was done at Tallulah in cooperation with manufacturers to improve its physical and chemical properties. Dusts, ranging in density from 80 to 160 cubic inches per pound, were prepared. Those with densities from 80 to 100 cubic inches per pound gave better coverage and were better suited for cotton. Some increases in yields were obtained from most of the treated plots in 1916, but the most striking results were obtained in a plot in a field of heavily weevil-infested cotton that was treated with calcium arsenate in August. The weevils were effectively controlled, and a fair crop produced on cotton the owner had abandoned as an absolute loss. The late season poison applications resulted in good gains in yield, whereas gains from the early season applications were slight.

Results of studies at Tallulah in 1917 to obtain information on the efficacy of different poisons, the time of day of applications, the proper intervals between applications, and other phases were inconclusive because of the light weevil infestation, but tests with calcium arsenate conducted in Mississippi and Arkansas again gave good control, with gains ranging from 250 to 1,000 pounds of seed cotton per acre. A large-scale field test in Arkansas in a heavily infested field of late cotton demonstrated for the first time the value of a late application of poison for protecting the bolls from weevil damage.

Who first made calcium arsenate is not known. Apparently, the first records of its use as an insecticide were in 1907 by John B. Smith of New Jersey and by Bedford and Pickering of England, who tested it as a substitute for lead arsenate during the same year. Pickering stated, however, that calcium arsenate had already been used in the United States, and Smith reported that combinations of arsenic and lime were well known and easily prepared by farmers. Bedford and Pickering used a homemade product and gave the proportions of an arsenate and a calcium salt, with the recommendation that an excess of lime be used to prevent an excess of soluble arsenic in the calicum arsenate. Smith used a calcium arsenate sent him by Dr. Fred P. Dewey, a chemist of Washington, D.C., thought to have been connected with the U.S. Mint.

The next reports of calcium arsenate as an insecticide were by Scott and Siegler, of the Division of Deciduous Fruit Insect Investigations of the Bureau, who used it in laboratory tests in comparison with many other arsenicals against the fall webworm, *Hyphantria cunea* (Drury), and in orchard tests against the codling moth, *Laspeyresia pomonella* (Linnaeus), in 1912 at Benton Harbor, Mich. The calcium arsenate used in 1912 was a "chemically pure" powder, applied as a spray (0.5 pound to 50 gallons of water). Against the fall webworm the results were about equal to that obtained with lead arsenate, and against the codling moth the results were somewhat below that obtained with lead arsenate.

In 1913 further tests were made by Scott and Siegler with two homemade formulations of calcium arsenate prepared in the laboratory from sodium arsenate and calcium acetate, and a commercially prepared calcium arsenate paste. The commercial calcium arsenate paste was as effective as the lead arsenate paste against the tent caterpillar (*Malacosoma* spp.).

An interesting account of the first commercial manufacture of calcium arsenate for insecticidal use was furnished by E. H. Siegler. While the tests at Benton Harbor were in progress, Scott's brother, W. M. Scott, of the Thompson Chemical Company, Baltimore, Md., became interested in the new insecticide. He made a calcium arsenate paste to test as an insecticide in 1913. In 1914, the Thompson Chemical Company also furnished a commercial calcium arsenate powder, which was as effective as lead arsenate against the fall webworm in laboratory tests at Benton Harbor. The powdered calcium arsenate was also furnished to several investigators for use against the codling moth, and over 2,000 pounds were used against shade tree insects in 1914.

Although calcium arsenate was first used in experiments against fruit insects, it was still a comparatively unknown insecticide when tested against the boll weevil. It gave better control than the other arsenicals then in use. The improvements in the physical and chemical properties of calcium arsenate and the rapid expansion in its use were due almost entirely to the work of the Bureau of Entolomogy on the boll weevil.

The results of the tests with calcium arsenate dust against the boll weevil in 1916 and 1917 were so successful and aroused so much interest and demand for information that USDA Bulletin 731, "Recent Experimental Work on Poisoning Cotton Boll Weevils," was issued in July 1918, although it was felt that further details should be worked out before recommendations were made to the public.

The machines then in use for applying dust formulations were as crude as the insecticides. From the beginning of the dusting experiments it was evident that improvements in machinery were necessary before application of dust formulations of insecticides to cotton on a large scale would be feasible. In 1916 Elmer Johnson, an engineer with the Bureau of Public Roads, was detailed to the Bureau to improve and develop dusting machines adapted to cotton. He was invaluable in improving the design and developing machines suitable for various acreages and types of farms. These improvements were covered by Public Patents and were available for use by all manufacturers.

In 1918 several thousand acres of cotton were dusted with calcium arsenate under the supervision of Bureau personnel. As a result of the success of this work, over 3 million pounds of calcium arsenate were used for weevil control in 1919 and about 10 million pounds in 1920. The increase in the use of calcium arsenate for control of the boll weevil was phenomenal, probably the most rapid of any insect control measure ever developed up to that time. Emphasis in lines of work changed almost entirely from cultural control to direct control by insecticides and development of dusting machines. Two new industries—the manufacture of calcium arsenate and of dusting machinery—were expanding simultaneously. Over 30 companies were making calcium arsenate in 1920, and many models of dusting machines were available.

With such rapid expansion in use, much of the calcium arsenate and machinery placed on the market were not suitable. The physical quality of some early calcium arsenate was poor and contained so much water-soluble arsenic that it was phytotoxic, or so little total arsenic that it was not sufficiently toxic to kill the weevils. The Tallulah laboratory tested all samples for growers or others, and in 1920 had tested over 2,000 lots. It also tested new models of dusting machines and suggested improvements to the manufacturers before they were placed on the market.

These services saved the growers much money that would have been expended for unsuitable insecticides and dusting machines. In addition, an educational campaign was urgently needed to advise growers, county agents, and others on the use of the new methods of control. Consequently, in 1921 most of the personnel at Tallulah were stationed at representative sections of several States to demonstrate dusting with calcium arsenate and to obtain additional information on its use under different conditions. Arrangements were made through the States Relations Service whereby the men worked with the county agents and issued timely advice on local insect conditions and dusting schedules.

Work on refinements in methods of applying dust formulations to cotton were delayed as every possible effort was made to help farmers in controlling the boll weevil. During this period of rapid expansion in the use of calcium arsenate, a shortage of white arsenic used in its manufacture occurred. The Bureau of Entomology surveyed available supplies and prospective insect conditions to aid in the proper distribution of calcium arsenate and dusting machines to meet critical needs. This action led to the annual installation of a large series of hibernation cages in different States to study the emergence and abundance of weevils in the new cotton-growing season. Such information was valuable to manufacturers in planning to meet the demand for calcium arsenate and dusting machines and to the farmers in stabilizing prices and preventing scarcity of materials.

The next important step in boll weevil control occurred when the method of applying dust formulations of insecticides with airplanes was developed. The possibility of using airplanes for this purpose was suggested by the work of the Ohio Experiment Station in distributing lead arsenate for the catalpa sphinx *Ceratomia catalpae* (Boisduval) in 1921. The first tests for control of cotton insects were against the cotton leafworm in 1922, through the cooperation of the Air Service of the United States Army that furnished planes and personnel.

In the first flights, calcium arsenate was dropped by hand from the planes, but it was soon evident that methods had to be developed to distribute the poison evenly at a controlled rate. After several years' work in cooperation with engineers of the Bureau of Agricultural Engineering, U.S. Department of Agriculture, hoppers were developed that would evenly distribute dust over a swath 150 to 200 feet wide, and aerial applications were equally as effective as those applied by ground equipment for boll weevil control.

Treatment with airplane was much faster than with ground equipment, as one airplane could treat from 750 to 1,000 acres per day. This treatment was especially important when the fields were too wet for use of ground equipment or when large acreages had to be treated quickly. Commercial airplane companies, under contract, did most of the aerial dusting. Growers did not need to purchase planes or other dusting equipment. These costs compared favorably with that of ground equipment and was much more convenient for the growers. At least 1,000 acres to be treated in a community were needed for economical operation of airplanes, and the dust companies contracted for treating fields within a radius of several miles of a landing field. This method of insect control for cotton was used extensively in Texas, Arkansas, Louisiana, Mississippi, and in other States for truck crops and orchards. Expansion in the use of airplanes was rapid, and many commercial companies maintained fleets of airplanes equipped for crop treating with as many as 100 planes ready for instant call. Treating with airplanes was spectacular, but at the same time entirely practical, economical, effective, and the most convenient method ever devised for treating large acreages of cotton or other crops (fig. 3). In December 1931, the Bureau of Entomology discontinued its work and disposed of its airplanes after such method of treatment was established commercially as a result of the research done by the Division of Entomology.

Following the first successful demonstrations with calcium arsenate for boll weevil control, experiments on insecticidal control by the various State agencies renewed. Information on treatment schedules best adapted to each locality and on the profits that could be expected at different points was in great demand. Many new remedies appeared on the market as a result of this renewed interest. A large part of the Bureau of Entomology's work during the next several years consisted of demonstrations in many areas to bring the results to growers and State officials by seeing that control methods were properly used and testing many proprietary remedies that appeared on the market.

There was such a lack of uniformity in the methods of experimentation and recommendations by the various agencies that the Association of Southern Agricultural Workers (ASAW) appointed a Cotton Council in 1922 to review the boll weevil situation thoroughly and to standardize the control recommendations. The Council adopted the following resolutions in 1924, which were slightly modified in 1926:

PN-4419

Figure 3.—Applying insecticides as dusts with aircraft.

For the boll weevil, one presquare poisoning may be applied if it appears there are numerous overwintered 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 (Proceedings, ASAW, 1926).

This action by the ASAW did much good in gaining the cooperation and coordination of the work of all agencies engaged in boll weevil control.

The boll weevil had spread over most of South Carolina by 1920 and, as usual in newly infested territory, was causing serious damage. The South Carolina Legislature made a special appropriation to conduct control investigations in cooperation with the Bureau of Entomology. This was an excellent opportunity for the Bureau of Entomology to obtain additional information on the weevil under the conditions in the Southeastern States, since most of the previous work had been done west of the Mississippi River. In 1922 a laboratory was established in Florence, S.C., which has operated continuously. In the first few years of operation, the work in the laboratory consisted largely of tests to determine the gains and profits that could be obtained under local conditions.

In 1925 a thorough study of the biology of the boll weevil in South Carolina began with the results published in 1929. Only four generations a year developed at Florence compared with seven at Tallulah. Studies on dispersal showed that the temperature and intensity of infestation were the principal factors causing the migration or flight of weevils from field to field and to new areas. After 1928 the attention of the Florence personnel was devoted largely to such phases of control as the value of the mopping technique of reducing the amount of calcium arsenate needed for control and the effect of calcium arsenate used for boll weevil control on aphids and on the soil. Root aphids and other insects affecting cotton, also, were studied.

From 1926 to 1940 several laboratories conducted research on improving and refining methods of boll weevil control to increase the efficiency of control and reduce the cost. Tests of applying insecticide dust formulations at various time intervals, at different times of the day, and in reduced quantities were conducted. Special attention was given to developing combinations of insecticides that would control some other insects that occurred simultaneously with the boll weevil. A mixture of calcium arsenate and sulphur was found to control combination infestations of the boll weevil and certain other insects such as the cotton fleahopper *Pseudatomoscelis seriatus* (Reuter) and other mirids.

Each year a large series of cage toxicity tests were conducted to compare other insecticides with calcium arsenate for effectiveness against the boll weevil. The promising materials from these tests were then tested under field conditions. Many arsenical, rotenone, nicotine, fluorine, and other insecticides were tested, but none were as effective and economical as calcium arsenate. Results of studies showed calcium arsenate was a complex material with varying physical and chemical qualities. This finding explains why some commercial calcium arsenates were more effective than others against the boll weevil although they all met the required specifications.

Commercial calcium arsenates with a high percentage of water-soluble arsenic by the Geneva method were more toxic to weevils in cage tests than those medium or low in water-soluble arsenic but were no better than those medium or low in water-soluble arsenic in field tests. The three forms found in the commercial products—mono-, di-, and tri-calcium arsenate—were separated and tested separately. Samples were fractionated into different sizes of particles. The indicated results of the tests were that if the most desirable physical and chemical properties could be determined they could be incorporated into commercial practice by modifying the manufacturing processes without increasing the cost of production.

Parasites.—Parasites of the boll weevil were studied again from 1932 to 1935 to determine the change in native parasites during the 20 years since the previous studies. About 20 species of parasites were found, 3 of which were new. Findings from these studies indicated little increase in the control of the boll weevil by parasites since the previous investigations. An average of 5.5 percent of the weevil larvae collected in several States were parasitized, and there was little hope of increasing the native parasites so that they would give greater control.

Effects of calcium arsenate on aphids, soils, and crops following its use for boll weevil control.—The use of calcium arsenate dust at first appeared to have solved the problem of controlling the boll weevil. However, soon after it came into extensive use, a conspicuous and often injurious increase in infestations of the cotton aphid *Aphis gossypii* (Glover) occurred following its use on cotton. This was noted in 1920 in Texas and about the same time in South Carolina and in other States. In some instances where large amounts of calcium arsenate were applied, the aphids increased to the extent that the gains from weevil control were offset by the damage caused by them. Investigations conducted from 1922 to 1929 to determine the reasons for the increase in aphids indicated that several factors were probably responsible for this complex problem. The initial increase in aphid infestation was thought to be due to the attraction of the winged females to the white deposit of calcium arsenate or other white dusts on the plants. The aphid population then increased because the hymenopterous parasites were killed when they emerged in the presence of the arsenical. Later tests with calcium arsenate colored with aniline dyes did not prevent the buildup of aphids. The aphid problem on cotton became more serious, especially in the Southeastern States. Rotenone dusts were not very effective against the cotton aphid and control with nicotine sulphate, the most effective aphicide, was expensive and somewhat erratic unless weather conditions were ideal.

Research on varietal resistance or tolerance of cotton to aphids started in 1934 with the establishment of a Cotton Insects Research Laboratory at Stoneville, Miss. The Bureau of Plant Industry maintained a large collection of exotic and domestic species, varieties, and crosses of cotton here. An endeavor to find strains of cotton or individual plants that were immune or resistant to aphid buildup showed that varieties with more pilose leaves retain the calcium arsenate for a greater time and that the aphids increased more rapidly than on the smoother leafed cottons.

The amount of damage actually caused was difficult to determine. Most farmers considered the benefits from boll weevil control more important than the aphid damage following use of calcium arsenate. There were some, however, who were reluctant to use calcium arsenate because of this factor.

About the same time that the effect of calcium arsenate on the increase in aphids was observed, a few cases were reported on the reduction in yield of cotton and other crops following its use on the light sandy soils of South Carolina. Later, similar reports were received regarding arsenical injury to soils on the ricelands of Louisiana. The injury from arsenic in South Carolina was manifested by poor stands of cotton and, more particularly, by the adverse effect on the germination and growth of oats and legumes. Workers from the Louisiana Experiment Station found that cotton treated with calcium arsenate was not affected, but rice following treated cotton was rather seriously injured. Other crops such as rye, corn, sweet potatoes, and tobacco were rather tolerant to arsenic, and some growth was even stimulated where considerable quantities had been applied. Injury from arsenic in South Carolina seemed to be correlated with soil deficiencies of iron and magnesium, and no injury was reported on dark or reddish soils. Also, all the reported injury in South Carolina were where larger quantities of calcium arsenate than recommended were used for boll weevil control, although there was no proof that the recommended quantities might not also cause damage in the future.

In experiments to determine the types of soils that would be affected and methods of overcoming the injury, 500 pounds of calcium arsenate per acre were applied to the soil at Tallulah, La., for 4 successive years, or a total of 2,000 pounds, without decreasing the yield of cotton. However, after this quantity was applied there was some deleterious effect on the germination and growth of vetch planted as a winter cover crop. Of the principal soil types in Mississippi, 7 were treated with calcium arsenate at rates from 50 to 1,600 pounds per acre and planted to cotton, corn, and soybeans in the spring, and to vetch, Austrian peas, and oats in the fall as winter cover crops. The germination and yields of some crops were reduced somewhat on the light sandy soils when 100 pounds of calcium arsenate were applied per acre, and when 200 pounds or more were applied per acre on some of the heavier soils.

Analysis of the soils showed that large quantities of water-soluble arsenic were lost by leaching or fixation in one year. Not more than 30 pounds of calicum arsenate per acre per year were estimated as needed to control the ordinary infestations of the boll weevil. With the rapid reduction in arsenic in the soils, there was little danger of soil injury to any of the soil types tested in Mississippi. No corrective measures were found for arsenic injury to the soil, but the damage naturally disappeared by fixation or leaching of the arsenic in a few years.

Progress was also made in avoiding soil injury by decreasing the amount of calcium arsenate dust used for boll weevil control by diluting it with sulphur, lime, or other inert materials. Injury was likely to occur only on certain soil types found in comparatively small areas of the Cotton Belt, and while danger of soil injury was recognized as being serious under certain conditions, the danger seemed to be overemphasized.

The two disadvantages in the use of calcium arsenate were factors in preventing its wide acceptance for boll weevil control.

Sweetened poison.—Besides dusting with calcium arsenate, the only other material generally used for weevil control was a mixture of calcium arsenate, molasses or syrup, and water—"sweetened poison" or "mopping" as it was usually called because the mixture was applied to the tops of the plants with a mop. The advantage of the mopping method was that the overwintered female weevils feeding in the terminal buds of the plants before the squares were present could be killed by ingesting the poisoned mixture before they oviposited.

Sweetened arsenicals were tested in the early investigations at Victoria, Tex., but were neither found to attract the weevils nor to give satisfactory control and were not recommended. After the weevil reached South Carolina, the use of sweetened poison was revived and was more extensively used in that State and in Florida than elsewhere. This method was advocated by some growers and State officials who claimed that it was a cheap method of control requiring no expensive application equipment. A great many of the early emerging weevils were killed by the presquare applications of sweetened poison, but enough weevils usually emerged from hibernation sites after squares formed, and sweetened poison was no longer effective to cause serious damage.

Mopping was extensively tested in Texas, Oklahoma, Louisiana, South Carolina, Georgia, and Florida. Its effectiveness varied somewhat in different localities, apparently depending on the time weevils entered the fields from hibernation shelter and climatic conditions. The more open type woods of the Southeast appeared to warm up earlier in the spring than the denser woods of the Middle Cotton Belt, and caused the weevils to emerge earlier over a shorter period. Under these conditions the sweetened poison seemed to be somewhat more effective.

More extensive tests with mopping were conducted in South Carolina than elsewhere because it was more generally used and recommended by the South Carolina Extension Service. In tests at Florence, S.C., over an 9-year period (1928–36), the average gain from mopping alone was 41.5 pounds of seed cotton per acre; from mopping followed by later dusting with calcium arsenate, 294.3 pounds per acre; and from dusting with calcium arsenate after 10 percent of the squares were infested, 270 pounds per acre. In tests in other States, the results were similar to those in South Carolina. On the basis of these results, the Bureau of Entomology did not recommend sweetened poison alone as a satisfactory control but did recommend presquare mopping to be followed by later dustings with calcium arsenate in the South Atlantic States. Later demonstrations showed that effective control of overwintered boll weevils could not be obtained in small-plot experiments, which no doubt influenced the poor results obtained.

Hibernation and survival.—Hibernation was considered to be the most critical period in the life history of the boll weevil and was studied under a great variety of conditions. In the extreme southern part of the Cotton Belt, cotton continued to fruit and weevils bred continuously all the year, but in most areas they passed the winter as adults in the old cotton bolls, weeds, and surface trash in fields and surrounding woods. Weevils entered hibernation in the fall when the mean temperature dropped to 40° to 50° F and emerged in the spring when the mean temperature averaged about 60°. Some activity occurred during warm days in the winter—weevils left hibernation sites, became active, and entered hibernation sites again when the temperature dropped. The hibernation and survival studies were of value in determining when boll weevils emerged from hibernation sites in the spring and early summer to enter cottonfields.

In 15 years of studies at Tallulah with various types of shelter material and dates of installation, survival ranged from 0.01 to 6.14 percent, with an average of 1.22 percent. The minimum temperature was the most important winter weather condition affecting survival, the lower the temperatures or the greater number of times the temperature was below freezing, the lower the survival. Hibernation experiments also were conducted at several other places to obtain information on survival, especially at Florence, S.C.., Stoneville, Miss., and College Station and Waco, Tex., representative of the different sections of the Cotton Belt.

Many boll weevils hibernated in Spanish moss although it is not very favorable for weevil survival because it is open and subject to sudden changes in temperature. Examinations were made of moss collected near cottonfields in the fall and again in the spring for many years as an index of weevil abundance at time of entering hibernation and spring survival and for predicting weevil abundance.

In 1957 Brazzel and Newsom of Louisiana State University found that the boll weevils developed diapause to survive the winter in hibernation sites. Much of the survival data developed in cage studies before that time became suspect since there was no way of knowing whether the weevils were reproducing or diapausing when they were installed in the cages. The diapause finding did not adversely affect results of surface woods trash examinations because most of the weevils that entered hibernation sites had developed diapause, enabling them to survive the winter.

Since about 1935 examinations had also been made of surface woods trash collected near cottonfields at Tallulah, La., and Florence, S.C., and in later years at Stoneville, Miss., and Waco, Tex. Machines have been developed that separate most of the trash and greatly reduce the labor involved in examining surface woods trash. These examinations have also shown that most of the weevils occurred in trash within 50 feet of the edge, and no weevils were found more than 300 feet from the edge of the woods. Weevils have emerged from hibernation, fed throughout the summer in the insectary, and entered hiberation again the second winter, but no survival over two winters was recorded.

Varietal resistance to boll weevil.—Another line of investigation was the study of immunity or resistance of cotton varieties to the boll weevil. The reduction in damage by the boll weevil through the development of improved varieties was due to the shorter fruiting periods and earlier maturity of the plants, and the morphological characters that might offer resistance were studied very little previously. Investigations of such characters as the thickness of boll walls, the toughness of the carpel lining, pilosity of leaves, amount of leaf area (shade), and early shedding of leaves were started at the Stoneville, Miss., laboratory in 1934.

No resistant varieties were found and special attention was given to the characters most likely to increase the difficulty of oviposition. Thickness of boll walls and toughness of carpel linings resisted oviposition, but as a strong negative correlation existed between the two characters, both were not present in any one variety. Toughness of the carpel lining without the protection of boll wall thickness was of little value in resisting weevil damage, and the least damage was caused to varieties with walls intermediate in thickness and toughness. This work was continued in cooperation with plant geneticists, as the development of a variety with only a slight degree in weevil resistance would mean a great saving to growers. The work on resistant varieties received increased emphasis in the 1960's and 1970's and is discussed under that section in this report.

Attractants.—Considerable attention was given to studies of the chemical constituents of the cotton plant that attract boll weevils with the hope of isolating and using them as baits. Chemists assigned to this work at Tallulah in 1923 distilled large quantities of cotton plants and separated the distillate into a number of constituents. As ammonia and trimethylamine were in greatest abundance, they were considered to be the most likely materials to attract weevils to cottonfields. Extensive tests with these materials in a chemotropometer and a specially designed apparatus for exposure in the field did not indicate that they would be of any practical value in attracting weevils though a few weevils were attracted. Recent work is discussed in the attractants section of this publication.

Boll weevils and Sea Island cotton.—The boll weevil caused more serious damage to Sea Island cotton than to short-staple and upland cotton for the following reasons: Sea Island cotton fruits over a much longer period; the boll walls are thinner and softer, bolls require longer to mature, and bolls are subject to attack almost until they open. Very little work was done on the boll weevil on Sea Island cotton, as production was discontinued shortly after the boll weevil reached the areas in Florida and Georgia where this cotton was grown. A movement was started in 1934 to revive the once prosperous Sea Island cotton industry, and one of the most important problems to be solved was the control of the boll weevil. The biology and habits of the weevil on Sea Island cotton had previously been studied in 1918, and experiments on control were undertaken at Tifton, Ga., in 1936 and in 1937 at Gainesville, Fla. The results indicated that the same methods that were successful on short-staple cotton could be used, although control was more difficult and expensive because of the longer growing season. Spraying instead of dusting calcium arsenate also appeared to be more effective on the smoother leafed Sea Island than on upland cottons. Most of the Sea Island cotton was produced in light sandy soils of low productivity, and despite the higher price per pound for Sea Island cotton, weevils could not be controlled profitably. Pima, long-staple varieties, are now grown only in western areas where the boll weevil does not occur.

Host plants other than cotton.—The boll weevil develops on the cultivated and wild cotton of the genus *Gossypium* and closely related genera. Fortunately, these are the only plants on which the weevil breeds in sufficient numbers to be of importance under normal conditions. However, plans proposed for eradication of the boll weevil with noncotton zones in the early days raised the question whether the elimination of cotton would force the weevils to other hosts and enable them to maintain populations in the absence of cotton. In the early investigations weevils were noted to feed and to deposit eggs on several malvaceous plants of the genus *Hibiscus*, but the larvae did not reach maturity. In 1913 weevils were bred for the first time on plants other than cotton when two completed development on althea, *Hibiscus syriacus* L., and others partially developed on two species of *Callirrhoe* under laboratory conditions. Weevils are also known to breed in *G. thurberia*, but it occurs only in New Mexico and Arizona and is infested with the thurberia weevil.

In 1932 when several States were considering legislation to eradicate the weevil, host plants studies were again started to determine changes in their status. Weevils were reared for the first time from buds of *H. syriacus* growing in a field of infested cotton and adults fed, and some oviposited, on several other species of *Hibiscus* although no larvae reached maturity. It was felt that in an eradication program other host plants could not be overlooked. Althea is an ornamental shrub that is generally distributed throughout the South.

In 1956 at Brownsville, Tex., M. J. Lukefahr noticed that several flower buds of *Thespesia populnea* (L.) Soland were turning yellow and shedding from the tree. He found that these buds were infested with boll weevil larvae and four adults were on the foliage. All the flower buds and seed pods eventually became infested. Several infested buds were collected, and 14 adult boll weevils emerged from them. Nine of them were placed in a cage containing potted cotton plants, and in a short time all the fruiting forms showed evidence of feeding or egg punctures. *Thespesia populnea* belongs to the family Malvaceae and is commonly called portia tree. Locally, it is referred to as the tulip tree.

J. K. Walker of the Texas Agricultural Experiment Station in 1957 found that boll weevil eggs removed from cotton squares and implanted individually in buds of the wine cup, *Callirrhoe involucrata* (Nutt.) A. Gray, produced adults. The wine cup is a common malvaceous plant in central Texas and blooms in April and May. Although boll weevils were forced to feed and oviposit on this plant, they produced no adults in this manner. It is doubtful that the wine cup is a significant host of the boll weevil.

After finding that boll weevils developed on a caged *Cienfugosia drummondi* (St. Hil.) Garcke plant, Lukefahr and Martin reported that four adults developed from 182 capsules of this plant collected on July 14, 1961, on the Welder Wildlife Refuge near Sinton, Tex. The nearest cottonfield was approximately 10 miles away and was fruiting at the time the seed capsules were collected.

On July 31, capsules and flower buds were collected from six locations in Nueces County, Tex., and plants from three of the locations were infested. Thirty-five weevils were reared from 104 fruiting forms that were collected from plants growing about 500 feet from a heavily infested cottonfield located near Port-land, Tex. Twenty-eight adult weevils were collected with an insect sweep net in an area 30 by 50 feet, containing approximately 100 plants, at this location. Another area near Gregory, Tex,. yielded 15 adults from 61 fruiting forms, and the third infested collection made near Corpus Christi, Tex., yielded 16 adults from 133 capsules. The plants in the three noninfested locations were widely scattered and were not in close proximity to cotton.

C. drummondi belongs to the family Malvaceae and occurs primarily in the Coastal Bend of Texas. It is a perennial, low-growing plant, about 8 inches high with runners as long as 2 feet. It is found in poorly drained places that have been undisturbed by cultivation. This plant has been observed blooming from April to October in Nueces County and in February at Brownsville, Tex. Its flowering cycle seems to be dependent on rains, but the plant is very drought resistant. Twenty immature fruiting forms and four mature capsules have been observed on one plant. A fully developed capsule has five locules with seven or eight seeds per locule. Each seed is covered with light-brown fibers that are closely appressed to it.

How long the boll weevil has been associated with *Cienfugosia* is unknown, but it seems probable that this insect may be able to maintain itself on some species of this genus and be entirely independent of cotton. The weevil infestation on *C. drummondi* plants growing on the Welder Wildlife Refuge may be an example of such a population. These plants were surrounded by mesquite trees and brush in a rangeland widely separated from cultivated land; however, they were found to be infested when examined during midseason. Collections of weevils in pheromone traps in the spring in these areas indicate that weevils can survive from one year to the next on hosts other than cotton.

Five additional species were found to be hosts of the boll weevil by Lukefahr and Martin. These were *Cienfugosia argentinia* Garcke and *C. sulphurea* (A. Gray), *C. hildebrandtii* Garcke of Africa, *Thespesia lampas* Cav. of Asia, and *Hampea sp.* of Mexico. Fryxell and Lukefahr postulate that the geography and ecology of the infested *Hampea sp.* trees in Veracruz, Mexico, suggest that they may be the long-sought primary host of the boll weevil. Large numbers can develop on one male tree.

In reviewing the hosts of the boll weevil other than cotton it seems that only Althea, (*Hibiscus syriacus*), *Thespesia populnea,* and *Cienfugosia* would pose much of a problem in an effort to eliminate the boll weevil as an economic pest from the United States. Insofar as Althea is concerned, it could be handled with regulatory procedures. Though homeowners may be reluctant to give up this ornamental, hopefully through education and information they could be persuaded to do so. Inspection of the many properties could be quite difficult. *Thespesia populnea* would be handled in the same way in the Lower Rio Grande Valley of Texas. *Cienfugosia* would pose some problem in a boll weevil elimination program. All colonies would have to be located and delimited. However, since infestations usually are light, they might be eliminated with release of sterile males or with pheromone traps or with a combination of the two techniques.

Thurberia Weevil

The Thurberia weevil (*Anthonomus grandis* var. *thurberiae* Pierce) was discovered by Dr. O. F. Cook of the Bureau of Plant Industry and the novelist, Harold Bell Wright, on Thurberia or "wild cotton" in the Arizona mountains in 1912. At first the boll weevil was thought to be breeding on a new host plant under climatic conditions where it had not previously been able to exist, and it was feared the weevils would spread to the large noninfested cotton areas of the West. Subsequent studies showed the Thurberia weevil was a variety or biological race of the boll weevil, difficult to distinguish from the true boll weevil.

Explorations were made to determine the distribution of the weevil and its host plant, and research on the biology, habits, and economic importance of the species was undertaken in 1913. These studies showed that the Thurberia weevil would readily attack cotton and would interbreed with the boll weevil. No commercial plantings of cotton were made at that time near the mountains where the weevils occurred, and the infestation was confined to Thurberia plants. However, an experimental planting of cotton became infested in 1914, indicating that the weevils would infest commercial cotton in the future. Following the development of irrigation, commercial planting of cotton was extended in the Santa Cruz Valley nearer the mountains, and in 1920 Thurberia weevils were found infesting cotton north of Tucson, Ariz.

In 1924 the State of Arizona attempted to establish a noncotton zone in the infested areas, but farmers took this matter to the courts and were granted a permanent injunction against it. The trial attracted much attention and disclosed the lack of entomological information on many of the issues involved. Since about 2 million bales of cotton, or about 15 percent of the U.S. crop was grown in the West where the boll weevil does not occur, the Bureau decided to obtain the much needed information on the importance of the Thurberia weevil. A laboratory was established in Tucson in 1925 to (1) delineate more thoroughly the range of the Thurberia plants and weevils in the United States, and (2) determine if the Thurberia weevil could maintain itself on cultivated cotton in the absence of Thurberia plants, and the damage it would cause to cotton.

An experiment was planned to rear the Thurberia weevil exclusively on cotton for at least 10 years to study any changes in its biology and habits. The study was to be made on a ranch isolated about 25 miles from any cotton or Thurberia plants. The work was delayed, however, as most of the weevils from the 1925 crop were used in working out fumigation and sterilization methods for use in movement of cotton products from the area to be quarantined. A Federal quarantine was promulgated in 1926, and the farmers filed suit to restrain the Department from enforcing it in the Marana district of Arizona. The case, which was finally won by the Department in 1928, was an important step in establishing the legality of Federal quarantines.

Detailed surveys in 1926 and 1927 and later studies showed that the Thurberia plants were found only in the mountains of eight counties in southeastern Arizona and Hidalgo County of southwestern New Mexico, while the weevil was limited to portions of the plant range in five counties in Arizona. Both the plants and the weevil also extended into Mexico, although the limits of distribution are not known.

Biological studies on the Thurberia weevil bred continuously on cotton for 10 years indicated that it was not likely to become a major pest of cotton in the *irrigated* sections of the Southwest. The weevils hibernate as adults within the pupal cells in old cotton bolls, and the necessary preplanting irrigation causes the weevils to emerge and die before cotton begins to fruit. Experiments extending over 4 years showed that agricultural practices used to produce the crop could eradicate the weevil in one year from cotton in the irrigated section not subject to reinfestation from Thurberia plants. Damage to commercial cotton plantings never was severe and occurred only where infestations occurred from Thurberia plants. Dispersal by flight is limited and the removal of infested Thurberia plants for 1 mile or more from cotton fields greatly reduces the infestation. Research, also, showed that the Thurberia weevil can be controlled with calcium arsenate.

A flareup in infestations in the 1960's caused renewed interest in research on the boll weevil. Results of the research substantiated much of the early data. It was determined that if "soca" or stub cotton was not grown in Arizona the problem would be eliminated or greatly minimized. State regulations now forbid growing stub cotton.

Bollworms

The bollworm is very generally distributed throughout the world and has been recorded as a cotton pest in the United States since 1820. Entomologists have devoted considerable attention to it since about 1854, and many early publications of the Patent Office and the Department deal with the bollworm.

The bollworm feeds also on corn, tomatoes, grain sorghums, peas, alfalfa, lespedeza, beans, soybeans, flax, peanuts, and many other plants. It is called the corn earworm on corn and the tomato fruitworm on tomatoes.

Development.—The bollworm has four stages in its development: Egg, larva, pupa, and adult. Only the larvae are destructive. Between spring and early fall, this insect produces 4 to 6 generations. The last generation remains in the pupal stage and passes the winter in the soil. For about a month in the spring, moths emerge from overwintered pupae. Moths are yellowish or brownish and have a wingspread of 1 to 1½ inches.

Female moths of the season's first generation lay eggs on clover, alfalfa, bluebonnets, winter peas, young corn, and other plants. Second-generation moths lay eggs on silks of young ears of corn, if they are available. If corn silks are not available, the second-generation moths lay eggs on other plants—on cotton in some areas. Third and later generations of moths (which often overlap) lay eggs on cotton.

On cotton, moths usually lay eggs on the tender, growing tips of plants and on the top sides of leaves. Sometimes they lay eggs on squares, bolls, and stems. Eggs, which are white, ribbed, and dome shaped, are about half the size of a pinhead. Larvae hatch from the eggs in 3 to 5 days.

Color of the larvae varies. It may be pale green, rose, brown, or almost black. Full-grown larvae are 1 to 1½ inches long. For a day or two after hatching, larvae feed on the nearest tender growth. Then, larvae on terminal buds of the cotton plant move downward; those on fruiting branches move toward the center of the plant. The larvae eat out the squares and tunnel into and eat the contents of the bolls. Mature larvae enter the ground and change into mahogany-brown pupae, from which moths emerge (fig. 4).

Research.—In connection with the boll weevil investigations, work on the bollworm started in 1903 at the Victoria, Tex., laboratory. This work was expanded in 1904 with headquarters at Paris, Tex.

Fortunately, most methods of control developed for the boll weevil were of value, also, against the bollworm. In the early investigations special attention was given to cultural methods, trap crops, and poisoning with paris green, the arsenical then in general use. Fall plowing of the land to destroy overwintering pupae and early maturity of the crop reduced infestations considerably. Investigations on the bollworm as a cotton pest were resumed in 1928 with headquarters at College Station, Tex. In 1939 the headquarters moved to Waco, Tex., and the work continued until June 30, 1973, when the laboratory closed. Work on the bollworm continued at other locations, however.

The bollworm is difficult to control because of the large number of wild and cultivated host plants and its habit of feeding within the squares and bolls, and because the damage extends over a long period. The larvae often are not sufficiently numerous at any one time on cotton to justify the expense of control yet the accumulative damage may be severe. Cotton is not the preferred host, and the abundance and succession of other crops such as corn, grain sorghum, cowpeas, vetch, alfalfa, and others from which the moths migrate to cotton are important factors in the damage caused to cotton.

The use of trap crops, especially corn, to prevent the early infestation on cotton was recommended but was not successful in actual use because of the reluctance of growers to destroy the crops sufficiently early to prevent maturity of the larvae. Studies of the factors attracting moths to cotton for oviposition have shown that the more succulent plants are favored for oviposition. Consequently, cotton on river bottom land that had been overflowed or had abundant moisture was usually the most seriously damaged. In control experiments with insecticides, the most important factor was the timing of applications so that the plants would be covered with insecticides when the larvae were hatching so as to kill them while they are small. The best early criterion for timing applications was egg deposition on plants. Treatments for control were recommended to begin when 25 to 30 eggs are found per 100 terminal buds. Unfortunately, egg counts are difficult to make and growers usually did not recognize the presence of injurious infestations until the bollworms were too large for successful control.

Tests were made with most of the common insecticides including arsenicals, pyrethrum, rotenone, sulphur, fluorine compounds, and others. Calcium arsenate or a mixture of calcium arsenate and paris green gave the best results. Cyrolite dust was not as effective for bollworm control on cotton as it was on lima beans. The most economical control on cotton was obtained by treating with 10 to 12 pounds of calcium arsenate per acre. Treating with hand-dust guns or ground machines that con-

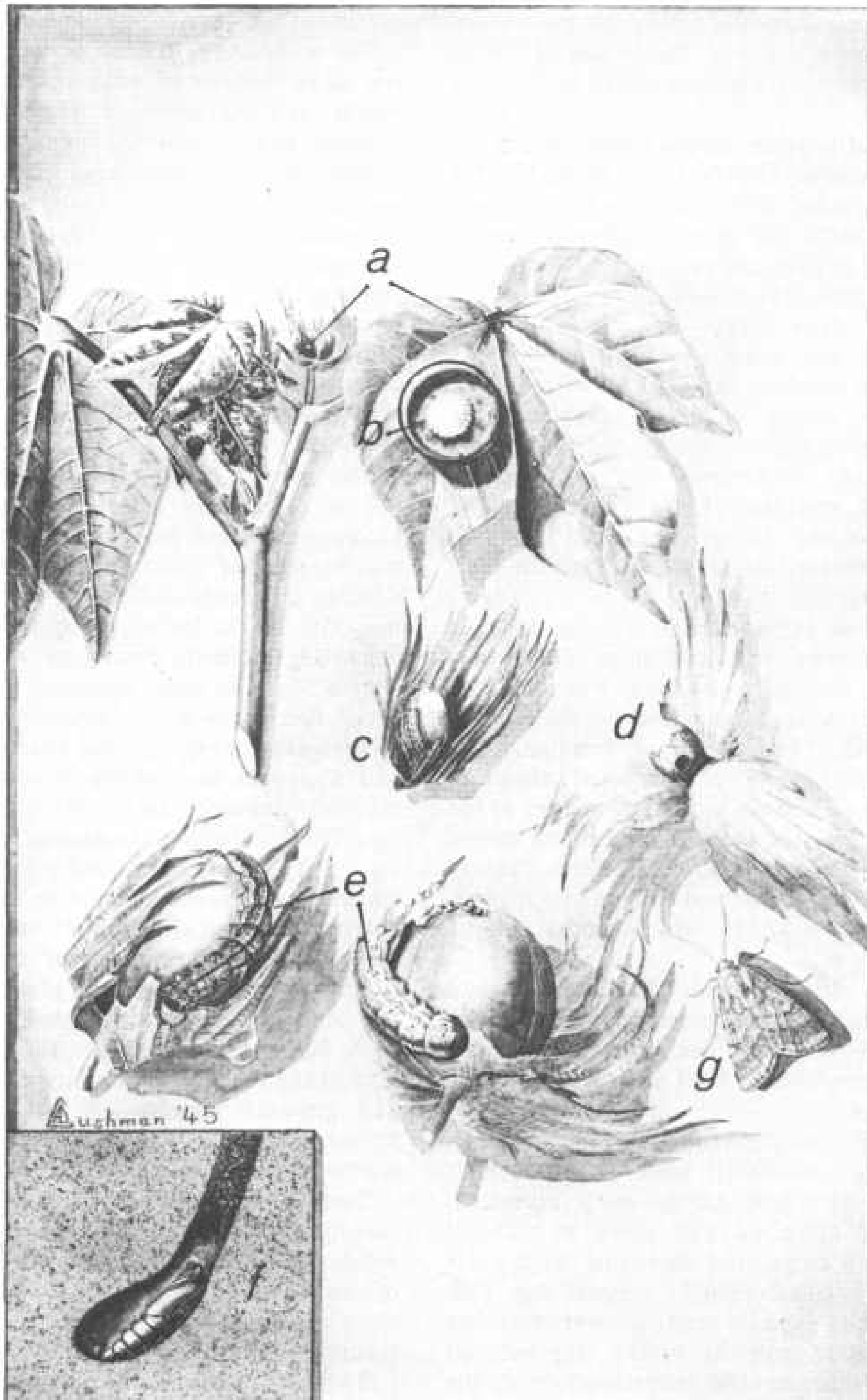

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Figure 4.—Bollworm and damage (a) eggs; (b) egg (15 times natural size); (c) young larva in square; (d) damaged square; (e) full grown larvae; (f) pupae in soil; (g) adult. (Eggs about 15 times natural size; other stages about natural size.)

centrated the arsenicals in the tops of the plants gave better results than aerial dusting, although thousands of acres were successfully treated by aerial dusting in the Brazos River bottom of Texas each year.

Naturally occurring predators and parasites often keep infestations of the bollworm at subeconomic levels. However, insecticides applied for the control of other insects, such as the cotton fleahopper and boll weevil, kill off the beneficial insects. Thus, continued use of protective measures is necessary until the crop matures and is no longer attractive to bollworms and tobacco budworms even though the target insect has been controlled.

In the 1940's organic insecticides such as DDT, toxaphene, endrin, methyl parathion, and carbaryl, and later monocrotophos were very effective. At the end of 1972, however, use of DDT on cotton was banned.

The tobacco budworm, *Heliothis virescens* (F.), which is even more difficult to control than the bollworm, did not become a serious pest of cotton until the 1960's. It developed resistance to available effective insecticides, creating a serious problem in several areas of Texas and Louisiana. The problem superimposed on other adverse factors resulted in abandoning cotton production in several localities in Mexico.

Cotton Aphid

The cotton aphid, *Aphis gossypii* Glover, occurs wherever cotton is grown. It was described by Glover in 1877 although he made previous references to an aphid observed on cotton in South Carolina, Florida, Georgia, and Mississippi in 1855 and in subsequent years. It attacks many plants in addition to cotton and is sometimes called the melon aphid because it is a serious melon pest.

Development.—The adult cotton aphid is a soft-bodied, sucking insect that ranges in color from light yellow to dark green or almost black. In the spring, it is dark green on the tender, growing leaves and terminal buds of cotton and about $\frac{1}{14}$-inch long. Later in the summer, it is usually found on the undersides of mature leaves and is light yellow and much smaller. In the fall, when plants often put on new terminal growth, the aphids are dark green to almost black, and about the same size as the spring aphids (fig. 5).

The cotton aphid multiplies rapidly under favorable conditions. Enormous populations may build up in a short time. New generations may occur every 5 days during summer months. Reproduction is slower and the lifespan longer during cold weather.

Only female cotton aphids occur in the Cotton Belt. They give birth to living young. As reproduction is continuous, generations are not distinct. These insects may spend part of the winter as winged adults, hibernating in field debris or in cracks in the soil. When warm periods occur, they fly to weed hosts on which they feed and continue to reproduce.

In the spring, winged adults develop on the weed hosts. They fly to cotton and melon plants, where they give birth to living young that develop into wingless females. Winged forms are produced on any host when crowding occurs or when food becomes scarce.

Males and females occur in the Northern States, where they feed on melons, cucumbers, and many other plants, both wild and cultivated. Females lay eggs that survive the winter and hatch in the spring.

This insect damages cotton by sucking juices from the plants, reducing both yield and quality, and often causes severe losses to growers. When heavy infestations occur on seedling cotton, the leaves curl or crinkle; plants become stunted and may die. This often happens in early spring, before natural enemies of the aphid become active.

When heavy infestations occur during the main fruiting period (from early bloom to full bloom), the older leaves turn yellow and shed, causing premature opening of bolls and immature development of fiber. Also, honeydew secretions from the aphids drop on the fiber, making it sticky. Often, a fungus develops in the honeydew deposits, causing the plants to appear black or sooty. Fiber picked from such plants is stained and sticky and of low quality; seeds are low in viability and lightweight.

The cotton aphid often is controlled by its natural enemies. It seldom increases to damaging numbers unless its natural enemies are killed or reduced to low numbers. When heavy

PN-4421

Figure 5.—Cotton aphid and damage (a) curled leaves; (b) aphids on under side of leaf; (c) aphids on stem; (d) honeydew on leaf; (e) winged female; (f) wingless female; (g) young. (Actual size depicted for a, b, c, and d; females and young, about 14 times actual size.)

infestations occur on seedling cotton in early spring, the cool weather prevents natural enemies from becoming active and numerous enough to control the aphids. When warm weather arrives, the natural enemies if left undisturbed, increase sufficiently to bring the aphids under control. However, severe damage may occur before natural enemies take over.

Research.—Use of calcium arsenate for boll weevil control was limited because of the buildup of cotton aphid populations following its use over wide areas (see p. 1). The only aphicide available was nicotine sulfate, which was expensive, difficult to apply, and effective only under ideal conditions. The new organic insecticides replaced calcium arsenate for boll weevil control; most organophosphorus compounds effectively control the cotton aphid.

Cotton Fleahopper

The cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter), was known as a cotton pest in local areas in southern Texas since about 1900, but its importance was not recognized until a serious general outbreak occurred in 1923 over a rather large area. The fleahopper is generally distributed over the Cotton Belt but causes the most serious damage in the Blacklands of Texas where it is often more injurious than the boll weevil.

Development.—The cotton fleahopper has three life stages—egg, nymph, and adult. In the fall, adult females lay eggs in weeds, usually in stems of croton. This plant, known as goatweed, is common throughout the Cotton Belt. The cotton fleahopper overwinters in the weeds, in the egg stage.

The eggs hatch in early spring. Newly hatched nymphs, which are about one twenty-fifth of an inch long, are white and translucent. After feeding they become pale green. They have prominent, scarlet-colored eyes. Nymphs progress through five instars before becoming adults. The last nymphal stage resembles the adult but does not have fully developed wings.

Adult cotton fleahoppers are about one-seventh of an inch long and are winged. They are pale green with small, dark spots on the body and four black marks near the wingtips.

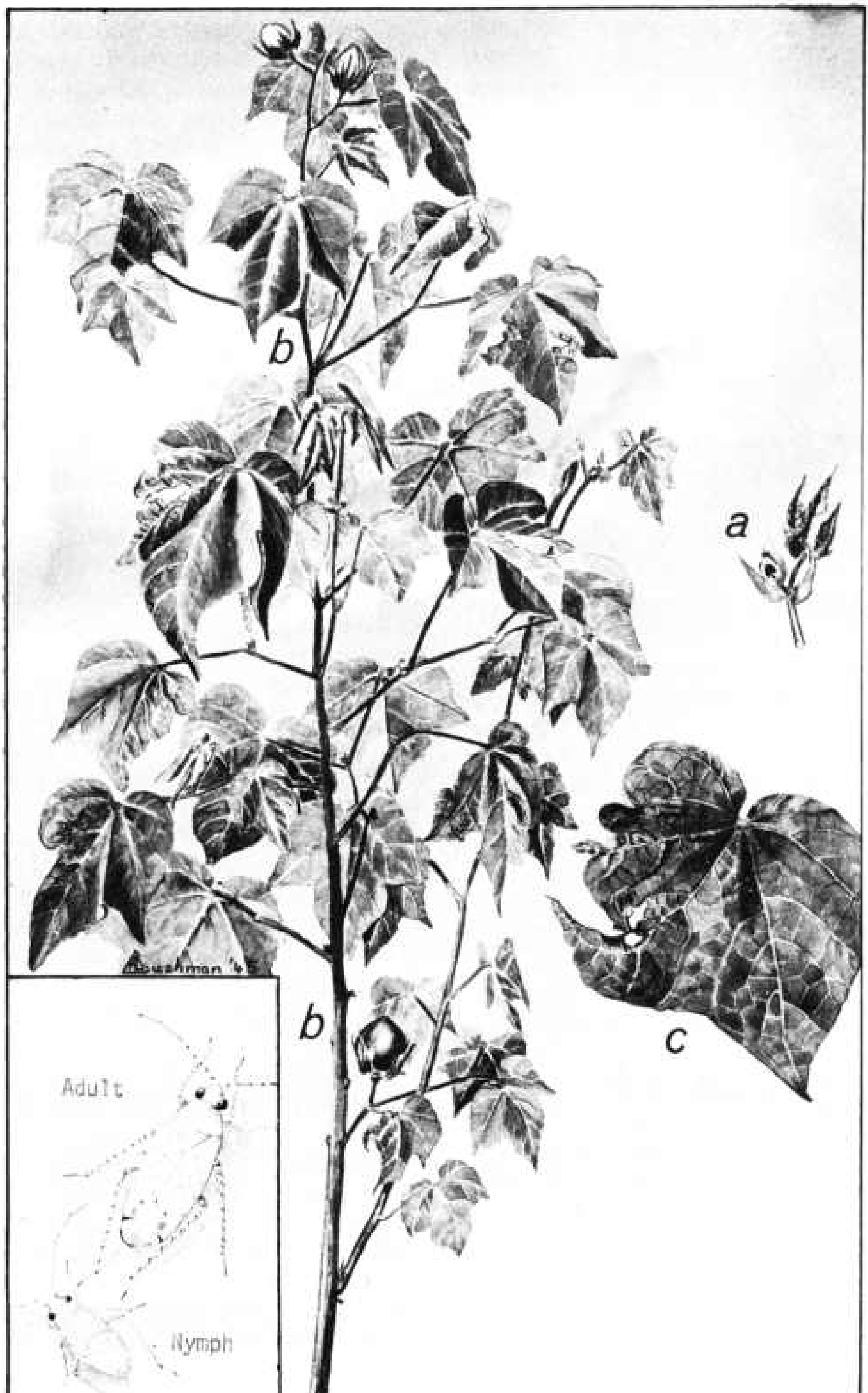
These insects feed and reproduce on tender weeds, such as evening primrose and horsemint. As the weeds mature and become less juicy, adults fly to cotton plants, which are usually in the presquaring or early fruiting stage. The pests stay on cotton as long as the plants are succulent. When cotton becomes tough, the fleahoppers generally leave it and go to croton and other weeds to feed and lay eggs. This insect may produce six to eight generations in a season. Cold weather kills both adults and nymphs.

The cotton fleahopper injures the entire cotton plant by feeding on juices from the tender parts. Leaves become ragged and deformed. Squares turn brown or black and are shed when they are the size of a pinhead. Heavy infestations of fleahoppers restrict the growth of fruiting branches. Vegetative branches may develop abnormally in length or in number. Affected plants often grow tall and whiplike (fig. 6).

If the cotton fleahopper is not controlled early in the season, fruiting is delayed. Cotton plants then may be attacked for a longer time later in the season by other insects, particularly by the boll weevil, bollworm, and pink bollworm.

Research.—Investigations started in south Texas on the biology, host plants, and control measures soon after the outbreak in 1923. These were followed by more detailed studies at Tallulah, La., of the habits of this and other species of mirids and their effect on the plant tissues. In 1933 a laboratory was established at Port Lavaca, Tex., to develop control measures for the cotton fleahopper. In the earlier Texas work sulphur had been used with fairly good results, but the details of application had not been worked out.

Extensive cage and field tests with many insecticides showed that sulphur was the most effective insecticide against the nymphs, but that a mixture of sulphur and an arsenical was more effective and gave quicker kill of the adults. Mixtures of paris green and sulphur (1 part to 13 parts) or calcium arsenate and sulphur (1 part to 2 parts) were almost equal in effectiveness against the fleahopper, but the calcium arsenate-sulphur mixture was recommended because it was somewhat cheaper and was also effective against other insects such as the boll weevil and cotton leafworm that usually occurred at the same time. Calcium arsenate



PN-4422

Figure 6.—Cotton fleahopper and damage (a) blasted square; (b) whiplike plant and lack of fruit resulting from blasted square; (c) injured leaf. ((A) and (c) actual size; (b) about one-fourth actual size; adult and nymphs 15 times natural size.)

and paris green alone killed a high percentage of fleahopper adults, although it was not determined how arsenicals kill these sucking insects. Results of field tests over a number of years showed that from 2 to 3 applications of 15 pounds per acre of the calcium arsenate-sulphur mixture gave good increases in yield in the Port Lavaca, Tex., area. The development of the arsenical-sulphur mixtures was the most popular control used for cotton insects since the discovery of calcium arsenate for the boll weevil. Large quantities of the mixtures were applied both with ground-dusting machines and airplanes. In Calhoun County, where most of the experiments were conducted, over two-thirds of the cotton acreage was treated with power dusters, primarily for fleahopper control.

Attention was also given to cultural methods of controlling the fleahopper since the insect overwinters in the egg stage in the stems of plants with approximately 99 percent overwintering in the stems of croton or "goatweed." In the winter of 1933, croton on 10,000 acres of ranchland in Calhoun County, Tex., was destroyed through a Civil Work Administration grant. The following spring practically no fleahoppers were found on cotton until a heavy migration of adults occurred. Results showed that fleahoppers migrated for at least 20 miles and that destroying croton would not be a feasible method of control.

In the spring of 1939, the Cotton Fleahopper Laboratory was moved from Port Lavaca to Waco, Tex., where this work was combined with that conducted at College Station, Tex., for the bollworm. A sublaboratory was maintained in Port Lavaca, however, until 1942.

The cotton fleahopper continues to be considered a key pest of cotton in many areas of Texas because treatment for control in the early fruiting stage often results in increased subsequent infestations of the bollworm and tobacco budworm. Beneficial insects that often keep the bollworm complex infestations below economic levels are killed off by the treatment for control of cotton fleahoppers, necessitating the continued use of protective measures until the crop matures and no longer is attractive to bollworms and tobacco budworms. The bollworm complex problem often can be avoided if treatment for cotton fleahoppers is needed in the early fruiting stages of the cotton plants. Treating in the early fruiting stages permits the reestablishment of beneficial insect populations before injurious bollworm complex infestations occur. This can only be done if horsemint matures early enough to result in migration of cotton fleahoppers to cotton by that time.

Cotton Leafperforator

As a result of the severe cotton losses in the Yuma and Imperial Valleys in 1925 from the cotton leafperforator (*Bucculatrix thurberiella* Busck), a substation of the Tucson, Ariz., laboratory was established at Calexico, Calif., in 1926 to investigate this insect. Very little information was available, and the work during 1926 and 1927 was devoted largely to life history studies reported but not published.

Work was resumed in 1930 to 1932 with particular attention to practical control methods, and while control measures were not satisfactorily worked out, considerable information was available. Barium fluosilicate was the most satisfactory insecticide used, and eliminating soca or stub cotton was valuable in reducing the overwintering populations.

Development.—Eggs of the perforator are laid on both the upper and lower leaf surfaces, with an occasional one being placed on a petiole. The extremely small, whitish, elliptical egg is attached to the leaf by one end with the longitudinal axis then being perpendicular to the leaf surface. The incubation period averages about 2.25 days under greenhouse conditions of 70° to 90° F. The first instar larva emerges directly through the attached end of the egg and into the leaf, thus becoming a leaf miner. The first three instars are spent mining through the leaf, feeding primarily on the palisade tissue. A larva seldom crosses a main leaf vein, and avoids gossypol glands. The feeding channels are most readily visible on the upper surface of the leaf, becoming progressively wider with each of the two subsequent mining instars. The duration of the first three instars (mining stages) averages 3.45 days (fig. 7).

After completing the third instar, the larva emerges from within the leaf and begins the

PN–4423

Figure 7.—Third-stage larva of the cotton leafperforator, almost full grown, feeding upon a cotton leaf (natural size). Two mines, one large and one small, can be seen in the leaf. The large mine is empty; the small one contains a miner, or first-stage larva, which is busily extending the large end of the mine.

fourth stage, feeding on the leaf surface. During the feeding of the fourth and fifth instars, the larva eats only to the opposite epidermis. Feeding occurs on either upper or lower surfaces, but during daylight hours the larvae generally feed on the lower surface of the leaf. When disturbed, both fourth and fifth instar larvae wriggle vigorously, usually dropping from the leaf on a silken thread and returning when the disturbance is over.

At completion of the feeding stage of the fourth instar, the larvae spins a weblike cell on the leaf surface and assumes a "horseshoe" shape during this resting stage. The duration of the fourth instar is 2.1 days, 1.0 day in the feeding stage and 1.1 days in the resting stage. After molting, the fifth instar larvae emerges from the cell and feeds on the leaf surface, as in the fourth instar, until mature. This requires about 2.6 days.

The fully grown fifth instar larva then spins an elongate silken cocoon. This may be on the leaf but is usually elsewhere such as on a main branch, dead leaves on the ground, or even in the soil. The pupal period averages 1.7 days.

The moth that emerges from the cocoon is about one-fifth inch long and covered with whitish scales with a few black or brownish spots. The head is concealed by a tuft of white hairs on the upper surface. After a preoviposition period of 4 days, the females begin laying eggs.

Adult activity occurs at twilight or after dark. Eggs are laid singly and usually near a leaf vein. The egg is white but darkens before hatching. The newly hatched larva (leaf miner) usually feeds in a tight circle before initiating its meandering course through the leaf. The first external feeding stage (fourth instar) spends less time feeding and does relatively little damage as compared with the fifth larval instar. The fifth instar does considerably more feeding in a single spot, thus creating larger "windows" in the leaf. As this stage completes development, it usually becomes restless and leaves the leaf in search of a suitable place to spin its cocoon.

One difficulty in controlling this insect with insecticides appears to be related to the disproportionate amount of time that the insect spends in protected areas. For example, the life cycle (egg to egg) in the greenhouse required 21.5 days. Only 3.6 days were spent as an exposed, feeding larva.

Research.—With the advent of the organochlorine insecticides, the cotton leafperforator rarely became a problem. However, when these insecticides were replaced by the organophosphorus insecticides because of resistance, the problem intensified and occurred, also, in far west Texas and in the Lower Rio Grande Valley. Research on the pest was resumed by the Arizona Agricultural Experiment Station and the ARS Western Cotton Insects Laboratory in the 1970's. Field tests for the evaluation of insecticides for its control were conducted, also, in the Lower Rio Grande Valley by the Texas Agricultural Experiment Station and the ARS Southwestern Cotton Insect Investigations Laboratory.

Cotton Leafworm

Though the cotton leafworm, *Alabama argillacea* (Hübner), is now considered to be a pest of little or no economic importance, it was a major pest in the early days and received equal billing with the bollworm in Professor J. H. Comstock's report in 1879 (*18*). He stated:

> The first appearance of the cotton worm in this country now on record was in 1793 in Georgia and South Carolina after cotton had been grown for 150 years.

It was recognized as the first serious pest of cotton.

The cotton leafworm is a tropical species that does not overwinter in the United States. Every year the moths migrate into this country from Central or South America or from Mexico. Each year since 1922 cotton leafworm larvae first have been found in southern Texas, usually in May but in some years in April, June, or July.

The cotton leafworms spread out from southern Texas. Usually by the end of a cotton growing season, they are present in every cotton-producing State from Arizona eastward. Larvae never have been reported in California or Nevada.

Before the organic insecticides came into general use in the late 1940's, the cotton leafworm often was one of the most destructive cotton pests. In outbreak years, supplies of insecticides, largely calcium arsenate, used in control were usually exhausted before the end of the season. Since then, the widespread use of organic insecticides for the control of other cotton insects in southern Texas usually delays population buildup so that migration to other areas occurs too late to be of much importance.

In the years before and through World War II, first findings of the pest in the United States were of considerable significance. Usually economic damage and migration to other areas could be expected from later generations. The planting period of the cotton crop in Texas ranges from February 1 in the Lower Rio Grande Valley in the extreme southern tip into June on the High Plains. Thus, population buildups in southern areas often resulted in injurious infestations in all other areas of the State as well as in Oklahoma and other States as the cotton-growing season progressed. Tremendous amounts of insecticides were often required to prevent defoliation of the crop by the pest. It was of utmost importance that industry be prepared to make sufficient quantities of insecticides available to meet the growers' needs.

Development.—The cotton leafworm has four stages in its life cycle—egg, larva, pupa, and adult.

The female moth lays bluish-green eggs, singly, on the undersides of cotton leaves. They hatch in 3 or 4 days. Newly hatched larvae are pale, dingy yellow. They feed only on the undersides of leaves.

There are five larval instars. In the summer the larvae usually become full grown in about 2 weeks and are about 1½ inches long. Their color varies with some being yellowish green, without prominent stripes, while others have a broad, black stripe and a fine central yellow stripe down their backs. All cotton leafworm larvae have a distinguishing characteristic—on the top of each segment are four black dots that form a square.

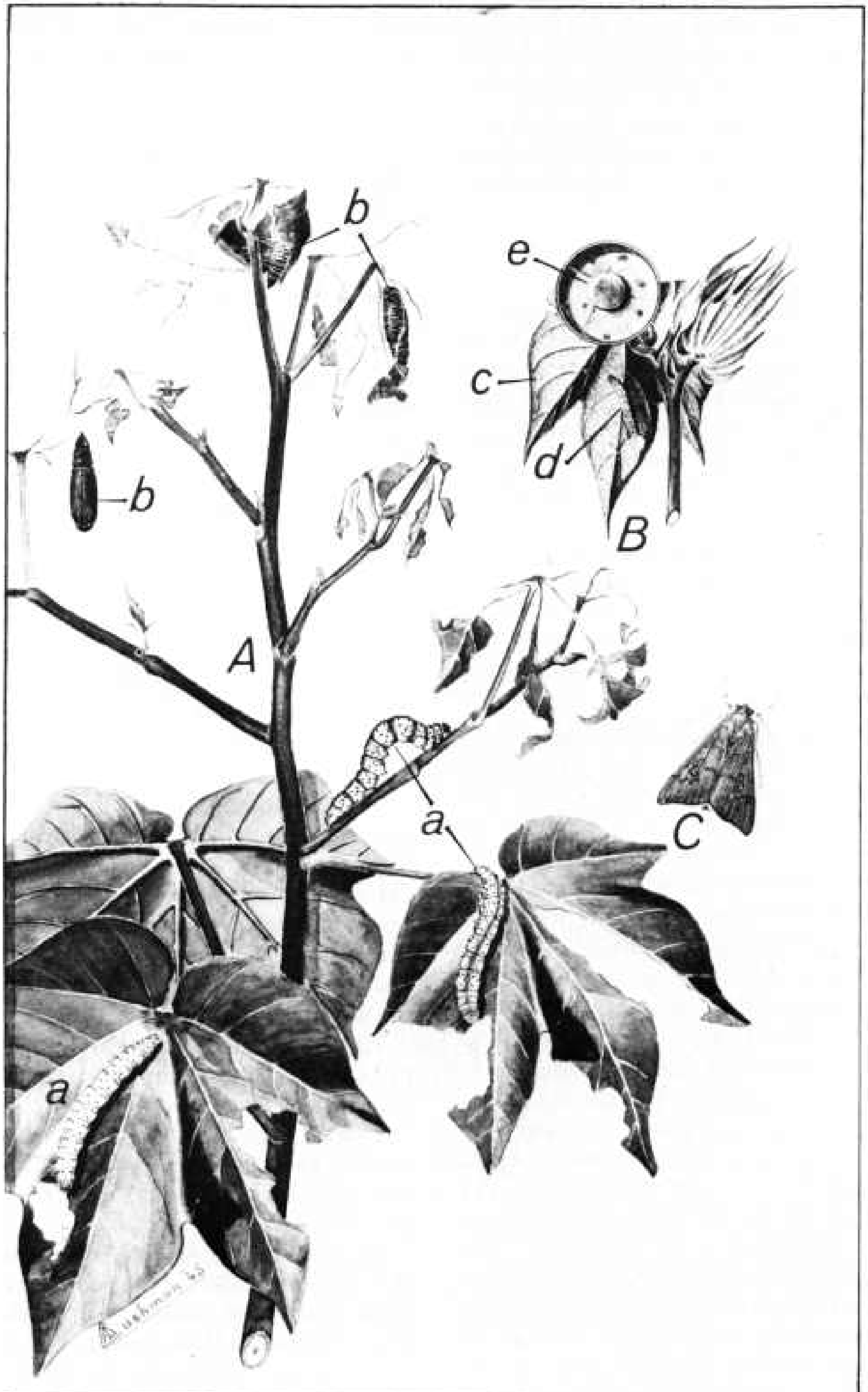
When a larva has completed its feeding, it "webs up" in the fold of a leaf and becomes a pupa. Other larvae may eat away the leaf, leaving the pupa hanging by a thread from the leaf vein or stem (fig. 8).

The pupal stage lasts about 1 week in midsummer, but it may last up to 4 weeks in the fall. The moth, which is olive tan, has a wingspread of about 1½ inches. It is a strong flier and, frequently, is found in the northernmost States and in Canada. In these areas, it feeds on ripe fruits, such as peaches, grapes, and cantaloups.

The life cycle of the cotton leafworm is completed in about a month with two to eight generations in a year.

Female cotton leafworm moths lay their eggs only on cotton in this country. However, in the mid-1960's *Hampea* sp. was discovered as a host in Mexico.

Damage is first evident when the leaves start to appear ragged. Larvae feed between the main veins and often skeletonize the leaves. When leaves become scarce, the larvae eat the bracts surrounding the squares and bolls. Finally, they may gnaw into the bolls. There is a characteristic, pungent odor in infested fields. Early infestations, if not controlled, prevent bolls from setting.



PN-4424

Figure 8.—Cotton leafworm (actual size stages): *A*, Damaged branch; (a) full-grown larvae; (b) pupae; ***B***, terminal bud with (c) eggs; (d) young larvae; (e) eggs (15 times natural size); *C*, adult.

Leafworms may cause defoliation before the crop is mature. Then some young bolls shed; older bolls open prematurely; and the quality of both fiber and seed is lowered. Lint often is stained by excrement from the larvae. Leaf skeletons become entwined in the lint and are difficult to remove.

The cotton leafworm has many natural enemies that help control it. Birds, wasps, ants, spiders, beetles, robber flies, mantids, and aphis lions are among the predatory enemies.

It has an egg parasite and several pupal parasites. Hot, dry weather causes many leafworm eggs to dry up, and the unhatched larvae die. Diseases often destroy leafworm larvae.

Research.—In the early years materials used for the control of this pest were mixtures of paris green or london purple with lime or flour applied primarily with the pole and bag method. The author as a small boy in Texas in the early 1920's observed his father controlling cotton leafworm infestations many times with paris green applied with the pole and bag method from his best saddle horse. This was usually done early in the morning or late in the afternoon with a slight cross breeze, if possible. Lead arsenate applied as a high volume spray was popular and effective. When calcium arsenate was developed in the 1920's, it was also found effective against cotton leafworms and was used to control this pest until the organic insecticides were developed in the mid-1940's.

Lygus Bugs

Lygus bugs are the principal insect pest of cotton in western areas of the United States. They are especially destructive where extensive alfalfa hay and seed crops are produced near cottonfields and where large pasture areas dry up in early summer. In the South lygus bugs often become abundant on weeds and leguminous crops and may move to nearby cotton and cause severe damage.

Development.—*Lygus hesperus* Knight is the predominant species in western areas; *L. lineolaris* (Palisat de Beauvois), known as the tarnished plant bug, is prevalent in the South. Other species of lygus bugs damage cotton, but usually they are of minor importance.

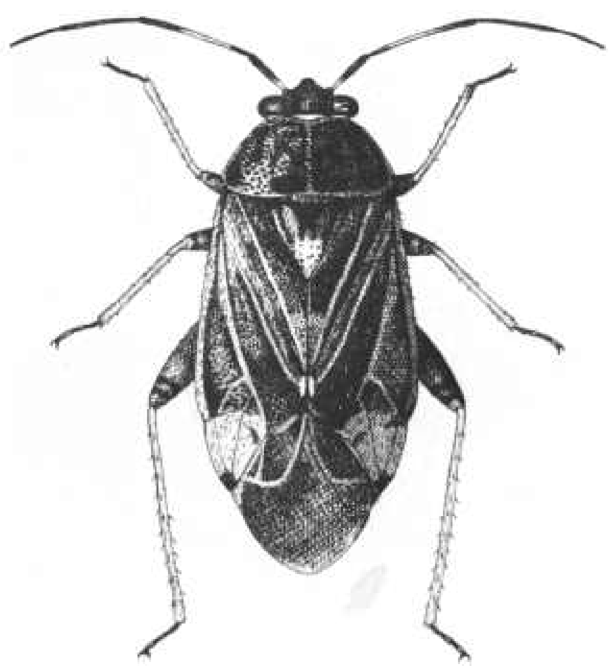
Lygus bugs develop in three stages—egg, nymph, and adult. Female adults use their swordlike ovipositors to lay eggs in plant tissues, particularly in stems and leaf petioles. Eggs are tiny, elongate, and slightly curved.

Nymphs develop through five instars before becoming adults. The life cycle is completed in about 4 weeks in summer with a longer time in other seasons.

Adults are flat and about one-fourth inch long. They range in color from straw green to dark brown and have a conspicuous lighter colored triangle between the wings (fig. 9).

When disturbed by the cutting of a host crop such as alfalfa, or when the plants are no longer attractive as food, adults fly to another host crop. They hide in plant foliage during the day when the weather is hot.

Lygus bugs feed by inserting their long, needlelike mouthparts into plant tissues and sucking out the juices. On cotton, they attack the tender terminal growth, squares, flowers, and young bolls. Injured squares and small bolls usually shed. Injured bolls that do not



PN-4425

Figure 9.—Adult lygus bug.

shed may open abnormally and produce inferior lint that clings to the warty carpels that result from lygus feeding.

Lygus damage reduces the yield. It causes the lint to be spotted and lower in grade. Injured plants develop abnormally, becoming tall and whiplike, with fewer fruiting branches (fig. 10).

In western areas of the United States, lygus bugs may develop on weeds such as wild mustard. They develop large populations on alfalfa, especially when the alfalfa is grown for seed. When lygus bugs infest an alfalfa hay crop, they have time to produce one generation between cuttings. The crop is cut several times in a season and is a constant source of infestation for cotton. An alfalfa seed crop requires at least 60 days before the seeds are mature and ready to harvest. This allows time for two or more generations of lygus bugs to develop in very large numbers. If uncontrolled, they may destroy the entire seed crop.

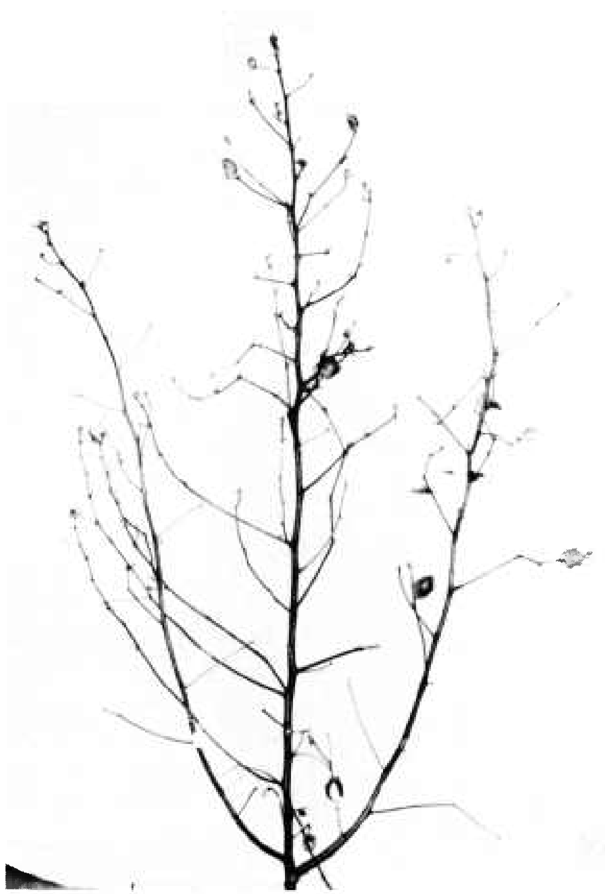


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Figure 10.—Damage to cotton plant exposed to lygus bugs for 7 weeks in a field cage.

Lygus adults leave alfalfa soon after a seed crop matures or a hay crop is cut. If cotton is growing nearby, the pests may move to it in large numbers and gradually disperse over the entire cottonfield. If other alfalfa is growing in the vicinity, they may move into it in preference to remaining in the cotton.

In southern areas, alfalfa and other legumes may serve as hosts for lygus bugs. Weed hosts, however, are more often responsible for the lygus populations that move to cotton. The more important weed hosts are butterweed, fleabane, goldenrod, aster, and dog fennel. When weed hosts mature or become otherwise unsatisfactory for feeding purposes, lygus bugs usually migrate to cotton if it is growing nearby.

Research.—Work on the biology and control of lygus bugs was conducted in Louisiana and in Arizona in the 1930's. Mixtures of calcium arsenate or paris green and sulphur gave effective control but were replaced by the new organic insecticides in the 1940's. Lygus bugs are key insect pests as insecticides applied for their control often result in subsequent injurious infestations of the bollworm complex necessitating continued treatment until the crop matures and is no longer attractive to bollworms.

Pink Bollworm

The pink bollworm, *Pectinophora gossypiella* (Saunders), was described in 1843 from specimen collected in India in 1842 and is probably indigenous to that country. It was reported as a serious pest of cotton in 1904, when it caused damage in what was then known as German East Africa. It has since become the most injurious insect pest of cotton in many cotton-growing regions of the world. Potentially, it is a serious pest of cotton in the United States. Quarantine regulations and cultural and chemical controls have reduced economic damage in most years in the infested areas of this country and have retarded the spread of this insect to new areas.

The pink bollworm was introduced into Mexico in 1911 through importing infested cottonseed from Egypt for planting and into the United States in 1916 in cottonseed from Mexico for milling. The pink bollworm was first found in Texas at Hearne near an oil mill that had received seed from Mexico.

Research on the pink bollworm first started in Hawaii. In February 1918, the Department established a laboratory for pink bollworm research at Lerdo, Durango, Mexico, where the insect populations were sufficient for such studies. The work in Mexico was interrupted late in 1919 until early 1921 and then resumed at Tlahualilo, Durango, until April 1925. At that time the Tlahualilo laboratory closed because infestations in southwestern Texas had built up to the extent that work on the pest could be conducted there.

In July 1927, headquarters for research on the pink bollworm by the Department was established at El Paso, Tex. Since that time, other Federal laboratories in Texas have conducted research in cooperation with the Texas Agricultural Experiment Station.

The first experiment conducted with the insect in this country began in the fall of 1927 at Castalon, now in the Big Bend National Park. A laboratory staffed by both Texas and Federal personnel was established at Presidio in April 1928, and it became headquarters for this work in 1933. In August 1928, a sublaboratory of the Presidio laboratory resumed work at Tlahualilo, Mexico, where it was operated until 1936. A sublaboratory established at Brownsville in 1939 became the headquarters laboratory in 1941. Then, the Presidio station became a sublaboratory and was operated as such until it closed in 1947. A sublaboratory was operated at Ysleta, El Paso Valley, from the fall of 1944 until the spring of 1952 and another at San Benito from 1944 to 1951. Later sublaboratories were operated at Lubbock and Port Lavaca, both from 1953 to 1956. Some phases of the work, coordinated by the Brownsville laboratory, were carried out by personnel of the cotton insect laboratories at College Station and Waco from 1954 to 1957 and 1954 to 1962, respectively. In 1965 a new laboratory was established at Phoenix, Ariz., to conduct research on the pink bollworm.

Although the infestation at Hearne, Tex., was eradicated, the insect later crossed the Rio Grande from Mexico into Texas, and its occurrence has been general throughout the State. Since 1952, this pest has caused considerable damage to cotton periodically in southern, central, and parts of western Texas. In 1958 and 1959 it caused heavy damage on some acreages in the El Paso Valley of Texas.

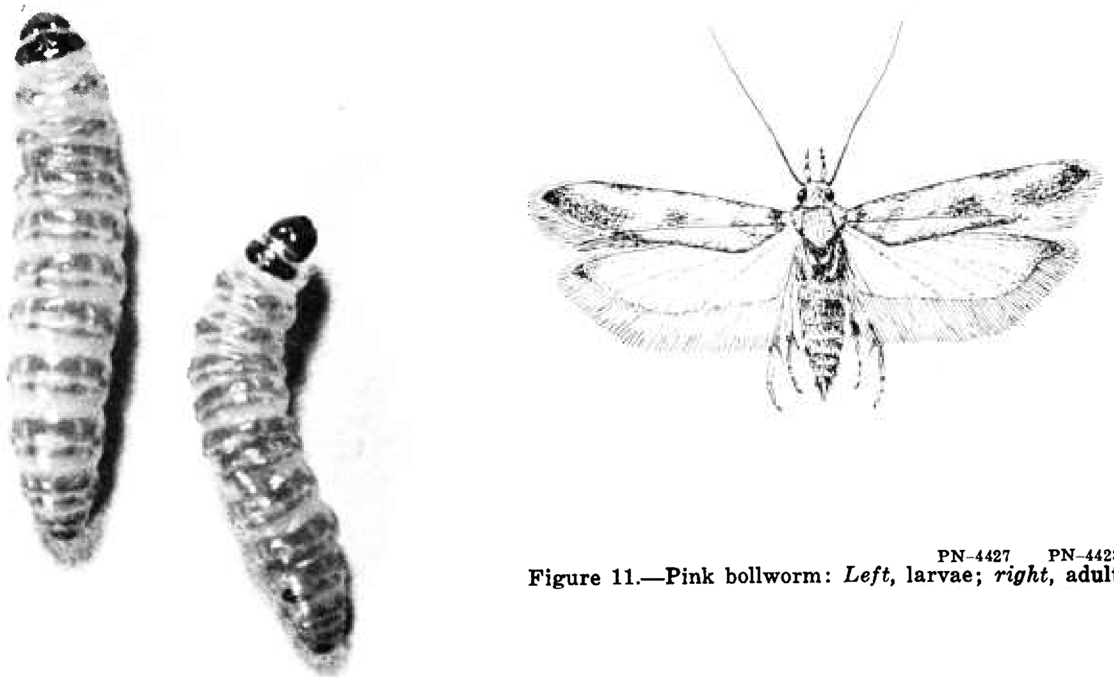
The pink bollworm soon spread to other States. General infestations have occurred throughout Oklahoma and New Mexico. Infestations in some parts of Louisiana and Arkansas have been light.

Since 1940, the pink bollworm has caused heavy cotton losses in some areas of Arizona. In 1958 and 1959, severe outbreaks of the pest occurred in the Gila Valley and in the Salt River Valley of that State, and extended into Pima County. In these same years—1958 and 1959—this insect caused serious cotton losses in some parts of the Mesilla Valley of New Mexico. In the 1960's, it became a serious pest in the Imperial and Coachella Valleys of California.

Development.—The pink bollworm has four stages of development: Egg, larva, pupa, and adult (fig. 11). Adults are small, grayish-brown moths with a wingspread of about one-half inch. The average life of the adult is about 2 weeks.

Early in the cotton season, females lay eggs on cotton stems, squares, and terminal buds. When green bolls are present, they usually lay most of their eggs in masses beneath the glovelike calyx at the base of the bolls. A moth lays 100 to 200 eggs, which are white and oval. In 4 to 5 days, the eggs hatch into larvae. Newly hatched larvae are glossy white and have light-brown heads. They eat their way into squares or bolls, where they feed 10 to 14 days. At the end of this period they are light cream, and about one-half inch long. They have fairly well-defined, transverse bands of mottled pink on the dorsal side.

Larvae feeding in squares usually complete development by the time the bloom opens and



PN-4427 PN-4428
Figure 11.—Pink bollworm: *Left*, larvae; *right*, adult.

rarely damage the developing boll. These larvae produce the typical rosette bloom that is readily recognized. Many of these larvae drop to the ground and pupate in cracks in the soil or in surface trash. A few remain in the bloom until it sheds. Occasionally, a square or young boll may shed as a result of feeding injury.

Larvae in bolls feed on the seeds. When a larva has finished feeding in a green boll, it either cuts a small hole through the carpel wall and drops to the ground to pupate or remains in the seed in which it completed feeding.

A larva that remains in the seed may hibernate in a single seed, or it may pull two hollowed-out seeds together and unite them by spinning a continuous cocoon within the two cavities. Seeds thus united are called double seeds. They become apparent after ginning and usually are an indication of the presence of the pink bollworm.

The larvae change to pupae, and the pupae transform to moths. In 3 or 4 days the female moths begin laying eggs. The moths are active only at night. In the daytime they stay under trash or clods of dirt or in cracks in the soil.

In midsummer the pink bollworm completes its life cycle in 25 to 30 days. As many as six generations may occur in a year.

Pink bollworm damage to cotton is caused by feeding of the larvae (fig. 11, *left*). Only minor damage results when larvae feed in squares, since blossoming is not hindered and the resulting young bolls usually are not damaged.

Severe damage occurs when larvae feed within the bolls, moving from one seed to another and eating out the kernel of each. This causes a loss of seed viability, and a reduction in the volume and quality of oil. Some bolls—often a high percentage of late-produced bolls—are damaged so severely that they are unpickable and therefore are a total loss.

When larvae feed within the bolls, they cut and stain the fibers resulting in low-grade lint. Fibers so damaged, when mixed with undamaged lint in the harvesting and ginning processes, reduce the average grade of the crop.

Some larvae may leave the bolls to pupate or hibernate by cutting exit holes in the carpels. This increases damage because a single hole permits entrance of moisture and disease organisms that cause boll rot. In fields heavily infested by the pink bollworm, boll damage may be so severe that the cotton may not be worth harvesting.

Control with cultural practices.—The pink bollworm is the only major cotton insect that passes the winter in cotton or okra residues left in the field after harvest, or in cottonseed and seed cotton taken from the field.

Many larvae left in the field in crop residue can be destroyed by using recommended cultural practices. To be more effective, cultural practices should be used as a community, county, State, or regional program and followed by every grower in the control area.

Control of the pink bollworm can be made more effective if other insects are controlled and if other sound production practices that promote rapid, early setting, and maturity of fruiting forms are used. Early bolls escape severe damage because they mature before the pink bollworm infestation builds up to its seasonal maximum intensity.

A thick, vigorous stand will hasten maturity and increase the efficiency of mechanical harvesting. Seed should be treated with fungicide, the variety of cotton recommended for an area should be planted, and a suitable fertilizer should be used. In a generally infested area, the insecticide-control practices recommended for that area in the State guide should be followed. At the proper time, chemical defoliants or desiccants to speed up harvest should be used.

Cotton should not be irrigated late in the season to prevent late-season generations of pink bollworms (and boll weevils, if they are present) from going into winter hibernation.

The possibility of a high winter carryover of the pest, plus the cost of additional insecticide applications, usually makes the production of a late top crop unprofitable to the cotton grower. The production of a top crop of bolls with resultant fall breeding of the pest seriously jeopardizes the efforts to suppress or eliminate the pink bollworm, and may greatly increase damage the following year.

Cotton should be produced in the shortest time possible and harvested promptly and completely. Most larvae in cotton taken to gins are destroyed in the ginning process, but approved sanitation practices should be followed to prevent carryover in waste cotton on the gin premises. Clean harvesting reduces the number of larvae left in the field.

Stalks should be cut promptly after harvest with a power-operated shredder (fig. 12). The flail-type shredder is preferred. It is quite effective in killing pink bollworms, and it spreads the residue evenly on the ground, thus aiding plow-under efficiency (fig. 13).

Crop residue, including infested material knocked to the ground at harvest, should be plowed under promptly to a depth of at least 6 inches—the deeper, the better.

Prefrost stalk destruction increases winter mortality of the pink bollworm. It reduces the pest's reproduction in the fall, sometimes by two or three generations.

Fields left fallow or unplowed in fall or winter should be plowed early in the spring. Survival of the pest is highest in bolls lying on the ground. In areas that have sustained low temperatures, high mortality occurs in bolls on standing stalks.

Soil moisture helps to kill pink bollworms. So in cold, arid climates, fall or early winter plowing of the dry soil may not be as effective against pink bollworms as it is in other climates. Under arid conditions, irrigation after winter plowing increases mortality of the pest.

Many pink bollworm moths from overwintered larvae emerge early in the spring and die before cotton squares become available for their reproduction. Thus, the degree of infestation can be influenced by the date of planting. Extremely early, scattered plantings attract moths emerging from hibernating larvae in surrounding fields; therefore, heavy infestations occur in these early plantings. When early plantings mature, the moths emerging in them migrate to later fruiting, more attractive cotton.

Usually, late plantings are severely damaged because moths migrate into them in large numbers. The potential overwintering population is increased because an abundance of green bolls are available for pink bollworm development after the early and intermediate plantings have

PN-4429

Figure 12.—Horizontal blade stalk destruction machines.

matured. An increase in the number of pink bollworm generations results when cotton is planted over a long planting period. Then, the increased population of the pest causes increased crop damage. Because of this, cotton should be planted within a short, uniform planting season for a given area. Planting should not be started until near the time when soil temperature becomes favorable for rapid seed germination and seedling growth. This is considered the best planting time whether or not an insect problem is present.

Control with insecticide.—For many years after it first appeared as a cotton pest, nothing was known of how to control effectively or eliminate the pink bollworm. Today, cultural methods of control can be effectively supplemented in either control or eradication programs by properly timed and adequate applications of insecticide. Effective insecticides did not become available until the organic insecticides were developed in the 1940's.

Research.—A detailed discussion of the research on the pink bollworm is given in "Fifty Years of Research on the Pink Bollworm in the United States" (*78*).

Spider Mites

Spider mites attack many plants. A number of species of these pests attack cotton, and often cause serious damage. The most important ones are carmine spider mite, *Teranychus cinnabarinus* (Boisdval); desert spider mite, *T. desertorum* Banks, *T. lobosus* Boudreaux; pacific spider mite, *T. pacificus* McGregor; schoene spider mite, *T. schoenei* McGregor; strawberry spider mite, *T. turkestani* Ugarov and Nikolski; tumid spider mite, *T. tumidus* Banks; and two-spotted spider mite, *T. urticae* Koch and *T. ludeni* Zacker.

The mites, which are barely visible, are red, green, orange, or straw colored. Usually, they are kept under control by weather, beneficial insects that kill the mites, other species of mites that prey on them, and disease (fig. 14). Outbreaks of spider mites are most likely to occur following application of a pesticide that destroys the beneficial insects and mites.

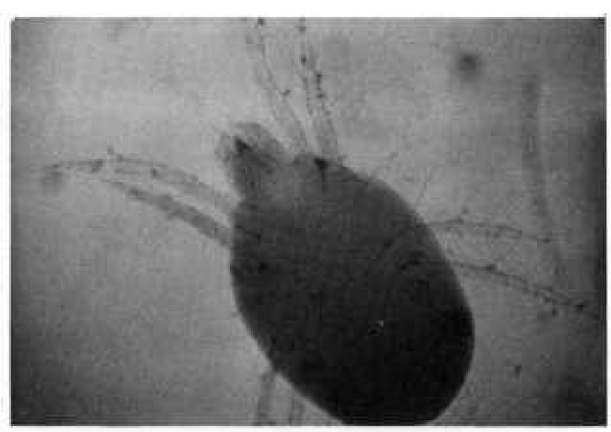
Development.—Spider mites develop in five stages—eggs, larva, two nymphal stages, and adult. Females are able to reproduce without mating and when they do, the offspring always are males.

PN-4430
Figure 13.—Stalk shredding with flail shredder (*top*) and machine lifting bolls from ground and shredding them (*bottom*).

Where winters are mild, as in the cotton-growing regions of the United States, spider mites may remain active and reproduce throughout the year. Under favorable conditions, some species complete a generation in 7 to 12 days. As many as 16 generations may occur in a year.

Spider mites may attack cotton at any stage of its growth, but usually they are most injurious from about July 1 until early September. Infestations are prevalent during periods of hot, dry weather. They may be detected by inspecting the undersurfaces of leaves of plants in different parts of the field—particularly in areas that were infested in previous years.

Severe infestations may be recognized by dust collecting in webs that the pests spin over



PN-4431
Figure 14.—Microphotograph of female twospotted spider mite. Note conidia of fungus Entomophthora attached to legs.

leaf surfaces for protection as they feed and lay eggs. Such infestations may enclose plant terminals in the webbing.

Spider mites damage cotton in all active stages of their life cycle. Larvae, nymphs, and adults suck the juices from leaves, stems, and fruits of the plants. Their feeding causes plant parts to become blotched or stippled and leaves to become discolored and drop prematurely (fig. 15). When plants are severely attacked, they may become defoliated and devitalized.

Research.—Before the advent of the organic insecticides, spider mites were minor pests of cotton. Infestations, when they did occur, often were confined to a small area within fields. Sulphur dust was an effective acaricide. Application of the organic insecticides for other cotton insects often resulted in subsequent infestations of spider mites. However, several organophosphorus compounds were effective. Some species, however, have developed resistance to these compounds.

Stink Bugs

Stink bugs that are sometimes serious pests of cotton are Brown stink bug, *Euschistus servus* (Say); the onespot stink bug, *E. variolarius* (Polisat de Beauvois); conchuela, *Chlorochroa ligata* (Say); dusky stink bug, *E. tristigmus* (Say), and *E. conspersus* (Uhler); green stink bug, *Acrosternum hilare* (Say), *T. pallidovirens spinosa* (Ruckers); Say stink bug, *Chlorochroa sayi* Stal; southern green stink bug, *Nezara viridula* (L.); and western brown stink bug, *Euschistus impictiventris* Stal.

The importance of these pests and the species involved vary from year to year and from area to area. The damage is confined principally to

PN-4432

Figure 15.—Damage to cotton foliage by spider mite.

the bolls and results in reduced yields and lower quality of both lint and seed.

Research.—Lint staining, causing serious loss in reduced grades and values, was found in much of Arizona cotton in the 1920's and 1930's. Several species of hemipterous insects were responsible for the reduction in yield through the shedding of squares and bolls and the production of nonpickable lint. The brown stink bug, the conchuela, and the redshouldered plant bug caused most of the staining. Surveys over a 4-year period showed an average of 25 percent of the bolls of short-staple cotton produced in Arizona were punctured. This group of insects are general feeders and frequently caused considerable damage to sugar beets, alfalfa, grain sorghums, and tomatoes.

Population buildup occurred in desert vegetation. Seasonal intercrop migrations of insects occurred, and the proportion of other crops, the time of harvest, and the effect of rain on desert vegetation all influenced the amount of damage to cotton. Indications were that migrations occurred for considerable distances from wild host plants. Staining of lint, which caused reduction in grade and, thus, the value of the crop, was caused by several micro-organisms that entered through the punctures made by the insects.

Plants caged with insects and field surveys of the seasonal abundance gave much information on the nature and extent of damage caused by the several species in different localities of the State.

Research on methods of control started in 1933 in cage tests and later in small plot and large-scale field experiments. Evaluation of a large number of insecticides showed that sulphur and mixtures of sulphur and arsenicals gave the best results and, in some cases, more than doubled the yield where the infestations were high. Mixtures of calcium arsenate and sulphur or paris green and sulphur applied at the rate of 15 to 18 pounds of dust per acre were about equal in effectiveness. The work on hemipterous insects aroused a great deal of popular interest among cottongrowers of Arizona. One company in 1939 cooperated in a large-scale experiment of airplane dusting by furnishing the planes and insecticides for dusting several thousand acres under the supervision of the Bureau of Entomology. Several organic insecticides give effective control of stink bugs, but stink bugs have not been a major problem in recent years.

Thrips

Thrips are small winged insects that injure plants by feeding on their juices. The following species of thrips attack cotton plants: *Frankliniella exigua* Hood; tobacco thrips, *F. fusca* (Hinds); *F. gossypiana* Hood; *F. occidentallis* (Pergande); flower thrips, *F. tritici* (Fitch); onion thrips, *Thrips tabaci* Lindeman, and *Sericothrips variabilis* (Beach). Most common of these are the flower thrips and their closely related species, tobacco and onion thrips. Two or more species may be found in the same cottonfield, often on the same plant, although one species usually predominates in a population.

Thrips are found on cotton in all the major cotton-producing States. Some species, such as onion thrips and *F. exigua,* occur across the entire Cotton Belt. Tobacco thrips are confined to approximately the eastern half of the United States with *F. occidentalis* occurring in the western half. The latter two species overlap in occurrence in western Oklahoma and in slightly more than the central third of Texas.

Tobacco thrips usually are predominant on seedling plants, but other species may become more numerous on plants beyond the seedling stage of growth. Onion thrips rarely cause serious injury to cotton in the eastern part of the Cotton Belt, except where onions are grown near cotton.

The duration and intensity of thrips infestations vary greatly in different seasons and locations. Experience is the best guide in predicting damage to cotton in an area.

Development.—Thrips develop in four life stages—egg, larva, pupa, and adult. Female adults lay their eggs in the tender tissues of plants. Eggs are creamy white and minute—about $\frac{1}{100}$-inch long. In about 4 days, the eggs hatch into tiny, white larvae. The larvae feed for about 6 days, shedding their skins twice during that time. Then, they burrow into the soil and transform into pupae. The pupae transform into adults and emerge from the soil in about 4 days.

Adult thrips may be yellow, brown, or black, depending on the species. They are slender and about $\frac{1}{16}$-inch long. They have two pairs of fringed wings and fly from plant to plant and from field to field.

Thrips complete a generation in about 2 weeks and produce many generations in a year. In southern areas, they breed all year on various host plants. In other areas, they pass the winter in plant residues and resume the life cycle when hosts become available in the spring.

Both thrips larvae and adults damage cotton plants. They pierce the leaf tissues with their sharp mouth parts and suck out the juices. These insects injure cotton seedlings and sometimes older plants. They attack leaves and terminal buds. Severely infested young plants may die, and the stand may be destroyed or reduced to the point where the crop must be replanted. This condition may occur when heavily infested onions, growing near cotton, are harvested.

Heavy feeding on cotyledons gives the plants a silvery appearance. A field of severely injured young cotton may appear to have been scorched by fire. Thrips injury to leaf tissue in terminal buds results in ragged, crinkled leaves that curl upward. (Aphid injury would cause leaves to turn downward.) The terminal buds may be killed. When this occurs, new buds develop and the plant becomes distorted and excessively branched.

Infestations usually abate after cotton plants are 4 to 6 weeks old. The plants recover from the injury, but those that are severely injured may continue to shed squares for a week or more after recovery seems apparent.

If an infestation occurs on seedling cotton and does not destroy the stand, it may retard plant growth and delay fruiting and maturing of the crop. The same is true if an infestation attacks cotton that has progressed beyond the seedling stage. In some western cotton-growing areas, cotton in the late-season stage of growth is sometimes severely attacked by thrips.

Thrips attack many wild and cultivated host plants. Large numbers of adults migrate to cottonfields in spring and early summer after other host plants begin to mature.

The abundance of thrips, extent of their damage, and need for their control vary greatly in different years and areas. Thrips may retard seedling growth and delay fruiting. They may be responsible for reduction in yield where droughts in late summer limit production or where boll weevils, bollworms, or pink bollworms are prevalent.

Research.—Considerable information on the species, host relationships, and factors causing outbreaks of thrips on cotton was accumulated at various research locations. Effective control measures were not developed, however, until organic insecticides were developed in the 1940's (fig. 16).

Miscellaneous Cotton Insects

All parts of the cotton plant are attacked by insects. In addition, the sweet liquid secreted by the nectaries of the leaves and bracts attracts a great variety of harmless and beneficial insects that are often mistaken for pests. The Department over the years has studied many minor pests. Some outbreaks are sporadic in local areas, and in others the species are generally distributed but are usually present in such limited numbers that their damage is not serious. Because of the great diversity of species that attack cotton, the total damage caused by the minor insect pests is considerable. About 50 species of miscellaneous cotton insects were studied in connection with the early boll weevil investigations.

Research.—Damage to cotton by the field cricket led to studies of the biology and methods of controlling this common species. The saltmarsh caterpillar, beet armyworm, cutworms, blister beetles, Fuller's rose beetle, and many other insects that attack cotton have been studied to some extent. The nature of the damage caused by about 40 species of Coleoptera and Lepidoptera that occur on cotton in Louisiana was studied at the Tallulah laboratory as late as 1934 and 1935. Many of these had not been recorded previously on cotton.

The brown cotton leafworm, *Acontia dacia* Druce, was collected on cotton from three counties in Texas in 1953. Damaging infestations have occurred through the 1950's over wide

PN-4433
Figure 16.—Thrips injured plants (*foreground*) and plants grown from cottonseed treated with systemic insecticide (*background*).

areas of Texas and in Louisiana. Recoveries have been reported from Arkansas.

Several *Anomis* leafworms are known to occur in the cotton-growing regions of Africa, Asia, all of the America's, and the East and West Indies. Three species—*A. erosa* Hübner, A. *flava fimbriago* (Stephens), and *A. texana* Riley —occasionally damage cotton in the United States. They are often mistaken for the cotton leafworm and are sometimes found on the same plants with it.

Several species of cutworms, including the following, may develop in weeds or crops, especially legumes, and then attack adjacent cotton or cotton planted on land previously in weeds or legumes: Black cutworm, *Agrotis ipsilon* (Hufnagel); palesided cutworm, *A. malefida* Guenée; variegated cutworm, *Peridroma saucia* (Hübner); granulate cutworm, *Feltia subterranea* (F.); rough-skinned cutworm, *Proxenus mindara*, Barnes and McDunnough; and army cutworm, *Euxoa auxilliaris* (Grote). Recommended control measures include thorough preparation of seedbed, elimination of weed host plants, and the use of insecticides. In western areas, irrigation forces the subterranean forms to the surface, where they may be treated with insecticides or destroyed by natural factors. If the vegetation in an infested area is plowed under 3 to 6 weeks before the cotton crop is seeded, insecticides may not be needed.

Root aphids known to attack cotton are the corn root aphid, *Aphis maidiracidis* (Forbes), *Smynthurodes betae* (Westwood), and *Rhopalosiphum rufiabdominalis* (Sasaki). So far as is known, injury before 1956 was confined to the eastern seaboard. *S. betae* destroyed spots of cotton up to 1½ acres in fields in Pemiscot County, Mo., in 1956. In 1961, root aphids caused some damage to cotton in the northeastern counties of North Carolina and Arkansas. Several species of ants are known to be associated with root aphids, the principal one being the cornfield ant, *Lasius alienus* (Foerster). Root aphids injure cotton chiefly in the seedling stage. Since cotton in this stage shows injury without any evidence of insects being present, the underground parts should be examined carefully. Ant mounds at the base of these plants indicate the presence of root aphids.

The cowpea aphid, *Aphis craccivora* Koch, the green peach aphid, *Myzus persicae* (Sulzer), and the potato aphid, *Macrosiphum euphorbiae* (Thomas), are common on seedling cotton. Cotton is not believed to be a true host of these species. However, in 1963, *A. craccivora* caused severe and permanent stunting of cotton plants in the San Joaquin Valley of California.

Darkling beetles, *Blapstimus* spp. and *Ulus* spp., the adults of false wireworms, occasionally adversely affect the stand of young cotton in western areas.

The garden springtail, *Bourletiella hortensis* (Fitch), has caused injury to cotton locally in Hertford County, N.C. Another springtail, *Entomobrya unostrigata* Stach, has occasionally damaged seedling cotton over a wide area of the southern high plains of Texas and New Mexico.

Leaf beetles of the genus *Colaspis* are widespread and often found on cotton, frequently on the foliage or near the base of squares and bolls where they usually feed on the bracts surrounding them.

The corn silk beetle, *Calomicrus brunneus* (Crotch), has been reported as a pest of cotton in localized areas in South Carolina, Georgia, Alabama, Mississippi, and Louisiana, but little is known about it.

The cowpea curculio, *Chalcodermus aeneus* Boheman, sometimes causes damage to seedling cotton.

A curculionid, *Compsus auricephalus* (Say), damaged young cotton plants and foliage in Grady County, Okla., in 1961. It also appeared in large numbers in cottonfields in Pope County, Ark. In 1963, heavy populations caused considerable foliage damage to young plants in localized areas of Grimes, Robertson, and Brazos Counties in Texas and in Obion and Lake Counties in Tennessee. A curculionid, *Conotrachelus erinaceus* (LeConte) caused damage to stems of seedling cotton in isolated instances in Marion County, Ala. in 1962. A curculionid, *Otiorhynchus cribricollis* (Gyllenhal), caused spotted heavy damage to cotyledons of seedling cotton in New Mexico in 1967 and 1972.

The cotton stainer, *Dysdercus suturellus* (Herrich–Schaffer), is found within the United States in Florida only. However, probably owing to mistaken identity, the literature also records it from Alabama, Georgia, and South Carolina.

Several leafhoppers of the genus *Empoasca* are often abundant on cotton in many sections of the Cotton Belt. Serious injury has been reported only in California, however, and this was caused by two species, southern garden leafhopper, *E. solana* DeLong, and potato leafhopper, *E. fabae* (Harris). These species are known to be phloem feeders on some crops and cause damage typical of this type of feeding on cotton.

The saltmarsh caterpillar, *Estigmene acrea* (Drury), is a late-season pest of cotton principally in western irrigated areas. Occasionally, the yellow woollybear, *Diacrisia virginica* (F.) and the hairy larvae of several other tiger moths, Arctiidae, including *Callarctia phyllira* (Drury), *C. arge* (Drury), and *C. oithona* Strk., cause serious damage to cotton.

The striped blister beetle, *Epicauta vittata* (F.), sometimes causes severe foliage damage in small localized areas. Damage usually results when weeds, which are preferred host plants, are cleaned out of cotton. Total loss of foliage may result in small areas before the insects move out of the field.

Field crickets, *Gryllus* spp., occasionally feed on cotton bolls and seedling plants in the Imperial Valley of California and in Arizona. During periods of drought late in the season, they may feed on the seed of open bolls, especially in the Delta sections of Arkansas, Louisiana, and Mississippi. This feeding is usually done at night as the crickets hide during the day in deep cracks in the soil.

Whitefringed beetles, *Graphognathus* spp., are pests of cotton and many other farm crops in limited areas of Alabama, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Tennessee. Infestations in recent years have been discovered in Maryland, Virginia, and Texas. The larvae feed on the roots of young plants.

The seedcorn maggot, *Hylemya platura* Meigen, may seriously affect the stand of cotton, particularly when planting closely follows the turning under of a green manure crop or other heavy growth.

The whitelined sphinx, *Hyles lineata* (F.), occasionally occurs in large numbers in uncultivated areas and migrates to cotton.

Several species of wireworms are associated with cotton. Damage is caused by the sand wireworms, *Horistonatus uhlerii* Horn, in South Carolina and Louisiana and by the Pacific Coast wireworm *Limonius canus* Leconte, in California. Adults of the tobacco wireworm, *Conoderus vespertinus* F., are frequently found on the cotton plant, and the larvae may cause damage to cotton. Wireworms, together with false wireworms and the seedcorn maggot, sometimes prevent the establishment of a stand. Approved crop-rotation practices, increased soil fertility, and added humus help to reduce damage to cotton by the sand wireworm.

Serpentine leafminers, *Liriomyza* spp., and *L. pictella* (Thomson), in California have been present in large numbers in some areas during the last few years. Drought conditions favor infestations of these pests. Heavy infestations may result in considerable leaf shed. Infestations often are brought under control by rain or irrigations.

Damage to cotton by periodical cicadas, *Magicicada* spp., in the United States was first reported in 1905. Damage is caused by the deposition of eggs in the stems of young plants, branches of older plants, and occasionally in leaf petioles. The parts of the plant above the oviposition puncture usually die. Growth below the puncture results in low bushy plants. Severe local damage to cotton by *Diceroprocta vitripennis* (Say) occurred in the river bottoms of nine counties in Arkansas in 1937. An undetermined cicada caused light damage to cotton in some areas in Maricopa County, Ariz. in 1961.

The harlequin bug, *Murgantia histrionica* (Hahn), heavily infested a few cottonfields in Graham County, Ariz., in August 1959. Feeding was similar to that of other stink bugs. No immature stages were noted.

The barberpole caterpillar, *Mimoschima rufofascialis* (Stephens), a pyraustid larva, is reported occasionally attacking cotton bolls in Imperial and San Joaquin Valley of California. It also has been reported from Ariozna, Oklahoma, and Texas.

Bugs of the genus *Nysius, N. ericae* (Schilling), *N. californicus* Stal, and *N. raphanus* Howard, commonly called false chinch bugs, frequently migrate to cotton from adjacent weed hosts. Stands of seedling cotton may be destroyed by adults and nymphs.

Snowy tree crickets, *Oecanthus* spp., infestations caused alarm to some southwestern Oklahoma cottongrowers in mid-July 1958. Approximately 3-percent lodging of plants occurred in the Blair area. There is evidence that this group of insects may be predaceous on aphids.

The European corn borer, *Ostrinia nubilalis* (Hübner), was first reported on cotton in the United States on July 3, 1955, in Franklin County, Tenn., in a 3-acre field adjacent to one that was in corn the previous year. A few plants near the edge of a field were severely damaged. The cotton plants were only 8 to 10 inches high, and the larvae had entered the stems 2 to 6 inches from the ground and burrowed up through their centers. In August light infestations were reported in cotton in Dunklin, New Madrid, Pemiscot, Butler, Stoddard, and Mississippi Counties, Mo., and in Madison County, Tenn. The insect had bored into the upper third of the stems, and second- and third-instar larvae were attacking small bolls. These records were of special interest because the European corn borer was apparently spreading in the Cotton Belt. No reports of this insect on cotton were received in 1956 and 1957.

In 1958, the European corn borer was found in cotton stalks in Autauga and Madison Counties, Ala., and in Washington County, Miss., in late July. In 1959, as many as 10 percent of the plants were infested in a 10-acre field of cotton in Etowah County, Ala. This field had been planted to corn in 1958. The borer was found, also, in Madison Parish, La., in 1959. Damage was confined to the terminal 6 to 8 inches of the plant. Other infestations were found in cottonfields in Autauga County, Ala. In 1961, larvae were found in cotton in Hardeman, Lincoln, and Fayette Counties in southern Tennessee. In 1966, larvae were found in cotton in Florence, S.C. In other parts of the world, particularly in Russia, Turkestan, and Hungary, it has been reported as a serious pest of cotton. One reference, Annual Conference Report on Cotton Insect Research and Control (*100*), states, "In Turkestan it is principally cotton which is attacked by the larvae and in which they bore long tunnels in the upper part of the stems."

The Fuller rose weevil, *Pantomorus cervinus* (Boheman), occasionally is a pest of cotton. It is a leaf feeder and usually attacks cotton in the early season, causing ragging of the leaves and partial defoliation. It overwinters as an adult in about the same habitat as the boll weevil. Examinations of surface woods trash for hibernating boll weevils often reveal specimen of the Fuller rose beetle. It has been reported from cotton in Georgia more frequently than from any other area.

The stalk borer, *Papaipema nebris* (Guenée), is widely distributed east of the Rocky Mountains. It attacks many kinds of plants, including cotton, and is so destructive that one borer in a field may attract attention. The borers are most likely to be found near the edges of cottonfields. Light marginal injury occurred in scattered fields in Missouri during June 1957. It was also reported as causing some injury to cotton in Mississippi and Tennessee in 1956. In 1961 it caused some damage along the edges of many cottonfields in western and southern counties in Tennessee. It is sometimes mistaken for the European corn borer. Clean cultivation and keeping down weed growth help to hold them in check. The use of stalk shredders early in the fall should reduce their numbers.

A white grub, *Phyllophaga ephilida* (Say), was reported to have destroyed 5 acres of cotton in Union County, N.C., in 1956. As many as 20 larvae per square foot were found. *P. zavalana* Reinhard is also reported to be a pest of cotton in the Matamoras area of Mexico, where the adults feed on foliage, particularly in the seedling stage. It is known to occur in Zavala and Dimmit Counties, Tex. *P. cribrosa* (LeConte), sometimes known as the "4 o'clock bug" in west Texas, has also been feeding on young cotton in that area. Moderate damage was caused to young cotton plants in the Arkansas Delta area in 1962 by larvae of *P. implicita* (Horn).

The cotton stem moth, *Platyedra subcinerea* (Haworth), a close relative of the pink bollworm, was first discovered in the United States in 1951, when larvae were found feeding in hollyhock seed in Mineola, Long Island, N.Y. It is recorded as a pest of cotton in Iran, Iraq, Morocco, Transcaucasia, Turkestan, and the U.S.S.R., and as feeding on hollyhock and other malvaceous plants in England, France, and central and southern Europe. Collections made in 1953 extended its known distribution in this country to a large part of Long Island and limited areas in Connecticut and Massachusetts. Extensive scouting during 1954 disclosed that it had reached 11 counties in four States as follows: Hartford and New Haven, Conn.; Essex and Plymouth, Mass.; Monmouth, Ocean, and Union, N.J.; Westchester and all counties of Long Island (Nassau, Queens, and Suffolk), N.Y. There has been no reported spread since 1954 until 1965 when it was reported from Rockingham County, N.H. Although this species has not been found in the Cotton Belt in the United States, it is desirable to keep on the lookout for it on cotton, hollyhock, and other malvaceous plants. In 1956 it was collected from a natural infestation on cotton growing on the laboratory grounds at Farmingdale, N.Y.

Several of the leaf rollers, Tortricidae, occasionally damage cotton. *Platynota stultana* (Williamson) and *P. rostrana* (Wilkerson) are the species most commonly recorded, but *P. flavedana* (Clemens), *P. idaeusalis* (Wilkerson), and *Sparganothis nigrocervina* (Williamson) have also been reported. These species are widely distributed and have many host plants. *P. stultana* has at times been a serious pest of cotton in the Imperial Valley of California and part of Arizona and New Mexico.

Heavy feeding on cotton by the Japanese beetle, *Popillia japonica* Newman, was reported in Sampson County, N.C., in 1961. Adults of the Japanese beetle caused 30- to 35-percent defoliation of cotton plants in fields in the more heavily infested areas in North Carolina in 1970.

A giant appletree borer, *Prionus* sp., caused isolated root damage to cotton in one county in Arkansas in 1962.

Adults of a buprestid beetle, *Psiloptera drummondi* Lap., occasionally cause damage to cotton. The damage consists of partly girdled terminals that break over and die.

The pink scavenger caterpillar, *Sathrobrota rileyi* (Walsingham), is one of several insects that resemble the pink bollworm and is sometimes mistaken for it by laymen. The larvae is primarily a scavenger in cotton bolls and corn husks that have been injured by other causes.

Several species of grasshopper, including the following, sometimes attack cotton: American grasshopper, *Schistocerca americana* (Drury); *Trimerotropis pallidipennis pallidipennis* (Burmeister); differential grasshopper, *Melanoplus differentialis* (Thomas); lubber grasshopper, *Brachystola magna* (Girard); migratory grasshopper, *M. sanguinipes* (F.); redlegged grasshopper, *M. fermurrubrum* (De Geer); and twostriped grasshopper, *M. bivittatus* (Say).

The American grasshopper overwinters as an adult and in the spring deposits eggs in the fields. Other species of grasshoppers overwinter as eggs in untilled soil, fence rows, sod waterways, around stumps, and similar locations. The species overwintering in the egg stage can be best controlled with early treatment of hatching beds before the grasshoppers migrate into the fields. Sprays or dusts have largely replaced poison baits, particularly where grasshoppers must be controlled on lush or dense vegetation.

The beet armyworm, *Spodoptera exigua* (Hbn.), is often a pest of seedling cotton, but it may also attack older plants. Squares and blooms may be destroyed, and feeding on the bracts may cause small bolls to shed. Although the beet armyworm has been a pest in the West and Southwest for many years, it was reported in Louisiana and Mississippi in 1962. Injurious infestations occurred in some localities in Alabama and Georgia in 1963, and in Alabama, Arkansas, and Mississippi in 1969. It was a serious pest of cotton in Georgia in 1973 and 1974.

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith), occasionally occurs in sufficient numbers to damage cotton.

The yellowstriped armyworm, *Spodoptera ornithogalli* (Guenée), and western yellowstriped armyworm, *S. praefica* Grote, sometimes cause considerable damage to cotton.

The cotton square borer, *Strymon melinus* (Hübner), occurs throughout the Cotton Belt, but rarely causes economic damage. The injury it causes to squares is often attributed to the bollworm.

The palestriped flea beetle, *Systena blanda* Melscheimer, the elongated flea beetle, *S. elongata* (F.) and *S. frontalis* (F.), sometimes cause serious damage to seedling cotton in some areas. The sweetpotato flea beetle, *Chaetocnema confinis* Crotch, injured seedling cotton in the Piedmont section of South Carolina in May 1954. The striped flea beetle, *Phyllotreta striolata* (Fabricius), caused damage to cotton in Alabama in 1959. Other species of flea beetles have been reported from cotton, but records regarding the injury they cause are lacking.

Whiteflies, the bandedwing whitefly, *Trialeurodes abutilonea* (Haldeman), the greenhouse whitefly, *T. vaporariorum* (Westwood), and the sweetpotato whitefly, *Bemisia tabaci* (Gennadius), are usually kept in check by parasites and diseases, but occasionally may be serious pests late in season. *Bemisia tabaci* is reported to be a vector of the leaf crumple virus of cotton. Whiteflies have caused damage to cotton in northwest Louisiana since 1964. Infestations have increased in Alabama and Mississippi in the early 1970's.

The cabbage looper, *Trichoplusia ni* (Hübner), is a pest of cotton in many areas. It is difficult to control with insecticides. It is frequently controlled by virus and fungus organisms. When diseased loopers are commonly found, chemical control may be delayed or omitted. The cabbage looper became more of a problem in cotton in the 1950's and less so since then.

The greenhouse leaftier, *Udea rubigalis* (Guenée), also known as the celery leaftier, has occasionally been abundant on cotton in the San Joaquin Valley of California. Despite the heavy populations, damage was generally slight and restricted to foliage on the lower third of the plants in lush stands. This pest caused considerable damage in three fields near Yuma, Ariz., in 1964.

The false celery leaftier, *Udea profundalis*

(Packard), caused considerable defoliation of cotton in some fields in Tulare, Kings, and Fresno Counties, Calif., in 1962. Control was difficult because of the insect's feeding habits on the lower part of plants within a web.

Damage to cotton stalks by termites, undetermined species, was reported in western Tennessee in 1961, and in previous years in Texas. Termites, *Reticulitermes* sp. (Rhinotermitidae), partly destroyed a stand of cotton in Little River County, Ark., in 1961.

Insects in or among cottonseed in storage.— Insect infestations in cottonseed during storage can be minimized if proper precautions are followed. Cottonseed, or seed cotton, should be stored only in a bin or room thoroughly cleaned of all old cottonseed, grain, hay, or other similar products in which insects that attack stored products are likely to develop. Among the insects that cause damage to stored cottonseed or to cottonseed meal are the cigarette beetle, *Lasioderma serricorne* (F.), the Mediterranean flour moth, *Anagasta kuehniella* (Zeller), the almond moth, *Cadra cautella* (Walker), and the Indian-meal moth, *Plodia interpunctella* (Hübner). Other insects commonly found in cottonseed are the flat grain beetle, *Crytolestes pusillus* (Schönherr), the red flour beetle, *Tribolium castaneum* (Herbst), and the sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.). The pink bollworm may be found in stored cottonseed, but such infestations would be present in the seed before they were stored.

RESEARCH 1941 TO 1974

Attractants

Boll Weevil

In the 1950's an observation was made at the Stoneville, Miss., Cotton Insects Laboratory that the female weevil sought the male rather than the usual procedure, most male insects seeking the female. This was verified in laboratory studies at the Boll Weevil Research Laboratory in the mid-1960's, and the attractant named grandlure was identified and synthesized. Now commercially available, grandlure is widely used in migration, survey, and detection procedures. Hopefully, it will be registered in the future for use in population management and eradication programs. A trap baited with grandlure was developed to capture female boll weevils. Grandlure is also an aggregant as early in the year males as well as females are attracted to it. As cotton plants begin to square, however, response to the pheromone is predominately by female boll weevils. Traps baited with grandlure placed along the edges of cottonfields capture tremendous numbers of overwintered boll weevils.

In the Pilot Boll Weevil Eradication Experiment conducted in south Mississippi and in adjoining areas of Louisiana and Alabama in 1971–73, traps baited with grandlure at the rate of two per acre were used as one of the suppression measures in the core or eradication area. Trap crops consisting of cotton planted some 2 weeks earlier than that of the grower cotton were baited with grandlure at 100-foot intervals. Plants in the trap crops were treated in-furrow at planting with aldicarb and side-dressed with it at early squaring to kill overwintered weevils attracted to them. The trap crops were treated with methyl parathion during periods when the aldicarb treatment was considered not to be effective. Very few weevils were found in the grower cotton before it began to fruit. Even after grower cotton began to square, weevils continued to be attracted to the trap crops as evidenced by the collection of sterile males released in the grower cotton being collected in the trap crops. The development of infield traps, those that can be used within fields without interfering with cultivation, baited with grandlure has great potential as a tool in population suppression or elimination programs.

In the previous discussion of the boll weevil, efforts to develop attractants from cotton plants to control the pest were unsuccessful. Interest in boll weevil attractants from the cotton plant was revived by researchers in the 1960's.

Water and chloroform extracts of cotton plant parts were attractive. A powerful arrestant and feeding stimulant was found in water extracts of all cotton parts and square components tested. A feeding deterrent was found in the calyx of an alternate host, *Hibiscus syriacus*. However, the chemistry of the arrestant and attractant compounds in the cotton plant is so complex that chemists have been unable to identify and synthesize all of them for use in control, suppression, or survey programs.

Pink Bollworm

In the mid-1960's research on the female pink bollworm moth showed that the female emitted a substance attractive to males. The chemists identified and synthesized the substance and named it propylure. Unfortunately, propylure, though attractive to males in the laboratory, failed to perform in the field. Apparently, something was missing in the synthesized compound. A somewhat structurally related compound, called hexalure, was found to be attractive to males and was widely used in the West in survey and detection operations. Though not as attractive as the natural pheromone, hexalure was sufficiently attractive to be used to bait traps so that use of live females was obviated. An intensive effort was made by ARS chemists to identify and synthesize the pheromone. However, progress was slow and in late 1973 researchers at the University of California, Riverside, identified and synthesized the compound. ARS chemists verified the finding. Named gossyplure, it has considerable potential for use in survey detection and population suppression programs and has been used in a large-field experiment as a confusant. When applied to a field of cotton, the male then cannot locate the female.

Tobacco Budworm and Bollworm

Females of the tobacco budworm and bollworm produce powerful sex pheromones or sex attractants to call males of the respective species for mating. Research has continued since 1963 on these pheromones with the ultimate goal of producing synthetic materials that could be used for population survey and suppression.

The pheromone of the female tobacco budworm was identified and synthesized. A crude extract of the pheromone from females had very short activity, and a similar problem has been found with the synthetic material. Research is currently directed toward development of a stable formulation of the synthetic pheromone to give long-term activity in the field.

A similar attractant has recently been discovered for the bollworm; however, it is as yet uncertain whether the synthesized compound is the natural sex pheromone.

Once stable formulations of the pheromones of the two species are devised, the possibility for developing population suppression schemes will be opened. Among the methods suggested for use of these materials are elimination of males by trapping or dispensing the attractant on an insecticide-treated substance, luring the males to substrate treated with chemosterilants, or saturating an environment with the pheromone, thus, interfering with the mating orientation of the males. However, it will be several years before these systems can be put to practical use. Development of methods of using the pheromones in traps to anticipate outbreaks of the pests for timing of insecticide applications is apparently more immediately promising.

A related approach has been the search for chemicals that will disrupt the chemical communication between sexes. Researchers have shown that the attractiveness of female tobacco budworms is greatly reduced if certain organic chemicals are released into the environment. However, these studies are in the preliminary stages.

Researchers have reported that the male tobacco budworm, when preparing to mate with a female, produces a substance that suppresses the emission of the female sex pheromone, but no work has been done on isolating the active agent. Possibly such a substance would be useful in combination with some of the previously noted techniques.

Results of recent research have shown that certain egg and larval parasites of *Heliothis* spp. are attracted to the host by host-seeking stimulants named kairomones.

Tarnished Plant Bug

In the early 1970's a researcher at the Stoneville, Miss., laboratory found that the female tarnished plant bug produced a substance attractive to males. Research is underway to identify the substance.

Biological Control

Predators, parasites, and diseases play an important role in the control of insect pests of cotton. The role of natural enemies in cotton insect control programs should be maximized by utilizing insecticides, cultural practices, and other agents and techniques in supportive ways. The role of beneficial insects in the field should be evaluated when possible. Some predaceous and parasitic insects of prime importance are discussed in this section.

Predators

Hemiptera

Orius insidiosus and *O. tristicolor,* often called minute pirate bugs or flower bugs, are predators of eggs and first instar larvae of the bollworm, thrips, and other small insects. Populations often build up in such crops as corn and grain sorghum. Big-eyed bugs, *Geocoris pallens* and *G. uliginosus,* are common predators of eggs and small larvae of the bollworm as well as of other Lepidoptera, mirids, and aphids. Damsel bugs of the genus *Nabis* are efficient predators of a wide range of prey including mirids, leafhoppers, aphids, and eggs and larvae of Lepidoptera. They attack bollworms as large as the second instar. Assassin bugs, particularly the genus *Zelus,* feed freely on eggs and larvae of the bollworm, tobacco bollworm, and cabbage looper. However, these insects are usually less abundant in cottonfields than those discussed previously. *Podisus maculiventris* is a common stink bug that preys on large bollworms and other caterpillars in the West.

Neuroptera

Larvae of green lacewings, *Chrysopa* spp., are important predators of eggs and small larvae of bollworm and other Lepidoptera and of many soft-bodied insects.

Coleoptera

Ground beetles of the family Carabidae have considerable potential as predators in the cottonfield, but knowledge is lacking on the habits and factors affecting abundance of the many species. Lady beetles (Coccinellidae) are common predators in cottonfields. The large species, including *Coleomegilla maculata, Hippodamia convergens,* and *Coccinella novemnotata,* feed on eggs and small larvae of bollworms, other Lepidoptera, and on aphids. Some smaller species in the genus *Scymnus* and all *Stethorus* spp. are primarily predators of mites. *Collops* beetles (Malachinnae in the family Malyridae) are often abundant in cotton. They reportedly feed on the eggs and small larvae of the bollworm and other lepidopterous species.

Diptera

Many families contain species predaceous as adults or larvae. Best known as predators in the cottonfields are the larvae of syrphid flies that prey primarily on aphids.

Hymenoptera

Ants (Formicidae) include many predaceous species; *Iridomyrmex pruinosus* is a predator of bollworm eggs. Paper-nest wasps, *Polistes* spp., and solitary wasps of the genera *Zethus, Eumenes, Rygchium,* and *Stenodynerus* provide their young in the nests with Lepidopterous larvae. Wasps of the genus *Sphex* nest in the ground and provide their young with grasshoppers and related insects.

Spiders

All spiders are predaceous and many species are common in cottonfields. Orb weavers capture many moths in their webs. Wolf spiders and lynx spiders capture moths and other insects. Larvae and adults of the bollworm and boll weevil adults are among the prey of jumping spiders.

Parasites

Hymenoptera

Numerous hymenopterous parasite species of several families are of great value in the biological control of most cotton pests. These parasites vary tremendously in size, behavior, ecology, and host preference. Within their ranks, however, effective or potentially effective parasites of nearly every developmental stage, egg through adult, of the majority of cotton pests may be found. Many of them occur naturally in great numbers in certain geographical areas. Some are now and many will eventually have to be augmented in the field by means of habitat management or mass release techniques so as to concentrate their populations at the time and in the place required for most effective control.

Diptera

Flies of the family Tachinidae are parasites primarily of larvae of Lepidoptera and Coleoptera. Several species are of value as parasites of cotton pests and should be examined with the same goals of augmentation through laboratory or field practices.

Control with Predators and Parasites

Native predators and parasites are often highly effective against aphids, the bollworm, beet armyworm, tobacco budworm, cabbage looper, cotton leafworm, cotton leafperforator, cutworm, lygus bugs, saltmarsh caterpillar, spider mites, whiteflies, and certain other pests. Diversified crops and uncultivated areas serve as refuge and reservoir areas for predators and parasites, and unfortunately for some pests.

The need for controlling such insects as the boll weevil, lygus bugs, and the cotton fleahopper with insecticides often results in increased subsequent infestations of the bollworm and tobacco budworm because beneficial insects that might hold such infestations below economic levels are killed off by the insecticides. The continued use of an insecticide then is necessary even though infestations of the primary insect have been reduced below injurious levels. If insecticidal control was not needed for these insects, the control problem with the bollworm complex would be eased considerably.

Augmentation of food for lacewings has shown promise in field experiments in California.

Naturally occurring parasitic and predaceous insects frequently destroy sufficient *Heliothis* to prevent outbreaks of these pests on cotton. However, supplementing natural control may be necessary to insure that adequate numbers of these entomophagous insects will be available to prevent the pests from causing economic damage.

Recent experiments have demonstrated that augmentation of entomophagous insects through mass rearing and release holds promise as an effective means of controlling *Heliothis*. Releasing large numbers (100,000) per acre of the predator, *Chrysopa carnea* Stephens, controlled *Heliothis* in field cages, which was confirmed in small field plots. Similar results were obtained with large releases of the egg parasite *Trichogramma*. A large-scale pilot test of augmentation was, therefore, undertaken. A mass-rearing facility was developed for producing *Chrysopa* and *Trichogramma* by using *Sitotroga* eggs as host material. In addition, development of an encapsulated artificial diet was undertaken.

In 1972-73, *Chrysopa* and *Trichogramma* were produced for a large-scale test of the augmentative release method in Frio Co., Tex. Methods of shipping and releasing the insects were devised, and releases were made on about 1,700 acres. However, failure of a diapause boll weevil control program to reduce populations necessitated insecticidal treatment for the boll weevil and negated much of the effect of the releases of the entomophagous species.

Results of this pilot test brought out several points to be considered in using this technique. Effective and economical use of this method will require the design and operation of a pest control system which makes possible the management of pests over large areas. Production practices on all farms in the area must be compatible with the management of parasites and predators. Releases of beneficial insects in cotton cannot be effective if conventional insecticides are applied at the same time to control other pests such as the boll weevil. Methods of determining and anticipating the numbers of pests and entomophagous species needed for release must be improved.

Two hymenopterous parasites, *Bracon kirkpatricki* (Wilkinson) and *Chelonus blackburni* (Cameron), were tested as control organisms for the pink bollworm in approximately 100 acres of irrigated cotton near Tucson, Ariz., in 1971 and 1972. The parasites were reared on the pink bollworm at the Biological Control Investigations Laboratory in Tucson. The pink bollworm populations were suppressed in the early season with releases of *B. Kirkpatricki,* but *C. blackburni* was somewhat less effective later in the season. These parasites were reared in the Animal and Plant Health Inspection Service, Methods Development Laboratory, Phoenix, Ariz., in 1973 and were released in the wild cotton in the southern most area of Florida. A few pink bollworm larvae infested with the parasites were recovered. Though the parasites show promise against low-level populations of the pink bollworm, the technique cannot be exploited until techniques for rearing them artificially are developed. An effective egg parasite is needed.

Additional research is needed to reduce the cost of rearing and to improve the quality of the released insects in various ways. More engineering research is needed to improve mechanization of the systems. It is anticipated it will be a number of years before all of the necessary components can be developed to the extent that this method can be used effectively by cottongrowers.

Biology and Ecology

Much of the biological work conducted on the boll weevil, bollworm, and pink bollworm in the early days continues to have validity. Progress has been considerable, however, in ecological studies as more sophisticated techniques became available. Sex attractants, light traps, and marking techniques, genetic as well as physical, have been invaluable in the furtherance of ecological studies.

Migration

Migration of the boll weevil usually occurred late in the season when populations developed in extremely large numbers and new sources of food and oviposition sites were needed. With the advent of the more effective insecticides and their widespread use, migration as occurred previously was not so pronounced. Surveys in the early days showed that the boll weevil moved eastward across the Cotton Belt at an average rate of about 50 miles per year. In Georgia in 1959, boll weevils infested a cottonfield 25.5 miles from other cottonfields. In 1968 boll weevils were captured in male-baited wing traps along the highway from Juarez to Chihuahua in Mexico though the traps were located 25 to 45 miles from cotton. During midseason in South Carolina, F_1 and succeeding generations of the weevil dispersed at least 19 miles to find new cotton. In south Mississippi, genetically marked weevils were collected in a pheromone-baited trap 25 and 35 miles from a release site.

Pink bollworms have long been known to move long distances when food supply became scarce late in the season. The collection of pink bollworm moths in traps operated from an airplane at 3,000 feet over cottonfields in Mexico indicated that moths could migrate several hundred miles from Mexico to the United States. Though in small numbers pink bollworm moths were collected in light traps early in the season, almost none were caught after cotton plants began to fruit, an indication that early-season movement was a search for oviposition sites in fruiting cotton. Collections in light traps increased as cotton plants began to mature and oviposition sites became scarce. Large numbers were captured when late season infestations were heavy. Results of tests conducted in Riverside County, Calif., in 1970 showed that moths from overwintering larvae were capable of migrating at least 35 miles to infest cotton in areas not previously infested. This finding will be of considerable value if any elimination program for the pest is ever undertaken.

Though the bollworm is known to migrate for considerable distances, definitive data have been difficult to obtain. Hibernation and survival studies in the early 1940's in central Texas showed that a generation developed in the field before moth emergence from hibernating pupae occurred in the cages. It was assumed that the field generation resulted from migrants from the South where earlier emergence occurred. Use of black light traps to which the moths are attracted has been most helpful in such studies. Results of studies in the Mississippi Delta area in the 1960's were similar. Moths were collected in the light traps some 30 days before moths emerged from hibernating pupae. In 1968 moths from larvae developing on a plot of radiolabeled sweet corn on St. Croix, U.S. Virgin Islands, dispersed in a nonrandom pattern for distances up to 10 miles to locate suitable hosts. In the same year, data for released marked moths at Tifton, Ga., indicated that moths dispersed over an extended distance, at least 16 miles in one night and at least 45 miles over a period of 1 to 4 days. Collections of moths in light traps at different heights indicated that bollworms are capable of obtaining controlled flight altitude in excess of 1,000 feet. A moth was collected in traps from aircraft at 500 feet. In the fall of 1973 three moths were captured in light traps on unmanned oil platforms in the Gulf of Mexico 100 miles from land.

In 1971 laboratory-reared adult tobacco budworms marked with dyes fed in the larval diet and sterilized with CO^{60} irradiation were released in northeastern Mexico and southern Texas and recovered in sex-lure traps at known distances at cardinal compass directions. In Mexico, male moths dispersed 10 miles north in 24 hours, and a distance-dilution effect was indicated. In southern Texas, moths dispersed as much as 70 miles from the release point within an estimated 4 to 5 days.

Collections of Insects in the Upper Air

In addition to being used for applying insecticides, the airplane equipment of the Department, also, was used for collecting insects in the upper air to obtain information on the flight or carriage of insects by air currents. Special traps were designed based on the principle of camera plat holders with screen-covered frames coated with adhesives carried in compartments for protecting the screens before and after exposure. The traps were mounted on the wings of the planes and controlled by wires to the cockpit so that exposures could be made for a specified time at known elevations.

Systematic flights were made during the 5 years, 1926–31, in which over 150,000 miles were flown and 1,007 hours spent in actual exposure of the traps. Most of the 1,385 separate flights were in Louisiana, but 44 were made in the Laguna section of Mexico. Flights were made during the day and night at all seasons of the year at elevations of from 200 to 15,000 feet, during which 30,033 specimens of insects, spiders, and mites were collected. The weaker fliers were taken in greater numbers at the higher elevations than the stronger fliers, and numbers of wingless adults, nymphs, and larvae were collected at elevations up to 14,000 feet. A spider was taken at 15,000 feet, the highest elevation at which flights were made. Temperature, surface vapor pressure, intensity of air currents, direction of the wind, and convection were the most important factors in determining the abundance of the insects in the upper air. These flights were the most extensive ever undertaken for studying insect abundance and distribution in the upper air. Additional flights were made over the Lower Rio Grande Valley and King Ranch areas of Texas in 1954. Late in the cotton season of 1956, flights were made over central Texas and in the Tri-State areas of Texas, Arkansas, and Mississippi.

Much information of scientific interest and practical value was obtained. The collection of pink bollworm moths at 3,000 feet in the air over the cottonfields of Mexico, for example, confirmed evidence that the moths were migrating several hundred miles from Mexico to the United States and were responsible for the failure of the eradication measures and the increase in infestation in the Big Bend area of Texas. Later flights over Texas resulted in captures of pink bollworm moths, which showed that they could disperse into Arkansas on wind currents from infested fields in central Texas. A boll weevil was taken at 2,000 feet in Louisiana and at 200 and 500 feet in the Lower Rio Grande Valley of Texas.

Genetic Control

Research on genetic control of cotton insects has centered on the sterile insect release approach that was so successful against the screwworm fly, *Cochliomyia hominivorax* (Coquerel). In this approach large numbers of insects are reared and exposed to ionizing irradiation or to chemosterilants to induce sterility; then, they are released among native populations at sufficient ratios to insure a high proportion of sterile matings. Developing this technique includes devising methods for rearing and sterilizing large numbers of insects with minimum effect on their competitiveness in securing mates, for shipping them from the rearing facility to release sites and releasing them so that they disperse among the native population, and for monitoring the effectiveness of the program. Frequently, preliminary application of other population reduction measures, such as insecticides, are needed to reduce native populations to levels low enough so that an effective overflooding ratio can be achieved.

Boll Weevil

Much research has been conducted on sterilizing the boll weevil. Effective doses of gamma irradiation reduce competitiveness and result in high mortality. Similar results were obtained with some chemosterilants. Finally, workers at several laboratories found that busulfan could achieve sterility in the male when incorporated in the adult diet for a 6-day feeding period. Two disadvantages of busulfan were the long feeding period and not sterilizing the female. Thus, in the Pilot Boll Weevil Eradication Experiment, the weevils had to be sexed for use of the sterile male component. Sexing has to be done manually and is, therefore, laborious and costly. In an elimination program, the cost of sexing would be prohibitive. An intensive effort, then, was made to find a chemosterilant effective against both sexes. A combination of a 4-day feeding of busulfan-treated diet to adults plus a few hours of fumigation with hempa appeared to sterilize both sexes satisfactorily. However, research continued because the long holding and feeding period needed to be reduced or eliminated. Thompson-Hayward's TH 6040 N-(4-chlorophenyl)-N^1-(2.6-difluro-benzoyl)urea has exciting possibilities. Use of fractioned doses of gamma irradiation applied at 4-hour intervals also appears promising. Chances are good that the problem will be solved before an elimination program is undertaken.

Bollworm and Tobacco Budworm

A great deal of research has been done on methods of sterilizing *Heliothis* and the effects on various aspects of sexual competitiveness. Gamma irradiation has been pursued most extensively because it is relatively easy to use and presents minimum environmental hazards when proper equipment is used.

A limited field test of this method against the bollworm conducted on St. Croix, U.S. Virgin Islands, was a partial success, but problems with rearing interfered.

More extensive tests were carried out on the same island in 1972-74. The results of these tests indicated that released mass-reared insects, whether irradiated or not, competed poorly for native mates, especially the males. However, populations of the bollworm were reduced to low levels because the sterile females mated earlier in the night than the native females. Since the sterile males were essentially noncompetitive with the native males and since both types of males were ready to mate at any time of night, the native males mated with sterile females when these females were ready. When the native females began mating at the later hour, the available native males had already mated and, as a result, the sterile males mated with these females with little competition. Since populations of the bollworms were limited to a few small plantings of corn on the island, relatively high ratios of sterile to native insect were achieved, and the population could be manipulated easily. Whether this procedure could be used on a large scale is questionable.

The test with the tobacco budworms showed that the sterile males were about 25 percent as competitive for mates as native ones. This resulted from the mass-rearing conditions and irradiation. A lack of synchrony in mating times of sterile and native insects of both sexes was noted, thus making the system used against the bollworm ineffective in this case. Also, populations of the tobacco budworm were much larger and more widely distributed than those of the bollworm, with the result that the sterile to native insect ratios were generally too low (5 to 1) to have much impact on the native populations when the competitiveness problem was considered.

Research is continuing on development of this method for use against the tobacco budworm with emphasis on defining and overcoming problems related to the poor competitiveness of the sterile insects. It will probably be a number of years before this method can be considered feasible for practical use.

Pink Bollworm

Gamma irradiation for sterilizing pink bollworms has been under study for some time. Research continues, and doses have been reduced to 20 kr, which has improved competitiveness of treated males with nonsterile males for females. The pink bollworm has been mass reared at the Methods Development Laboratory, Animal and Plant Health Inspection Service (APHIS), USDA, Phoenix, Ariz., since 1967. Migrants from the Imperial and Coachella Valleys have been detected in relatively low numbers in certain localities of the San Joaquin Valley in California each year since 1967. Sterile moths have been released in these localities annually beginning in 1968. Approximately 100 million were released annually from 1970 through 1973, but rearing problems reduced the numbers released in 1974. The releases apparently have prevented establishment of infestations in this important cotton producing valley. Such treatment must continue until the pest is eliminated or populations are reduced to low levels in the Coachella and Imperial Valleys so that they no longer will provide migrants to the San Joaquin Valley.

Beginning in November 1972, sterile moths have been released in the off-cotton seasons in the extreme southern tip of Florida to suppress pink bollworm populations in wild cotton growing in the area. For many years, population suppression was attained by manual destruction of wild cotton plants, which was both costly and difficult as the cotton was impossible to eradicate with this procedure. The sterile male release technique hopefully will suppress populations to the extent that the pink bollworm cannot migrate to the northern part of the State where cotton is grown.

If elimination of the pink bollworm is undertaken in the future, the sterile male release technique will no doubt be a major component in the program.

Host Plant Resistance

In the early days of the boll weevil when effective insecticides were not available, emphasis was given to cultural controls and early maturing cotton varieties which made possible the production of a crop before the boll weevil could build up extremely high populations. With the advent of better insecticides and needs for higher yields, varieties of indeterminate growth were developed for the rain belt and the irrigated areas of the West. Such varieties and production practices favored the boll weevil and pink bollworm. Though good yields were produced with the intensive use of insecticides, large populations diapaused in the fall, enhancing survival for infesting the subsequent crops and necessitating repetition of the control cycle year after year.

Boll Weevil

When resistance to the organochlorine insecticides developed in the boll weevil in the mid-1950's, research turned to alternative methods of controlling the boll weevil and other cotton insects. Though considerable effort was expended, progress in the development of varieties resistant to the boll weevil was slow. In the 1970's Frego bract cottons, the bracts are distorted and do not envelop a square as is done with normal bract cottons, reduced boll weevil oviposition by 50 percent or more when compared with normal bract varieties. However, the reduction in oviposition has been considerably less than that when the variety was grown under "no choice" situations. Frego bract varieties with acceptable agronomic characters might have a place in boll weevil control when field plantings are interspersed with trap crop plantings of normal bract cottons to attract overwintered weevils which could then be killed with insecticides. Unfortunately, Frego bract cottons are more susceptible to lygus bugs.

Some short-season determinate cotton varieties are now grown extensively in Texas and show promise in reducing late-season insect damage, especially by the boll weevil. They also may help alleviate some damage caused by *Heliothis* by maturing before the damaging late-season peak of population occurs.

Bollworms

The development of cotton varieties resistant to the tobacco budworm and bollworm has centered on three morphological characters of the cotton plant and on the development of early-maturing, determinate types of cotton that set the bulk of their fruit 2 to 3 weeks earlier than the nondeterminate cottons usually grown commercially. Research is in progress, also, to develop cotton varieties resistant to the cotton fleahopper, plant bugs, and the boll weevil, which would help alleviate the *Heliothis* spp. problem by reducing the insecticide applications for these pests, thus, conserving the natural enemies of Heliothis spp.

The first morphological character is lack of nectaries. Normal cottons have extrafloral nectaries on leaves and fruiting forms. The absence of these structures deprives *Heliothis* adults of an important source of food when and where alternate food sources are not available. In controlled tests, the absence of extrafloral nectaries (nectariless cotton) resulted in at least a 40-percent reduction in egg deposition and reduced longevity of adults.

The second character measurably reducing populations of *Heliothis* spp. is a smooth (glabrous) plant surface. Commercial cottons have 2,000 to 5,000 trichomes per square inch on the small terminal leaves and buds, which are the preferred oviposition sites of *Heliothis* spp. Glabrous stocks with less than 200 trichomes per square inch have reduced egg deposition by 50 percent.

The third character showing impact on *Heliothis* spp. populations is a high level of gossypol in the flower buds (squares). Gossypol content in buds of commercial cotton is about 0.5 percent, which affects larvae very little. However, larval mortality of 50 percent occurs when the gossypol level is 1.2 percent or higher.

Studies in field cages with cotton strains in which all three morphological characters have been combined showed that populations of the tobacco budworm increased 1.1-fold in two generations, and those on glabrous plus high-gossypol cotton or nectariless cotton plus high-gossypol cotton increased 2-fold; meanwhile populations on commercial cotton increased 10- to 12-fold. In field tests a glabrous cotton suppressed *Heliothis* spp. larval population 68 percent compared with the population on commercial cotton, and cottons with both the glabrous and high-gossypol characters reduced larval populations 60 to 80 percent. In field tests with advanced strains, one strain with the glabrous-high gossypol combination yielded 700 pounds per acre more seed cotton than a commercial variety. The nectariless cotton could not be properly evaluated in the field because the size of the plots was too small to prevent moths from obtaining food outside the plots.

In 1974 a nectariless cotton strain was released to commercial seed companies and may soon be available to growers for large-scale planting. However, unless this cotton is planted on a community-wide basis and alternative sources of food are not available for moths, its effectiveness against *Heliothis* could be limited.

Cotton Fleahopper

Cottons with the glabrous character are well advanced and could be expected to have considerable impact on *Heliothis* when available to growers. There is a complication with these cottons, however. Although these cottons have a significant impact on infestations of the cotton fleahopper as well as on infestations of *Heliothis* spp., these cottons are actually more sensitive to fleahopper attack than more hirsute strains and, despite lower infestation levels, suffer greater damage. This damage, however, may result from infestations of leafhoppers rather than cotton fleahoppers. Until these problems are resolved and overcome, the use of glabrous cotton may be questionable.

Cottons with the high-gossypol character or those with this character combined with other resistant characters also show a great deal of promise against *Heliothis* spp. In the late 1960's these cottons showed some resistance against the cotton fleahopper; they have produced yields above those of current commercial varieties. These varieties will probably not be available to the grower in any quantity, however, for several years.

Tarnished Plant Bug

The nectariless character in cotton has reduced reproduction of the tarnished plant bug, *Lygus lineolaris* (Palisat de Beauvois), with considerably fewer nymphs developing on nectariless plants than on plants with nectaries. Apparently, the leaf nectaries are an important food source for the developing nymphs.

Other Insects

Research on the development of varieties resistant to the pink bollworm, cotton leafperforator, and spider mites is in progress; some success has been attained against spider mites.

Gossypol and Gossypol-Free Cotton

Generally, varieties having a high-gossypol content are more tolerant to insect attack than those with a low-gossypol content. Cottonseed from commercially grown cottons could not be used as a source of protein in food for man and in feed for nonruminant animals because of gossypol content. Removing gossypol from the meal was too costly. A new process, however, has been developed for extracting gossypol from cottonseed meal that may have considerable impact as a source of protein for man. A mill in the High Plains of Texas is producing gossypol-free cottonseed flour and another mill is planned for South Carolina. Before this new process was developed for removing gossypol, breeders spent considerable effort to develop gossypol-free varieties. These varieties had acceptable agronomic characters, but they were more susceptible to attacks of bollworms and certain species of insects that do not attack commercial varieties. Though the protein source for human food was needed, the need for additional applications of insecticides to control these insects offset any gain in gossypol-free varieties. With the new gossypol-removal process, the need for gossypol-free cotton varieties is less critical.

Appraisal of Cotton Varieties Resistant to Insects

Although only modest success has been achieved in developing resistant varieties to cotton insects, this effort is important. Varieties with comparatively low levels of resistance to certain insects could be an essential factor in an insect population management system.

Insecticides

For many years before 1945, arsenicals and sulfur were the principal insecticides used for cotton insect control. Calcium arsenate was the main weapon against the boll weevil, bollworm, and cotton leafworm, but its application usually resulted in injurious infestations of cotton aphids.

Nicotine, the only available aphicide, was mixed with calcium arsenate or was used alone for aphid control although expensive and not very effective under certain conditions. Mixtures of sulphur and calcium arsenate were widely used for control of combination infestations of boll weevils and cotton fleahoppers.

Paris green and sulphur became popular in the Far West for control of hemipterous insects. Sulphur suppressed aphid populations but, in combination with arsenicals, did not always prevent injurious infestations. In the early part of the century, or before the advent of calcium arsenate about 1916 to 1920, paris green and lead arsenate were the principal insecticides used to control outbreaks of the cotton leafworm.

Organic Insecticides

In the mid-1940's, the new organochlorine insecticides were developed and resulted in the first major change in insecticides used on cotton since the development of calcium arsenate. Federal and State research workers rapidly explored their possibilities. Their general effectiveness against most of the injurious insects resulted in wide acceptance by growers so that by the late 1940's considerably more cotton acreage was being treated than ever before. Much of this development was accomplished at Cotton Insect Research Laboratories in Florence, S.C.; Stoneville, Miss.; Tallulah, La.; Waco and Brownsville, Tex.; Tucson, Ariz.; and at many of the State agricultural experiment stations.

The organochlorine compounds largely replaced calcium arsenate though it continued to be used for some years to some extent in localized areas. Some of them, BHC, aldrin, dieldrin, chlordane, and heptachlor, were effective against boll weevils but were ineffective against bollworms. Mixtures of these materials with

DDT gave effective control of combination infestations of these two important pests. Toxaphene, and later endrin, were effective against both pests.

Application equipment available at first was that used for applying calcium arsenate, and for several years the new insecticides were applied only as dusts. One limiting factor for wider acceptance was the critical weather conditions needed for effective dust applications. Dusts had to be applied during late afternoon, at night, or early morning when the air was calm or nearly so. In many areas satisfactory dusting conditions were of short duration and often nonexistent. Consequently, only limited acreages could be treated in a day's operation.

With the advent of organochlorine insecticides, entomologists at the Waco, Tex., Cotton Insects Laboratory took a new look at "presquare" boll weevil control with the idea of also controlling other early-season injurious insects. Previously no insecticides were available that would control combination infestations of such early-season pests as thrips, cotton aphids, overwintered boll weevils, and cotton fleahoppers.

The organochlorine insecticides filled this need. Small plot and large-scale experiments (plots ranging in size from 1 to 5 acres) were not too successful in 1946 and 1947. Community-wide experiments in early-season cotton insect control experiments conducted in Wharton County, Tex., in 1948 proved conclusively that an early-season insect control program was profitable and simplified the farmer's control problem. Dusts were used in these experiments, and again it was realized that critical application requirements would limit the effectiveness of the program.

Insecticide Sprays

During the same year the new insecticides were found effective when formulated as emulsifiable concentrates and applied as emulsion sprays in low-pressure, low-volume spray equipment. Community-wide, early-season insect control experiments with sprays conducted in central Texas in 1949 and 1950 gave outstanding results, and the bottleneck was broken. The early-season control program was practiced by growers over wide areas where early season insects were a menace. In the 1950's and 1960's as much as 80 percent of the cotton acreage received such treatment in the Blacklands of central Texas. These experiments were the forerunners of the total insect population suppression and integrated control concepts that attained much popularity in the 1970's.

Spray applications of insecticides for late-season insect control were readily accepted by growers because of several advantages over dusts. They fitted well into a daytime farm operation since they could be applied under more adverse weather conditions than dusts (fig. 17). The spider mite problem, which became somewhat more serious with spray applications of the organochlorine insecticides, was solved when organophosphorus insecticides such as parathion, methyl parathion, and demeton became available as sprays.

In the 1960's the ultra-low volume spray appication of technical materials (less than 0.5 gallon of total spray per acre) was developed. Research results showed that most materials are at least equally effective when they are applied as ultra-low volume sprays compared with the same dose applied as low-volume (conventional) sprays. Only malathion, azinphosmethyl, endosulfan, methyl parathion, and a mixture of malathion plus methyl parathion, however, are approved for ultra-low volume aerial applications to control certain cotton insects. This application technique has the advantage of increased pay load over conventional sprays, which reduces application costs. It is used especially in USDA-sponsored programs of insect suppression.

Resistance to Insecticides

The boll weevil developed resistance to the organochlorine insecticides in the mid-1950's in Louisiana, Arkansas, and Mississippi, and in the other boll weevil infested States in subsequent years. Fortunately, an organophosphorus compound, methyl parathion, was effective and available. Azinphosmethyl, EPN, and malathion became available later. Azinphosmethyl was believed to be the most effective weevilcide available. The carbamate, carbaryl, was used as a control but never gained full grower acceptance because it could be formulated only as a

PN-4434

Figure 17.—Eight-row, low-volume, low-pressure spraying machine in operation.

wettable powder and was more difficult to apply than an emulsifiable concentrate. The toxaphene plus DDT mixture, though both are organochlorines, continued to be effective against resistant boll weevils. But DDT was banned for use on cotton by the Environmental Protection Agency (EPA) on December 31, 1972.

Cotton insects rapidly have developed resistance to insecticides in recent years. Since 1947 when organic chemicals began to have wide usage on cotton, 25 species of insects and spider mites that attack the crop have developed resistance and several other species are strongly suspected of having developed resistance. At least one of these resistant species occur in localized areas in most cotton-producing States from California to North Carolina. Most of these pests are resistant to the organochlorine insecticide, but four species of spider mites, the armyworm, banded wing whitefly, bollworm, and tobacco budworm, are known to be resistant to the organophosphorus compounds.

Resistance in the tobacco budworm and bollworm is serious as few effective insecticides are available. However, the insecticides, methomyl and chlordimeform, which were recently developed, may be of help in this respect. Unfortunately, methomyl is phytotoxic and cannot be used to a regular schedule of applications, and researchers are studying how chlordimeform should be used for greatest effectiveness. The synthetic pyrethroid compounds showed considerable promise for the control of these pests in preliminary tests.

Systemic Insecticides

Systemic insecticides such as phorate and disulfoton developed in the mid-1950's applied to cottonseed protect plants for several weeks after plant emergence from such pests as thrips, the cotton aphid, and spider mites. This method of control, however, has not been widely accepted because the insecticides are expensive, do not give protection as long as desired early in the season, often reduce plant emergence, and may delay fruiting. Granular formulations of systemic insecticides are applied, also, in the seed furrow at planting and as side dressings to established plants. Aldicarb developed in the 1960's applied in the seed furrow at planting killed overwintered boll weevils and controlled cotton fleahoppers 8 weeks after planting. It kills boll weevils developing in cotton squares when applied to plants as a side dressing in the early squaring stage. The application of this compound, especially as a side dressing in the early squaring stage, often results in increased subsequent infestations of the bollworm. Research in the early 1970's showed that aldicarb may be useful in boll weevil eradication or suppression programs when about 2 percent of each field is planted to a trap crop (cotton planted at least 2 weeks before the rest of the field is planted) treated with it.

Appraisal of Insect Control with Insecticides

Three ARS laboratories, Florence, S.C., in the Southeast; Tallulah, La., in the South; and Waco, Tex., in the Southwest, kept annual comparative records of yields in treated and untreated plots for periods of 31, 37, and 32 years, respectively. These results are indicative of the crop losses to insects when insecticides are not applied for their control in those areas. The use of the best insecticides, however, does not prevent all insect damage, and a certain amount of damage can be tolerated before the use of an insecticide is economically feasible. Because more than one insect was usually involved in the experiments, no attempt was made to show how much of the loss in yield was due to a particular insect. Insects involved at all locations were boll weevils, bollworms, cotton aphids, and spider mites. In addition, lygus bugs were involved at Tallulah and the cotton fleahopper and thrips at Waco.

Insect infestations and weather conditions vary from year to year. Thus, comparative records over a period of years are more meaningful than those of selected years. The average increase in yield in treated over untreated plots at Florence for the 31-year period, 1928 to 1958, was 40.6 percent with a range from 5.3 percent in 1942 to 217.9 percent in 1950. At Tallulah for the 37-year period, 1920 to 1956, it was 31.2 percent with a range of 1.1 percent in 1924 to 112.8 percent in 1950; and at Waco for the 32-year period, 1939 to 1970, it was 54.3 percent with a range of 9.9 percent in 1939 to 426.0 percent in 1961.

Considerable improvement has been made in cotton insect control since 1945 with the advent of the organochlorine and later organophosphorus and carbamate insecticides. Before that time growers depended primarily on such inorganic insecticides as the arsenicals and sulphur for insect control. The following tabulation illustrates improvement in insect control since the new insecticides have been used:

Location	Study period	Increase in yield in treated over untreated plots		
		Average	Before 1945	After 1945
		Percent	*Percent*	*Percent*
Florence, S.C.	1928–58	40.6	23.6	53.9
Tallulah, La.	1920–56	31.2	26.4	41.3
Waco, Tex.	1939–70	54.3	34.0	77.6

Total reliance on the control of cotton insects with insecticides is no longer acceptable because of adverse effects of insecticides on the environment. However, development of alternatives to control insects is difficult and costly. Though development of such alternatives has received much emphasis, insecticides will continue in importance in the control of cotton insects (fig. 18). Much concern has arisen because comparatively few candidate insecticides have been researched in recent years. Only chlordimeform, Chevron Ortho 9006, (Monitor), (*O,S*-dimethyl phosphoromidothioate), methomyl, and methidathion have recently been developed and show promise in control of cotton insects and spider mites. A new class of insecticides, however, the

PN-4435

Figure 18.—Cotton untreated (*left*) and treated (*right*) with insecticide.

synthetic pyrethroids, showed promise in preliminary tests toward the end of the reporting period.

The cost of developing and registering a compound is expensive. Industry, therefore, is having to take an extremely hard look at compounds after the initial screening to see whether continuing their development is justified. Consequently, few compounds are being made available in the testing program and even fewer of those make the grade insofar as registration and ultimate use by growers are concerned. The situation is serious in the control of the bollworm complex with development of resistance to the comparatively few available effective insecticides. Hopefully, some of the alternatives to insecticide may be used with insecticides in a pest management system so that crises in insect control may not occur because fewer effective insecticides are available.

Recommendations in the use of insecticides to control the various cotton insects are subject to change from year to year so they are not included in this publication. For such suggestions on control, please consult the respective State Guides for Controlling Cotton Insects.

Juvenile Hormones

The effects of juvenile hormones on several cotton insects have been studied at several laboratories. Though some activity was noted in the boll weevil, lygus bug, cotton aphid, and bollworm, it was not great enough to justify field tests. Activity in the boll weevil was in the larval and pupal stages with no means available to introduce the hormone under field conditions since immature stages develop within the square (fruiting buds) and bolls. In addition, the hormones affecting lygus bugs and the cotton aphid affected some of the predaceous insects, such as the green lacewing. Studies are continuing with the bollworm.

For several years chemists at the Boll Weevil Research Laboratory have attempted to identify a compound from the boll weevil with juvenile hormone activity, and also, to determine whether the *Cecropia* juvenile hormone is the juvenile hormone in the boll weevil. They were unable to isolate a fraction from the boll weevil that was active at less than one microgram though several methyl esters of fatty acids were active at 15 to 30 micrograms. They were unable to isolate the *Cecropia* juvenile hormone from the boll weevil with gas chromatographic and mass spectral procedures on larvae, adults, and adult frass.

Pathogens

In the need for developing alternatives to conventional control of insects with insecticides, attention was given to pathogens for the control of such cotton insects as the boll weevil and the bollworm complex. Evidence of the occurrence of pathogens had been known for many years. For instance, infestations of the cabbage looper, *Trichoplusia ni* (Hübner), were often decimated by a nuclear polyhedrosis virus. Cultures of bollworms being reared under insectary conditions often were wiped out by a virus, and large larvae killed by the virus were observed in the field though the disease never reached epizootic proportions as with the cabbage looper.

Bacillus thuringiensis

The (delta) δ-endotoxin of *Bacillus thuringiensis* (*B.t.*) has insecticidal activity against several species of Lepidoptera including the tobacco budworm and bollworm. It has been shown to be entirely safe to other groups of animals including man, wildlife, beneficial insects, and plants. On this basis, EPA has granted the formulations an exemption from tolerance; however, it is not registered for use against *Heliothis* spp. on cotton.

Before 1973 *B.t.* was assumed to be a disease-producing organism, and the potency of preparations could not be judged by the quantity of spores present. The presence of a toxic crystal associated with the *B.t.* spore, later named the δ-endotoxin, was demonstrated in the 1950's. However, it was not until the early 1970's that the entire activity of the organism was shown to result from the δ-endotoxin. This work showed that toxicity varied from *B.t.* isolates, regardless of serotype, and depending on the medium used for bacterial fermentation. These findings opened the way for development of a bioassay standardization procedure that could be used to gage the potency of preparations and ultimately to provide more potent preparations. An isolate 15 to 20 times more active against the tobacco budworm and some other insects than commercial materials available at the time was then developed. This development was rapidly put to use by commercial producers of *B.t.*, which led to a great increase in the use of the product, chiefly against certain vegetable insects such as the cabbage looper and against *Heliothis* on tobacco.

Tests with *B.t.* against *Heliothis* in the laboratory and in the field on cotton have shown it to be effective. The rates, however, required to achieve control on cotton in the field (2 to 12 pounds per acre) are not economical. The primary reason why large amounts of *B.t.* are needed to achieve control of *Heliothis* on cotton is that the material must be ingested by the larvae to be effective, and most of the feeding by *Heliothis* on cotton is within the fruit where little *B.t.* is present.

Research is continuing to increase the potency of *B.t.* preparations against *Heliothis* spp. by selection of new isolates. Improvement of fermentation media has achieved a 15-fold increase in the yield of δ-endotoxin, thus, reducing the amount of material needed to control the pests. Also, the use of various baits containing cornmeal or cottonseed oil to increase the amount of larval feeding on the *B.t.* has shown promise of reducing the quantity of *B.t.* needed for control of *Heliothis*. Despite this continuing research, an effective and economical formulation will probably not be available for commercial use on cotton for a few years.

Heliothis Nuclear Polyhedrosis Virus

The nuclear polyhedrosis virus of *Heliothis* is an obligate parasite that multiplies within the cells of larvae of *Heliothis* spp. and causes a fatal disease. The virus was found first in this country in larvae collected from cotton near San Benito, Tex. (fig. 19). Since then, the material has been developed through laboratory, pilot-plant, and commercial stages.

The virus has received a temporary exemption from tolerance by EPA with annual renewals and has been registered for sale in Spain. It is completely harmless to all animals (including man) except *Heliothis* spp. Before this product can be registered, however, its efficacy must be more fully demonstrated.

Since the virus is an obligate parasite, it must be produced in living *Heliothis* spp. larvae or on tissue cultures. Two companies are currently producing it in living *Heliothis* larvae. An estimated 2,000 to 4,000 pounds of the product were produced in 1974.

Results of field tests of this virus against *Heliothis* spp. on cotton have been variable, control equal to or better than that produced by standard insecticides has been achieved in some instances, and inadequate control has resulted in others. These differences appear to result from the rapid deactivation of the virus by sunlight and the feeding behavior of *Heliothis* noted in the section on *B.t.*

Studies by several workers indicated that the unprotected virus on foliage was deactivated by exposure to sunlight, with most of the activity gone after 24 hours. Some progress has been made in overcoming tnis problem by adding various ultraviolet-screening agents to formulations of the virus. The activity has been extended at least 25 hours by this means, but apparenty none of the preparations was considered adequate for further development.

Research to overcome the problem relating to the feeding behavior of *Heliothis* spp. by obtaining better coverage of the plants, increasing the amount of virus applied, and using baits has been partially successful. Better control was obtained by reducing the size of the spray particle and by increasing the volume of spray applied per acre. Some workers reported the effectiveness was substantially improved by increasing the rate of application from the suggested 40 diseased larval-equivalents to 5,000 per acre. Baits containing such ingredients as water extract of corn silks, cottonseed oil, and sugars have improved efficacy.

Apparently, the formulations of the *Heliothis* virus that have been studied do not give the

PN-4486

Figure 19.—Diseased bollworm larva on leaf.

desired degree of control on cotton, especially when heavy infestations occur. Effective economical formulations, however, may be produced in the next few years.

The alfalfa looper, *Autographa californica*, nuclear polyhedrosis virus has shown activity against several lepidopterous pests of cotton and may have potential in their control.

Other Pathogens

At the Boll Weevil Research Laboratory results of biological control tests showed that *Beauveria bassiana* can infect larvae, pupae, and adult boll weevils in the laboratory, but it cannot be cultured for practical use in the field. Laboratory cultures of the boll weevil became infected with a new species of neogregarine that subsequently was named *Mattesia grandis* McLaughlin. The ensuing epizootic resulted in destruction of the boll weevil colony. To be effective, the neogregarine had to be ingested by the adult boll weevils. A cottonseed oil bait was developed to enhance ingestion of the pathogen. Production and application problems have prevented the pathogen from becoming a practical tool in the control of the boll weevil.

Physiology and Morphology

Boll Weevil

In the late 1950's a study was made of the reproductive system of the boll weevil. The genitalia and reproductive organs of the reproducing male and female were described and illustrated. The musculature associated with the reproductive systems of both sexes were described. Results of studies at the same time showed that the spermatheca of the female may provide a useful basis for identification of Thurberia weevils.

Dehydrogenases were studied in the brain and in the related neural and secretory structures in the boll weevil. The fatty acid fraction of the boll weevil is a complex mixture of 23 fatty acids ranging in chain length from 6 to 20 carbon atoms. Total body fat of the boll weevil and relative distribution in major lipid classes are dependent on adult age, larval and adult diet, and diapause. Neutral glyceride and free fatty acid fractions account for as much as 90 percent of extractable lipids of diapausing adults. Newly emerged weevils have 2 to 6 percent body fat (about 2 percent triglyceride). After 2 to 3 weeks of feeding, nondiapausing adults have 6 to 10 percent body fat (40 to 60 percent triglyceride), but diapausing adults have 18 to 25 percent body fat (75 to 85 percent triglyceride). The triglyceride level drops during the winter when the insects are not feeding.

Several guanine analogs were tested as inhibitors of reproduction. Two, 8-bromoguanine and 9 methyl, 2 butyl guanine were effective ovarial growth inhibitors in the boll weevil. Larvae reared in a radioactive medium were inhibited in their development and only a small percentage developed to adulthood. The purine guanine was identified in the excreta of the boll weevil. The effects of nitrogenous-end products of the metabolism of the boll weevil fed on artificial diet, cotton squares, or bolls were determined. Fecal analyses for amino acids, nitrogen, ammonia, creatines, creatinine, guanine, urea, and uric acid showed that presence of these materials varied with the type of diet fed the insects. The purine guanine was found in relatively large quantities in the feces of weevils fed all three diets. The feces of the boll weevil were examined for nonprotein amino acids. A total of 20 amino acids were detected in ethanalic extract with chromatographic techniques, and 23 acids were detected by acid hydrolysis. The free and bound nonprotein amino acids and ammonia accounted for 3.23 percent of total feces nitrogen.

No striking effects of DDT, toxaphene, or a combination of these two insecticides on the activity of succinic dehydrogenase were shown. In a study of the activity of ATPase in homogenates of the boll weevil, sufficient magnesium occurred to activate the enzyme. Additional magnesium did not increase activity of the enzyme. A higher level of ATPase occurred in a laboratory-reared than in a field-cultured population.

Bollworm

Differences in percentages of phospholipids, partial glycerides, and triglycerides were found between large and small larvae of the tobacco budworm and the bollworm and, also, between the two species. The difference may explain the greater tolerance of the tobacco budworm to insecticides. High percentages of fatty acids in bollworm larvae may have a role in the naturally greater tolerance of the tobacco budworm to insecticides because they could affect the solubility of insecticides in lipids or the characteristics of cell membrane.

The bollworm moth vibrates its wings during courtship, and the male wipes the scales of his claspers on a supporting surface between periods of vibration. Receptive females extend the terminal abdominal segments and vibrate their wings. Then, the receptive female, whose terminal abdominal wings are extended, is approached from behind by the male who taps the ovipositor of the female with his antennae, crawls to a position at the side of and about 2 cm from and parallel to her, and snaps his claspers around her genitalia to complete the copulatory connection. Mated pairs remain in copula from ¾ to 1½ hours.

Histological studies of the structure of the compound eyes of the tobacco budworm and bollworm indicated that the major structural difference between the eyes of the two species is the relatively shorter ommatidia in the eye of the tobacco budworm. Whether this morphological difference affects the sensitivity of the eye to wavelength or intensity of light stimuli is not known. Results of behavioral and electrophysiological studies on the visual sensitivity of the bollworm and tobacco budworm indicate that these moths detect the radiant energy from 15-W ultraviolet lamps from a limited distance only and that the 15-W BL lamp would be useful only for surveying the activity of the bollworm and tobacco budworm moth population in a limited area near the trap.

Rearing

Research on cotton insects was hampered for many years because of difficulties encountered in rearing them in the laboratory. Rearing insects on their hosts was difficult from the standpoint of needed numbers as well as being quite expensive. Major breakthrough in research could only come with ability to mass rear the various insects on artificial diets.

Pink Bollworm

The first phytophagous insect to be reared on an artificial diet was the pink bollworm so reared in the early 1950's at the College Station, Tex., ARS Cotton Insects Laboratory. The artificial diet developed for this insect served as the basic diet for many phytophagous insects now being mass reared in the laboratory as a result of this research. The pink bollworm was mass reared in tremendous numbers in the late 1960's and 1970's in the USDA, of the now Animal and Plant Health Inspection Service Laboratory in Phoenix, Ariz. (See section on Genetic Control in this publication.)

Boll Weevil

In the early 1960's boll weevils were reared on artificial diets at the College Station, Tex., Cotton Insects Research Laboratory. Progress in mass rearing the insect was made with the establishment of the Boll Weevil Research Laboratory on the Mississippi State University Campus in 1962. After it became apparent that the insect could be reared in sufficient numbers, it was deemed that a Pilot Boll Weevil Eradication Experiment should be conducted to determine whether it was technologically and operationally feasible to eradicate the boll weevil. Through a more than a half million dollar appropriation by the Mississippi Legislature, the Gast Insect Rearing Laboratory was built on the campus of Mississippi State University. Though problems with the facility and with rearing procedures were such that numbers of boll weevils needed for sterile male releases in the experiment were not reached, the facility made a significant contribution to the success of the experiment. It is expected to make an even greater contribution if elimination of the insect from the United States is undertaken.

Bollworm

Nutrition and techniques for rearing the bollworm, also, were developed at the College Station laboratory. Though small cultures have been reared at several laboratories, the major thrust in mass rearing has been done at the ARS Southern Grain Insect Laboratory at Tifton, Ga. A prototype machine for mass rearing the insect has been developed at this laboratory.

Tobacco Budworm

Techniques for mass rearing the tobacco budworm were developed at the Brownsville, Tex., laboratory in the late 1960's and early 1970's. Production was stabilized at about 60,000 pupae per day. Pupae were furnished from this laboratory for the sterile male release study conducted on St. Croix, U.S. Virgin Islands, in the early 1970's. In addition, moths were reared for several years for the identification of the sex pheromone emitted by the female. Chromatographic analysis indicated the pheromone to be a multiple component system. The sex pheromone was isolated, purified, identified, and synthesized early in 1974.

Lygus Bugs

Lygus bugs, *Lygus hesperus* and *L. Lineolaris,* have been reared on artificial diets. Techniques for mass rearing them on these diets, however, have not yet been developed.

Saltmarsh Caterpillar

The saltmarsh caterpillar, *Estigmene acrea* (Drury) has been reared on the wheat-germ diet at the Cotton Insects Research Laboratory, College Station, Tex., and has been mass reared at the Biological Cotton Insect Control Laboratory, Tucson, Ariz.

Beneficial Insects

The green lacewing has been reared on an artificial diet, and some progress has been made in mass rearing it on this diet. Some progress has been made in rearing *Campoletis perdistinctus* and *Micropletis senorensis,* parasites of *Heliothis* spp., on artificial diets.

Pilot Boll Weevil Eradication Experiment

Cotton leaders have repeatedly emphasized that the economic survival of the industry depends on adequate research necessary to strengthen cotton's ability to compete for markets. Scientists and industry leaders agreed that the boll weevil represented one of the most costly problems confronting the cotton industry and, therefore, was one of cotton's major problems in urgent need of research support. In the Agricultural Appropriation Reports for Fiscal Year 1959, both the House and Senate Committees requested the Secretary of Agriculture to review the boll weevil problem and to submit a report on research and facility needs to meet the problem to the next appropriations committees.

The Office of the Secretary appointed a working group consisting of E. R. McGovran, Cooperative State Research Service (CSRS), USDA; H. G. Johnston, National Cotton Council of America, and E. F. Knipling (chairman) and C. R. Parencia (secretary), ARS, USDA, to study the problem. In addition the group was to (1) develop information on current research programs devoted to boll weevil investigations by State, Federal, and private industry; (2) determine the needs for an overall comprehensive research program; and (3) determine the broad areas of research that would be appropriate for Federal attention and support in an effort to help meet the overall needs. The group's report was submitted to the Secretary on December 30, 1958. This report culminated in appropriations by Congress to establish the Boll Weevil Research Laboratory at State College (now Mississippi State), Miss., and to strengthen ongoing research programs at the Cotton Insect Research Laboratories at College Station, Tex.; Baton Rouge, La.; and Florence, S.C. The new research facility at Mississippi State was dedicated in a formal ceremony in March 1962. Research on the boll weevil was simultaneously strengthened in several State agricultural experiment stations.

Significant research findings resulting from the expedited research on the boll weevil were: (1) Techniques for mass rearing the boll weevil; (2) development of the reproduction-diapause control program; (3) development of ultra-low volume spray applications of insecticides; (4) development of the systemic insecticide, aldicarb, that controls the boll weevil; (5) finding that the male boll weevil emits a pheromone that attracts females and, also, acts as an aggregant; (6) identification and synthesis of the attractant, grandlure, and development of traps baited with it for capturing boll weevils; (7) progress in development of a chemosterilant making the male-sterile release technique feasible; (8) use of trap crops treated with aldicarb in furrow and as a side dressing together with grandlure bait in reducing overwintered boll weevil populations; and (9) progress in the development of a frego bract strain of cotton with considerable resistance to the boll weevil.

In recognition of the importance and urgency of eliminating the boll weevil problem as soon as it became technically and operationally feasible, the National Cotton Council of America in its 1969 annual meeting established a Special Study Committee on Boll Weevil Eradication. The Special Study Committee met in Memphis, Tenn., on May 6, 1969, to review the status of current knowledge of boll weevil suppressive measures and to consider actions that should be taken in efforts toward the elimination of the boll weevil as a pest of cotton. The chairman of the Special Study Committee appointed a Subcommittee of P. L. Adkisson, Texas A&M University; J. R. Brazzel, APHIS, USDA; H. G. Johnston, National Cotton Council; D. F. Young, Mississippi State University; and C. R. Parencia (secretary) and E. F. Knipling (chairman), ARS, USDA, to select areas representative of boll weevil conditions in the southeast, south, and southwest areas of the Cotton Belt that would be suitable for undertaking large-scale experiments to determine if boll weevil eradication is feasible with currently available suppression techniques. The Subcommittee prepared a report dated August 15, 1969, that was presented to the Special Study Committee on Boll Weevil Eradication in Memphis, Tenn., on September 16, 1969. It recommended that a Pilot Boll Weevil Eradication Experiment be conducted beginning in calendar year 1970 in an area centered in South Mississippi and including adjacent cotton acreages in Alabama and Louisiana.

The Special Study Committee accepted the recommendations of the Subcommittee and its representatives met with USDA officials to discuss ways of financing the experiment. A decision was made that the project would be financed by $1 million from ARS (later with APHIS), $500,000 from CSRS, and $500,000 from industry, Cotton Incorporated, for each of 2 years. Mississippi was to provide a rearing facility. A detailed study of the area was made, and the cost of the experiment was estimated at $2.5 million. Since only $2 million was available, the experiment was delayed for a year or until the needed additional funds could be obtained. In 1971, however, the new cotton program resulted in a considerable reduction in the cotton acreage to be planted, making it possible to start the experiment with available funds. The Director of Science and Education of the Department appointed a Technical Guidance Committee for the Pilot Boll Weevil Eradication Experiment.

The experiment got under way in July 1971 (fig. 20). It was conducted cooperatively with the Departments of Agriculture, Experiment Stations, and Extension Services of Mississippi, Louisiana, Alabama, and Texas; with Cotton Incorporated and the National Cotton Council representing the industry; and with USDA's APHIS, ARS, CSRS, ASCS, and ES. The reproduction-diapause phase of the experiment was carried out in the fall of 1971. Unfortunately boll weevil populations were very heavy, and as a result of the mild winter, survival of boll weevils was high. A trap crop treated with aldicarb was planted in each field in the eradication and first buffer areas, and pheromone traps at the rate of 2 per acre were placed around each field in 1972. An insecticide application was made when plants began to square. A period of dry weather resulted in late emergence of weevils from hibernation sites, leaving too many weevils in the fields for the sterile male releases to be effective.

Five in-season applications of azinphosmethyl were made followed with 13 applications for reproduction-diapause control. By October adults were too scarce to be detected. Pheromone trap catches in the spring of 1973 indicated very low surviving populations in the eradication and first buffer areas. Release of sterile males began in early June, but rearing problems necessitated reducing releases to 50 per acre instead of the hoped for 100 in the eradication area and extending only 5 miles into the first buffer area. Both areas originally were planned to receive 100 sterile males per acre per week. Fields with infestations in the remaining first buffer fields were to be treated with insecticides.

Only 33 of the 236 fields were infested in the eradication area, and they were in the northern zones nearest the first buffer. Indications were that the problem was caused by migration from the second buffer where overwintering populations were considerably higher. Infested fields were treated at 3-day intervals with azinphosmethyl. As a result of these treatments, reproduction could not be detected in 32 of the 33 fields at the end of the experiment. The infestation in the one field was not detected until the last week of the experiment so that time did not permit total elimination of reproduction in it.

The experiment was terminated on August 10, 1973, and the Technical Guidance Committee met on August 30 to evaluate the results. The committee concluded "that it is technically and operationally feasible to eliminate the boll weevil as an economic pest in the United States by the use of techniques that are ecologically acceptable."

Members of the committee were as follows: P. L. Adkisson, Texas A&M Univ.; F. S. Arant, Auburn Univ.; Richard Carleton, La. Dept. Agr.; T. B. Davich, E. F. Knipling (co-chairman), and C. R. Parencia (secretary), ARS;

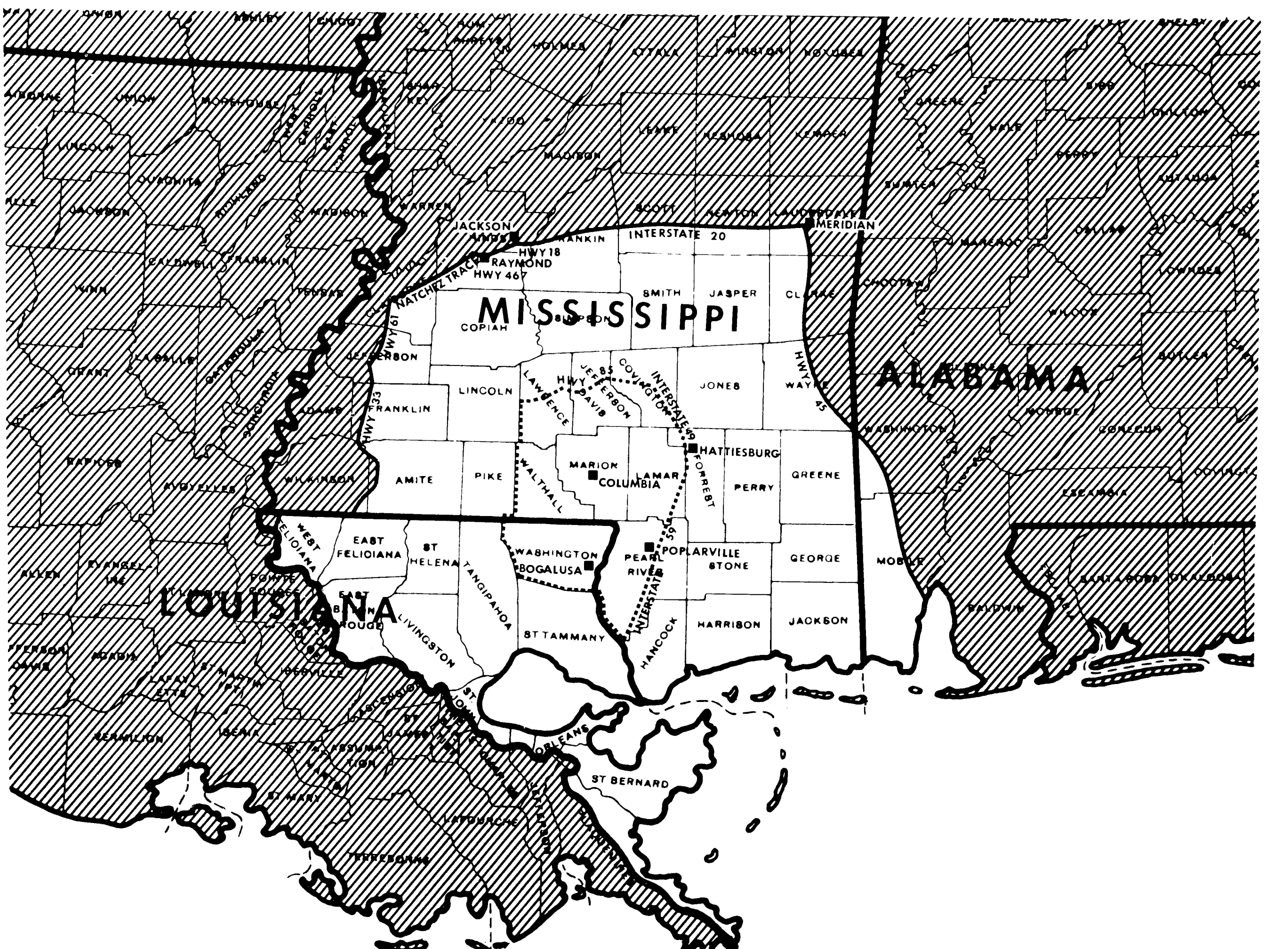


Figure 20.—Site of Pilot Boll Weevil Eradication Experiment, 1971–73.

R. C. Riley, CSRS, and W. F. Helm, J. R. Brazzel, and D. R. Shepherd, APHIS, USDA; C. C. Fancher and O. T. Guice, Miss. Dept. Agr. and Com.; F. G. Maxwell and David Young, Miss. State Univ.; J. S. Roussel, La. Agr. Expt. Sta.; W. A. Ruffin, Ala. Dept. Agr.; George Slater, Cotton, Inc.; and Ritchie Smith, National Cotton Council.

The National Cotton Council's Special Study Committee for Boll Weevil Eradication met in Memphis, Tennessee, on January 10, 1972, to review the progress and status of the experiment. The Committee expressed a need for a comprehensive, overall eradication plan that would outline areas for initiation and subsequent target zones, timetables, probable costs, program requirements, operational arrangements, and the like. The chairman appointed a Technical Committee to Develop a Plan for Overall Boll Weevil Eradication.

Members of the Technical Committee were P. L. Adkisson, Texas A&M Univ.; C. R. Jordan of Univ., Ga.; D. F. Young, Miss State Univ.; H. L. Breur, Tenn. Dept. of Agric.; George Slater, Cotton Incorporated; James Brown, the National Cotton Council; H. M. Taft, ARS; C. R. Parencia, ARS, Secretary; J. R. Brazzel, APHIS, Vice Chairman; and E. F. Knipling, ARS, Chairman.

Though two preliminary meetings were held in November 1972 and early January 1973, the work of the Committee did not gain impetus until results of the experiment became available at the end of August. An overall Plan for a National Program to Eliminate the Boll Weevil From the United States was presented by the Technical Committee to the Special Study Committee on December 4, 1973. It was accepted and, in turn, presented to the Secretary of Agriculture on December 12. In the Agricultural Act of 1973, the Secretary had been instructed to carry out elimination programs for the boll weevil, pink bollworm, and other cotton insects if he determined that it was feasible to do so.

After much discussion with various agencies, it was decided that a 3-year Boll Weevil Eradication Trail be conducted in northeast North Carolina and adjacent cotton growing areas of Virginia. Funding for the trail was included in the Department of Agriculture's budget but was not included in the budget presented to the President by the Office of Managèment and Budget. Initiation of the trail is awaiting funding.

Field Laboratories

Tallulah, La.

The Tallulah laboratory was established in 1909 and was in continuous operation until it closed at the end of June 1973. The laboratory was the oldest continuously operated insect research laboratory in ARS. It was selected as an ideal location to do research on the boll weevil, and it developed the first practical method of controlling the boll weevil with calcium arsenate. Its acknowledged leadership in research on the new cotton pest was discussed in the section of the boll weevil. It continued to be an ideal location to do practical field research on the boll weevil because winter survival was usually high and climatic conditions were favorable for rapid population buildup. It was in a remote location, and the facilities were poor with no opportunities for laboratory personnel to associate with other research scientists. For these reasons and for economy, the laboratory was closed and the equipment and personnel transferred to the Stoneville, Miss., laboratory. The program of research in recent years was centered around the biology and control of the boll weevil with some emphasis on the bollworm, lygus bugs, and thrips. Large plot field tests were conducted to evaluate promising new insecticides and formulations against these insects.

Florence, S.C.

The Southeastern Cotton Insects Investigations Laboratory was established in 1921 in cooperation with the South Carolina Agricultural Experiment Station and thereafter has been in continuous operation. The program involves (1) electrophysiological research to discover and develop practical methods of using electromagnetic energy to control the bollworm, tobacco budworm, and boll weevil; (2) ecological research on the boll weevil, bollworm, and tobacco budworm; (3) physiological and nutritional research on the boll weevil and bollworm; (4) evaluation of insecticides against cotton insect pests indigenous to the Southeastern States; and (5) development of machinery for applying insecticides (in cooperation with agricultural engineers).

Tucson, Ariz.

The Cotton Insects Biological Control Investigations Laboratory was established in the spring of 1925 (Tucson, Ariz., Cotton Insects Laboratory) to study the life history and habits of the Thurberia weevil. After these investigations showed that this insect would not likely become a serious cotton pest, research was turned to hemipterous insect pests and later to lepidopterous insect pests of cotton. Primary emphasis now is on the biological control of cotton insects. The program consists of research on (1) population dynamics of cotton insects, (2) bioclimatology, and (3) biological control agents, particularly parasites and predators of cotton's lepidopterous insect pests, including the development of mass-rearing techniques and field evaluations.

Stoneville, Miss.

The Delta Cotton Insects Investigations Laboratory was established in Stoneville, Miss., in 1934 in cooperation with the Mississippi Agricultural Experiment Station. It has recently been made a part of the Bioenvironmental Insect Control Laboratory in Stoneville. The research program at Stoneville involves (1) biological and ecological research on the boll weevil under Mississippi Delta conditions; (2) small field plot and entire field evaluations of insecticides for control of boll weevil, bollworm, tobacco budworm, plant bugs, thrips, spider mites, and cotton aphids; (3) biological, nutritional, and physiological research on the bollworm, tobacco budworm, plant bugs, and spider mites; (4) development of cotton varieties resistant to or tolerant of attack by lygus bugs and spider mites; (5) biological control involving parasites and predators; and (6) insect population management programs.

Waco, Tex.

The Blacklands Cotton Insects Investigations Laboratory was established in Waco, Tex., in March 1939 by consolidating the work of the two laboratories located at Port Lavaca and College Station. The laboratory continued in operation until it was closed at the end of June 1973. The program was concerned with research on (1) biology and ecology of the boll weevil, bollworm, tobacco budworm, cotton fleahopper, and thrips; (2) comparative field plot evaluation of promising new insecticides and formulations; (3) large-scale evaluation of seasonal control programs; and (4) development of a practical insect population management program for the Blacklands area.

Baton Rouge, La.

The Cotton Insects Physiology Investigations Laboratory was established on July 15, 1956, in cooperation with the Louisiana Agricultural Experiment Station. It was first designated as Cotton Insects Insecticide Resistance Investigations and was specifically set up to study factors influencing resistance of the boll weevil to insecticides and to develop methods of overcoming this resistance. Much of the work was physiological and biochemical. After more than 12 years of work on the resistance problem, it became evident that this line of research would not attain its objective. Many other investigators working simultaneously on other insect resistant problems came to the same conclusion. Since the staff members were trained in insect physiology and biochemistry and since it was actually contributing much to physiological research, the laboratory was redesignated as the Cotton Insects Physiology Investigations Laboratory on July 17, 1969. The program is centered around research on (1) chemosterilants, (2) hormones and other essential metabolites and biological regulators, and (3) carbohydrate metabolism in the boll weevil.

Brownsville, Tex.

The Southwestern Cotton Insect Investigations Laboratory was established in 1941 specifically to conduct research on the pink bollworm. It had operated as a sublaboratory of the

Presidio, Tex., laboratory in 1939 and 1940. Research was primarily concentrated on the pink bollworm until findings showed that the insect could be controlled with cultural methods. Gradually, the pink bollworm became less of a problem, while the bollworm-tobacco budworm problem intensified. The program now is largely concerned with research on lepidopterous insect pests of cotton. The program consists of research on (1) developing practical ways of sterilizing the pink bollworm and the tobacco budworm, (2) developing practical and economical ways of mass rearing the tobacco budworm, (3) studying the biology and ecology of the boll weevil, bollworm, and tobacco budworm, (4) isolating, identifying, and synthesizing the sex pheromone of the tobacco budworm, (5) evaluating promising new insecticides and formulations against Southwestern insect pests of cotton in laboratory and field tests, (6) developing practical ways of using *Bacillus thuringiensis* and other pathogens for control of cotton insect pests, (7) evaluating parasites and predators as biological control agents of cotton insect pests, (8) developing cotton varieties resistant to or tolerant of attack by insect pests of cotton, (9) studying alternate host plants of the boll weevil, bollworm, tobacco budworm, and cotton fleahopper, and (10) studying, both biochemically and nutritionally, lepidopterous insect pests of cotton.

College Station, Tex.

The Cotton Insects Systemic Chemical and Nutritional Investigations Laboratory was established in 1948 in accordance with the terms of the Research and Marketing Act of 1946 in cooperation with the Texas Agricultural Experiment Station. The program is concerned with research on (1) the nutritional requirements for several cotton insects including predaceous and parasitic insects, (2) the development of nutritionally adequate artificial diets on which these insects may be reared, (3) the discovery and development of systemic chemicals that may be useful in cotton insect control, (4) the development of practical methods of utilizing predators and parasites for the control of lepidopterous insect pests of cotton, (5) determination of the metabolites and other degradation products in the breakdown of insecticides, and (6) development of slow release formulations of systemic insecticides and synthetic pheromones.

Mississippi State, Miss.

The Boll Weevil Research Laboratory was established in 1961, resulting from recommendations made by The Secretary's Working Group on Boll Weevil Research Programs in 1958. Its primary objective is "the elimination of the boll weevil as an economic factor in cotton production," with the ultimate objective of eradicating it. The research program is multidiscipline involving entomologists, chemists, plant geneticists, plant physiologists, agricultural engineers, and soil and water research scientists. A comprehensive program of research is currently underway involving (1) biology and ecology of the boll weevil, (2) development of an attractant bait containing pathogens to control the boll weevil and bollworm, (3) mechanical control of the boll weevil, (4) research on the male pheromone (grandlure) as a survey, control, and possible eradication tool, (4) chemosterilant research on the boll weevil, (6) breeding cotton varieties resistant to or tolerant of attacks of the boll weevil, (7) integrated control of cotton pests, (8) physiological and nutritional research including mass rearing of the boll weevil, and (9) large-scale evaluations of promising leads in the suppression or eradication of the boll weevil.

Phoenix, Ariz.

The Western Cotton Insects Investigations Laboratory was established in October 1965. Previously, a sublaboratory of the Tucson laboratory had been operated at Mesa. The Department's 1965 Appropriation Act (78 Stat. 862), approved September 2, 1964, authorized and provided planning money only for a Western Cotton Insects and Cotton Physiology Laboratory. The 1966 Appropriation Act (79 Stat. 1165), approved November 2, 1965, authorized and provided funds. The laboratory was completed in 1970 and was fully staffed in 1972. The program is concerned with (1) ecological investigations of the pink bollworm, (2) evaluation of sex pheromones and different trap designs for luring and trapping the pink bollworm, (3) genetic investigations of the pink bollworm and other Western cotton insect pests, (4) development of methods other than chemical for control of Western cotton insects including breeding cotton varieties resistant to or tolerant of attack by insects and pathogens, and (5) development of insect population and management programs.

ANNUAL CONFERENCE ON COTTON INSECT RESEARCH AND CONTROL, 1947-74

Each year research and extension entomologists and associate technical workers from 14 cotton-growing States, the United States Department of Agriculture, the National Cotton Council of America, and Cotton Incorporated meet to review research and experiences of the previous year and to formulate guiding statements for control recommendations in the subsequent year.

The advent of the organic insecticides for cotton insect control in the mid-1940's was responsible for the origin of the conference. DDT was used experimentally in 1944 and 1945, BHC, the BHC plus DDT mixture, and toxaphene in 1946. Others, such as aldrin, dieldrin, endrin, heptachlor, and parathion, followed shortly thereafter. These new insecticides were such an improvement over those previously available that their evaluation as quickly as possible was imperative. Equally important was that all concerned with cotton insect control have the latest information on the performance of the various insecticides available to them.

R. W. Harned, who was in charge of cotton insect research for the Department from 1931 to 1953, is credited with being the "father" of the conference. In the fall of 1946, he called a conference of employees of his Division's laboratories at Tallullah, La. Appropriate agricultural experiment station and extension service personnel of Louisiana and Texas were invited to participate. That conference was a forerunner of the First Annual Conference on Cotton Insect Research and Control held in Stoneville, Miss., November 17-19, 1947. Others in the Agricultural Research Administration (ARA) who supported Professor Harned in initiating the conference in addition to laboratory leaders F. F. Bondy, E. W. Dunnam, R. C. Gaines, K. P. Ewing, and A. J. Chapman were A. S. Hoyt, F. C. Bishopp, R. L. Haller, E. R. McGovran, and M. P. Jones. Others from the States supporting the conference were Dwight Isely and Charles Lincoln, Arkansas; F S. Arant and Jerry Ruffin, Alabama; C. E. Smith and W. S. McGregor, Louisiana; Clay Lyle and L. C. Murphree, Mississippi; Walter Kulash and Jim Conner, North Carolina; M. D. Farrar and W. C. Nettles, South Carolina; H. G. Johnston and C. A. King, Texas; and F. A. Fenton and C. F. Stiles, Oklahoma.

ARS and its predecessor, ARA, have always had the major responsibility for the management and coordination of the conference. R. W. Harned served as general chairman for the first six conferences, K. P. Ewing for the next four, C. F. Rainwater for the next eight, and C. R. Parencia for the next nine. The structure has not been changed because it has worked well. Also, it was essential that the revised conference report be made available at an early date and ARS had the mechanism for its publication. With the help of many people, the report has been published by the end of February each year after the January conference. The general chairman serves as chairman of the program committee that develops the program for each conference and, also, has the responbility for the annual revision, publication, and distribution of the conference report. The report is generally considered to be the cotton insect control bible of the world. It is distributed throughout the world where cotton is grown.

As a result of the annual conferences, there is no other agricultural area with as much compatibility among State, ARS, and industry personnel in the research, extension, and control efforts for insects than those that attack cotton. The Twenty-Seventh Annual Conference was held in Dallas, Tex., on January 7–9, 1974.

STATUS OF COTTON INSECT CONTROL

Much has been accomplished in the development of procedures for the control of cotton insects, and growers are doing a better job of controlling them than they have ever done before. However, much continues to need to be done, especially since growers face resistance to insecticides in more and more insects and more and more restrictions are being placed on insecticides used to control various pests. These restrictions may result in reduced development and availability of new insecticides in the future. Thus, future procedures for controlling insects will have to be even more sophisticated.

Research has progressed to the extent that it is operationally and technologically feasible to eradicate the boll weevil as an economic pest of cotton from the United States with environmentally acceptable techniques. Various known components need to be put together and tested in a large field trial to determine whether the pink bollworm, too, can be eradicated. Both pests are host specific to cotton for all practical considerations. Unfortunately, this is not true with the other injurious pests.

Much progress has been made in developing procedures for managing cotton insect populations. However, it would be much easier to manage populations of the bollworm and tobacco budworm if the boll weevil were eradicated. Insecticides used for the boll weevil destroy beneficial insects, which often in the absence of insecticides keep bollworm populations below economic levels. As a result subsequent injurious infestations of bollworms occur, necessitating treatment for these insects until the crop matures even though boll weevil populations have been reduced below injurious levels. The mass release of predators or parasites cannot be used for control of bollworms when insecticides are applied for the control of another pest. Presently known procedures for reducing boil weevil populations permit effective management of bollworm populations, but this would be much easier to accomplish if the boll weevil did not have to be considered.

In the Imperial and Coachella Valleys of California, insecticidal control for the pink bollworm precludes management of bollworm populations. In areas of the Southwest where cultural and other controls keep pink bollworm populations at low levels, the pink bollworm is not considered a key insect and thus does not contribute to the disruption of management of insect populations.

The cotton fleahopper in the Southwest, Texas and Oklahoma, is a key insect. Unless a way, such as a resistant variety, is developed to eliminate the need for its control with insecticides, it will, just as was discussed for the boll weevil, continue to interfere with management of bollworm populations. Lygus bugs have similar status in the Far West, Arizona and California.

The changing status of the bandedwing whitefly, the cotton leafperforator, and the beet armyworm as pests of cotton must be considered. The bandedwing whitefly is becoming a problem in areas other than in northeast Louisiana. The cotton leafperforator, though a pest commonly associated with the Far West, is becoming more prevalent in certain areas in Texas. The beet armyworm, also, considered to be a pest of cotton in the Far West, has increased in importance in the Midsouth and Southeast.

Though much progress has been made in cotton insect control, improvements continue to be needed, and judging from progress made in the last two decades they will be developed in the future.

REFERENCES

(1) Adkisson, P. L., E. S. Vanderzant, D. L. Bull, and W. E. Allison. 1960. A wheat germ medium for rearing the pink bollworm. Journal of Economic Entomology 53: 759–762.

(2) Agee, H. R. 1969. Mating behavior of bollworm moths. Entomological Society of America Annals 62: 1120–1122.

(3) ——— 1972. Histology of the compound eye of *Heliothis virescens* (Lepidoptera: Noctuidae). Entomological Society of America Annals 65: 767–768.

(4) ——— 1972. Sensory responses of the compound eye of adult *Heliothis zea* and *H. virescens* to ultraviolet stimuli. Entomological Society of America Annals 65: 701–705.

(5) Bariola, L. A., J. C. Keller, D. L. Turley, and J. R. Farris. 1973. Migration and population studies of the pink bollworm in the arid west. Environmental Entomology 2: 205–208.

(6) Bierl, B. A., Morton Beroza, R. T. Staten, and others. 1974. The pink bollworm sex attractant. Journal of Economic Entomology 67: 211–216.

(7) Bishopp, F. C. 1911. An annotated bibliography of the Mexican cotton boll weevil. United States Department of Agriculture, Bureau Entomology Circular 140, 30 pp.

(8) ——— 1929. The bollworm or corn earworm as a cotton pest. United State Department of Agriculture Farmers' Bulletin No. 1595, 15 pp.

(9) ——— and C. R. Jones. 1907. The cotton bollworm; a summary of its life history and habits with some results of investigations in 1905 and 1906. United States Department of Agriculture Farmers' Bulletin 290, 32 pp.

(10) Boheman, C. H. 1843. Genera et species curculionidum cum synononynia hyjers familiae. Ed., C. J. Schonherr. 5: 232–233.

(11) Byran, D. E., R. E. Fye, C. G. Jackson, and R. Patana. 1973. Releases of *Bracon kirkpatricki* (Wilkinson) and *Chelonus blackburni* Cameron for pink bollworm control in Arizona. United States Department of Agriculture Production Research Report No. 150, 22 pp.

(12) ——— R. E. Fye, C. G. Jackson, and R. Patana. 1973. Releases of parasites for suppression of pink bollworms in Arizona. United States Department of Agriculture, Agricultural Research Service, ARS W–7, 8 pp.

(13) Bryan, D. E., C. G. Jackson, and Adair Stoner. 1969. Rearing cotton insect parasites in the laboratory. United States Department of Agriculture Production Research Report No. 108, 13 pp.

(14) Bullock, H. R., and H. T. Dulmage. 1969. *Bacillus thuringiensis* against pink bollworms on cotton in field crops. Journal of Economic Entomology 62: 994–995.

(15) Burton, R. L. 1969. Mass rearing the corn earworm in the laboratory. United States Department of Agriculture, Agricultural Research Service ARS 33–134, 8 pp.

(16) Chapman, A. J., R. A. Bell, and C. M. Ignoffo. 1967. Field tests with nuclear polyhedrosis virus for control of *Heliothis* in the southern high plains of Texas. Journal of Economic Entomology 60: 655–656.

(17) Coad, B. R. 1918. Recent experimental work on poisoning cotton boll weevils. United States Department of Agriculture Bulletin 731, 15 p. 10 fig.

(18) Comstock, J. H. 1880. Report on cotton insects. United States Department of Agriculture, Washington, D.C., 1879, 315 pp.

(19) Cook, O. F. 1913. A wild host plant of the boll weevil in Arizona. Science 27: 259–261.

(20) Cowan, C. B., C. R. Parencia, and R. N. McBride. 1972. Collections of pink bollworm moths in a light trap, 1953 to 1971, Waco, Texas. Cooperative Economic Insect Report 22: 448–450.

(21) Davich, T. B., D. D. Hardee, and J. Alcala M. 1970. Long-range dispersal of boll weevils in Mexico determined with wing traps baited with males. Journal of Economic Entomology 63: 1706–1708.

(22) Dulmage, Howard T. 1970. Studies on the insecticidal activity of HD-1, a new isolate of *Bacillus thuringiensis* var *Alesti*. Journal of Insect Pathology, 15: 232–239.

(23) ______ 1973. Report on the adoption of a primary U.S. reference standards for formulations of α-endotoxin of *Bacillus thuringiensis*. Bulletin of Entomological Society of America 19: 200–202.

(24) ______ and H. de Baiyas. 1973. Hd-187, a new isolate of *Bacillus thuringiensis* producing high yields of α-endotoxin. Journal of Insect Pathology 22: 273–277.

(25) Dunn, Henry A. 1964. Cotton boll weevil *Anthonomus grandis* Boh, abstracts of research publications 1843–1860. United States Department of Agriculture Miscellaneous Publication No. 985, 194 pp.

(26) Ewing, K. P. 1929. Effects on the cotton plant of the feeding of certain Hemiptera of the family Miridae. Journal of Economic Entomology 22: 761–765.

(27) ______ and C. R. Parencia, Jr. 1949. Experiments in early-season application of insecticides for cotton-insect control in Wharton County, Texas, during 1948. United States Department of Agriculture, Bureau of Entomology and Plant Quarantine E–772, 6 pp.

(28) Ewing, K. P. and C. R. Parencia, Jr. 1949. Early-season applications of insecticides for cotton-insect control. United States Department of Agriculture, Bureau of Entomology Quarantine, E–792, 9 pp.

(29) ______ and C. R. Parencia, Jr. 1950. Early-season applications of insecticides on a community-wide basis for cotton-insect control in 1950. United States Department of Agriculture, Bureau of Entomology and Plant Quarantine, E–810, 8 pp.

(30) Fenton, F. A., and E. W. Dunnam. 1929. Biology of the cotton boll weevil at Florence, S.C. United States Department of Agriculture Technical Bulletin 112, 75 pp.

(31) Fryxell, Paul A., and M. J. Luhefahr. 1967. *Hampea schlecht*; possible primary host of the cotton boll weevil. Science 155: 1568–1569.

(32) Fye, R. E., and C. R. Parencia, Jr. 1972. The boll weevil complex in Arizona. United States Department of Agriculture Production Research Report No. 139, 24 pp.

(33) Glick, P. A. 1939. The distribution of insects, spiders, and mites in the air. United States Department of Agriculture Technical Bulletin 673, 150 pp.

(34) ______ 1955. Pink bollworm moth collections in airplane traps. Journal of Economic Entomology 48: 767.

(35) ______ 1957. Collecting insects by airplane in southern Texas. United States Department of Agriculture Technical Bulletin 1158, 28 pp.

(36) ______ 1967. Aerial dispersal of the pink bollworm in the United States. United States Department of Agriculture Production Research Report 96, 12 pp.

(37) Glover, T. 1854. The bollworm patent office agricultural report. 64 pp. Washington, D.C.

(38) ______ 1855. The bollworm patent office agricultural report. 99 pp. Washington, D.C.

(39) ______ 1866. Insects injurious to the cotton plant. United States Department of Agriculture Monograph Report, pp. 282–285.

(40) Guerra, A. A., D. A. Wolfenbarger, and R. D. Garcia. 1973. Activity of juvenile hormone analogues against the tobacco budworm. Journal of Economic Entomology 66: 633–635.

(41) Hanson, H. C. 1923. Distribution of Arizona wild cotton. Arizona Agricultural Experiment Station Technical Bulletin 3, 59 pp.

(42) Hardee, D. D. 1972. A bibliography of research on pheromone of the boll weevil *Anthonomus grandis* Boheman Coleoptera-Curculionidae. Cooperative Economic Insect Report 22: 200–207.

(43) ______ O. H. Lindig, and T. B. Davich. 1971. Suppression of populations of boll weevils over a large area in West Texas with pheromone traps in 1969. Journal of Entomology 64: 928–933.

(44) Hendricks, D. E., H. M. Graham, and J. R. Raulston. 1973. Dispersal of sterile tobacco budworms from release points in northeastern Mexico and southern Texas. Environmental Entomology 2: 1085–1088.

(45) Howard, L. O. 1896. Insects affecting the cotton plant. U.S. Department of Agriculture, Office Experiment Station Bulletin No. 33, p. 328.

(46) ______ 1897. Insects affecting the cotton plant. U.S. Department of Agriculture Farmers' Bulletin No. 47, 10 pp.

(47) Hummel, H. E., L. K. Gaston, H. H. Shorey, and others. 1973. Clarification of the chemical status of the pink bollworm sex pheromone. Science 181: 873–875.

(48) Hunter, W. D. 1924. The so-called cotton flea. Journal of Economic Entomology 17: 604.

(49) ______ 1926. The cotton hopper or so-called cotton flea. United States Department of Agriculture Circular 361. 15 pp.

(50) Ignoffo, C. M. 1964. Bioassay technique and pathogenicity of a nuclear-polyhedrosis virus of the cabbage looper *Trichoplusia ni* (Hübner). Journal of Insect Pathology 6: 237–245.

(51) ______ 1965. The nuclear-polyhedrosis virus of *Heliothis zea* (Boddie) and *Heliothis virescens* (Fabricius). I. Virus propagation and its virulence. Journal of Insect Pathology 7: 209–216.

(52) ______ 1965. The nuclear-polyhedrosis virus of *Heliothis zea* (Boddie) and *H. virescens* (F.). II. Biology and propagation of diet reared *Heliothis*. Journal of Insect Pathology 7: 217–222.

(53) ______ 1966. Insect viruses in insect colonization and mass production. Ch. 36: 501–530. Academic Press.

(54) ______ A. J. Chapman, and D. F. Martin. 1965. The nuclear-polyhedrosis virus of *Heliothis zea* (Boddie) and *Heliothis virescens* (F). III. Effectiveness of the virus against field populations of *Heliothis* on cotton, corn, and grain sorghum. Journal of Insect Pathology 7: 227–232.

(55) ______ R. L. McGarr, and D. F. Martin, 1964. Control of *Alabama argillacea* (Hübner) with *Bacillus thuringiensis* Berliner. Journal of Insect Pathology 6: 411–416.

(56) Jenkins, J. N., and W. L. Parrott. 1971. Effectiveness of frego bract as a boll weevil resistance character in cotton. Crop Science II: 739–743.

(57) Jones, R. L., W. J. Lewis, M. Beroza, and others. 1973. Host-seeking stimulants (kairomones) for the egg parasite *Trichogramma evanescens* Westwood. Environmental Entomology 2: 593–596.

(58) King, W. V., and W. S. Cook. 1932. Feeding punctures of mirids and other plant sucking insects and their effect on cotton. United States Department of Agriculture Technical Bulletin No. 296, 11 pp.

(59) Lloyd E. P., M. E. Merkl, F. C. Tingle, and others. 1972. Evaluation of male-baited traps for control of boll weevils in Monroe County following a reproduction diapause program. Journal of Economic Entomology 65: 552–555.

(60) Lowry, W. L., and R. S. Berger. 1965. Investigations of pink bollworm resistance to DDT in Mexico and the United States. Journal of Economic Entomology 58: 590.

(61) ______M. T. Ouye, and R. S. Berger. 1965. Rate of increase in resistance to DDT in the pink bollworm. Journal of Economic Entomology 58: 781–782.

(62) Lukefahr, M. J., C. B. Cowan, and J. E. Houghtaling. 1970. Field evaluation of improved cotton strains resistant to cotton fleahopper. Journal of Economic Entomology 63: 1101–1103.

(63) ______ and J. E. Houghtaling. 1969. Resistance of cotton strains with high pigment content to *Heliothis* spp. Journal of Economic Entomology 62: 588–591.

(64) ______J. E. Houghtaling, and H. M. Graham. 1971. Suppression of *Heliothis* populations with glabrous cotton strains. Journal of Economic Entomology 69: 486–488.

(65) ______ D. F. Martin, and J. R. Meyer. 1965. Plant resistance to 5 lepidopterous insects attacking cotton. Journal of Economic Entomology 58: 516–518.

(66) ______ L. W. Noble, and J. E. Houghtaling. 1966. Growth and infestation of bollworms and other insects on glanded and glandless strains of cotton. Journal of Entomology 59: 817–820.

(67) ______ and T. N. Shaver. 1972. The potential of resistant cottons in the suppression of *Heliothis* populations. Southern Cooperative Bulletin No. 169, pp. 27–32.

(68) Mally, F. W. 1891. The bollworm of cotton. United States Department of Agriculture, Division of Entomology Bulletin No. 24 (old ser.), 50 pp.

(69) ______ 1893. The bollworm of cotton. United States Department of Agriculture, Division of Entomology Bulletin No. 29 (old ser.), 73 pp.

(70) McGarr, R. L., and C. M. Ignoffo. 1966. Control of *Heliothis* spp. with a nuclear polythedrosis virus, EPN, and two newer insecticides. Journal of Economic Entomology 59: 1284–1285.

(71) McHaffey, D. G., M. H. Flint, J. W. Haynes, and others. 1972. Sterility induced in boll weevils by alkylating agents administered in an adult diet. Journal of Entomology 65: 13–19.

(72) McLaughlin, R. E. *Glugea gasti* sp. m. 1969. A microsporidian pathogen of the boll weevil. Journal of Protozology 16: 84–92.

(73) ______ and M. R. Bell. 1970. Mass production *in vivo* of two protozoans, *Mattesia grandis* and *Glugea gasti*, of the boll weevil. Journal of Insect Pathology 16: 84–88.

(74) Mitlin, L. L., and N. Mitlin. 1968. Boll weevil *Anthonomus grandis Boheman.* Abstracts of Research Publications 1961–65. United States Department of Agriculture Miscellaneous Publication No. 1092, 32 pp.

(75) Moore, R. F., Jr., and H. M. Taft. 1969. The relationship of insecticide tolerance and the lipids of early and late instar larvae and pupae of the bollworm and tobacco budworm. Journal of Economic Entomology 62: 1397–1400.

(76) ______ and H. M. Taft. 1970. Fatty acids in lipid fractions from early and late instar larvae of *Heliothis virescens.* Annals of the Entomological Society of America 63: 1275–1279.

(77) ______ and H. M. Taft. 1971. Difference in fatty acid contents of triglycerides and phospholipids from *Heliothis zea* (Boddie) and *H. virescens* F. larvae as a factor in their tolerance to insecticides. Journal of Economics Entomology 64: 1060–1062.

(78) Noble, L. W. 1969. Fifty years of research on the pink bollworm in the United States. United States Department of Agriculture, Agriculture Handbook No. 357, 62 pp.

(79) Ouye, M. T., R. S. Garcia, and D. F. Martin. 1964. Determination of the optimum sterilizing dosages for pink bollworms treated as pupae with gamma radiation. Journal of Economic Entomology 57: 387–390.

(80) Parencia, C. R., Jr., J. W. Davis, and C. B. Cowan, Jr. 1957. Control of early-season cotton insects with systemic insecticides employed as seed treatments. Journal of Economic Entomology 1: 31–36.

(81) Parencia, C. R., Jr., J. W. Davis, and C. B. Cowan, Jr. 1957. Further field tests with systemic insecticides employed as seed treatments. Journal of Economic Entomology 5: 614–617.

(82) ______ C. B. Cowan, Jr., and J. W. Davis. 1958. Field tests with the systemic insecticides Thimet and Bayer 19639 as cottonseed treatments in 1957. Journal of Economic Entomology 6: 872–875.

(83) ______ C. B. Cowan, Jr., and J. W. Davis. 1962. Relationship of Lepidoptera light-trap collections to cotton field infestations. Journal of Economic Entomology 5: 962–965.

(84) ______ and C. B. Cowan, Jr. 1972. Comparative yields of cotton in treated and untreated plots in insect-control experiments in central Texas, 1939–70. Journal of Economic Entomology 65: 480–81.

(85) Quaintance, A. L. 1904. The cotton bollworm: An account of the insect with results of experiments in 1903. United States Department of Agriculture Farmers' Bulletin No. 191, 24 pp.

(86) ______ and F. C. Bishopp. 1905. The cotton bollworm: Some observations and results of field experiments in 1904. U.S. Department of Agriculture Farmers' Bulletin No. 212, 32 pp.

(87) ______ and C. T. Brues. 1905. The cotton bollworm. United States Department of Agriculture, Bureau of Entomology Bulletin 50, 55 pp.

(88) Raulston, J. R., and P. D. Lingren. 1972. Methods for large-scale rearing of the tobacco budworm. United States Department of Agriculture Production Research Report No. 145, 10 pp.

(89) Ridgway, R. L., and S. L. Jones. 1969. Inundative releases of *Chrysopa carnea* Stephens for control of *Heliothis* spp. on cotton. Journal of Economic Entomology 62: 177–180.

(90) ______ R. K. Morrison, and M. Badgley. 1970. Mass rearing a green lacewing, *Chrysopa carnea*. Journal of Economics Entomology 63: 834–836.

(91) Riley, C. V. 1885. The bollworm. Fourth Report. U.S. Entomological Committee 1883–1885, ch. 16: 355–385.

(92) ______ 1885. The cotton worm. Fourth Report. U.S. Entomological Committee Ch. 13: 1–354.

(93) ______ 1885. Natural history of other species of the genus Anthonomus. Agriculture Committee Report 1885: 299.

(94) Russell, L. M. 1968. *Aphis gossypii* Glover 1877 (Insecta, Hemiptera-Homoptera): Request for validation under the plenary powers. I.N.(S.) 1943. Bul. Zool. Nomevel 25: Pts. 213.

(95) Smith, J. B. 1907. Report of Entomolgical Department, N.J. Agriculture Experiment Station, for 1907.

(96) Snow. J. W., R. L. Burton, A. N. Sparks, and W. W. Cantelo. 1971. Attempted eradication of the corn earworm from St. Croix, U.S. Virgin Islands. United States Department of Agriculture Production Research Report No. 125, 12 pp.

(97) Sparks, A. N. 1972. *Heliothis* migration —distribution abundance and control of *Heliothis* species in cotton and other host plants. Southern Cooperative Bulletin No. 169, pp. 15–17.

(98) Suffrian, E. 1871. Verzeichners den von Dr. Grundloch auf der insect Cuba gesammelten Russelkafer. Archiv, f. Naturg. 37. Jahrg. 13., pp. 130–131.

(99) Taft, H. M., A. R. Hopkins, and S. H. Roach 1972. Suppression of emerging early-season boll weevils using integrated control. Journal of Economic Entomology 65: 1663–1666.

(100) U.S. Department of Agriculture, Agricultural Research Service. Twenty-seventh annual conference report on cotton insect research and control. 94 pp. Washington, D.C.

(101) Vail, P. V., D. L. Jay, and W. F. Hink. 1973. Replication and infectivity of the *Autographa californica* nuclear polyhedrosis virus produced in vitro. Journal of Insect Pathology 22: 231–237.

(102) Vanderzant, E. S. 1967. Rearing lygus bugs on artificial diet. Journal of Economic Entomology 60: 813–816.

(103) ______ 1967. Wheat germ diets for insects: Rearing the boll weevil and the salt-marsh caterpillar. Annals of the Entomological Society of America 60: 1062–1066.

(104) ______ 1969. An artificial diet and a rearing method for *Chrysopa carnea* larvae and adults. Science 62: 256–257.

(105) ______ 1973. Improvements in the rearing diet for *Chrysopa carnea* and amino acid requirements for growth. Journal of Economic Entomology 66: 336–338.

(106) ______ and R. Reiser. 1956. Methods for the mass rearing of the pink bollworm. Journal of Economic Entomology 49: 559–560.

(107) ______ and R. Reiser. 1956. Studies of the nutrition of the pink bollworm using purified casein midia. Journal of Economic Entomology 49: 454–458.

(108) ______ C. D. Richardson and S. W. Fort, Jr. 1962. Rearing of the bollworm on artificial diet. Journal of Economic Entomology 55: 140.

(109) Warner, R. E., and C. Smith, Jr. 1968. Boll weevil found in pre-Columbian cotton from Mexico. Science 162: 911–912.

(110) Watson, T. F., and P. H. Johnson. 1972. Life cycle of the cotton leafperforator. Progressive Agricultural Arizona 24: 12–13.

(111) Wilkinson, J. D., and R. K. Morrison. 1973. Angoumois grain moth: Grain treatment and infestation level effects on rearing. Journal of Economic Entomology 66: 107–109.

(112) Wolfenbarger, D. A., M. J. Lukefahr, and H. M. Graham. 1971. A field population of bollworms resistant to methyl parathion. Journal of Economic Entomology 6: 755–756.

GPO 924-374