FIFTY YEARS OF RESEARCH ON THE PINK BOLLWORM IN THE UNITED STATES

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FIFTY YEARS OF RESEARCH ON THE PINK BOLLWORM IN THE UNITED STATES

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The pink bollworm (*Pectinophora gossypiella* (Saunders)) was described in 1843 from specimens 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 spread of this insect to new areas.

The U.S. Department of Agriculture recognized the pink bollworm as a potential pest of cotton in this country before its discovery in Mexico, and sent August Busk to Hawaii to observe the pest there in 1915. It has conducted research on control of the pink bollworm in Mexico and the United States since 1918. Through cooperative arrangements with the Mexican Government, work has been done in Mexico as though no border separates the two countries. The research has been conducted by the Entomology Research Division of the U.S. Agricultural Research Service or its predecessor agencies. Much of the work has been performed in cooperation with the Texas Agricultural Experiment Station and also more recently with States that participated in a regional project planned for research on the insect.

In addition to the cooperative work with Mexico and Texas, the agricultural experiment stations of Alabama, Arizona, Arkansas, Georgia, Louisiana, Mississippi, New Mexico, Oklahoma, Puerto Rico, and, since 1965, California have participated in pink bollworm research. Cooperating agencies in the Agricultural Research Service are the Agricultural Engineering Research, Crops Research, and Plant Pest Control Divisions. Industry has cooperated in the work and the Oscar Johnston Cotton Foundation has contributed funds to support the research. The outstanding research findings reported by authors of these Federal and State agencies [1] are summarized here, including some unpublished observations.

[1] See references at end of this publication.

BACKGROUND

This report on pink bollworm research would be incomplete without an account of the establishment and spread of the pest in this country, with current delineation of the infested areas, and a brief description of the research laboratories since 1918.

Initial Infestations and Spread

Surveys to detect the pink bollworm, eradication of isolated infestations, and suppressive measures to slow or prevent spread have been carried out by the Plant Pest Control Division or its predecessor agencies in cooperation with industry and with regulatory agencies of the States and counties involved. Cooperative suppressive measures adopted in Mexico are the same as in the United States.

The pink bollworm entered Mexico in seed imported from Egypt in 1911, but it was not discovered until the fall of 1916, when an infestation was found near Torreón, Coahuila. This finding in 1916 presented immediate, especially grave problems for the U.S. Department of Agriculture, because recent importations of seed from Mexico had been received at widely distributed oil mills in Texas, some as far east as Houston and Beaumont.

Infestations West of the Mississippi River

The pink bollworm was first found in Texas by Ivan Shiller at Hearne, Robertson County, in the fall of 1917. This infestation was near an oil mill that had received seed from Mexico. From 1917 through 1921, infestations were found in several other counties in eastern Texas and southwestern Louisiana. By using noncotton zones and regulatory and cleanup measures, these early infestations were eradicated. However, the insect has persisted in an area along the Mexican border in western Texas since 1918 and probably longer. In that year infestations were found along the Rio Grande in Presidio and Brewster Counties and in the Pecos River Valley in Ward and Reeves Counties. In the next decade infestations were discovered in the El Paso area of Texas and New Mexico and in the Pecos Valley of New Mexico in 1920, eastern counties of Arizona in 1926, Plains area of western Texas in 1927, and Salt River Valley of Arizona in 1929.

Infestation was not seen in the lower Rio Grande Valley of Texas and adjacent Mexico until 1936. Gradual spread from this area and western Texas left some sections of Texas free of known infestation until the early 1950's. A relatively rapid spread in the late 1940's and early 1950's expanded the infested area to include all cotton-growing areas of Texas, New Mexico, and Oklahoma and sections of Arizona, Arkansas, and Louisiana. At that time the insect had been long established in all cotton-growing areas along the border in Mexico except in the western States of Sinaloa, Sonora, and Baja California. Infestations were found near Culiacán, Sinaloa, in 1954 and in 1957; both were eradicated. From the mid-1950's to 1967 the eastern boundaries for this insect in the United States have remained nearly unchanged, whereas western spread has included parts of California and Nevada with an increased intensity of infestation in Arizona.

The initial infestation in the Salt River Valley was eradicated and the quarantine was removed in 1934. Infestation reappeared in 1938. After a buildup in only a limited area by 1946, this infestation was eradicated, and after negative inspections in 1947–49, the area was released from quarantine for a second time in 1950. Infestation was found again in central Arizona in 1958. An eradication program was vigorously conducted in the area from mid-1958 through 1963 and was successful in greatly reducing the infestation.

During this program, however, pink bollworm populations increased considerably in immediate outlying eastern areas and thus presented new problems involving suppression of the insect in eastern Arizona and western New Mexico to prevent its movement into central Arizona. This and other problems, chiefly withdrawal of cooperator support, resulted in termination of eradication activities following the 1963 harvest. Since 1958 all cotton-growing counties of Arizona have been under quarantine regulation except Yuma, Mohave, and Yavapai. Yuma County was placed under regulation in 1965 and the other two counties are being recommended for inclusion in the regulated area.

The pink bollworm was discovered in 1965 in limited areas of California and in 1966 in Nevada and additional areas in California, where many fields in Imperial, Riverside, San Bernardino, and San Diego Counties were severely damaged during the 1966 season. The pink bollworm was also found for the first time in 1965 in limited areas of Sonora and Baja California, Mexico.

Infestations in Florida and Georgia

The pink bollworm has existed in wild cotton in southern Florida since its discovery there in 1932. How long it had been there or where it came from is unknown. First indication that the insect had become established in Florida was on June 1, 1932, when larvae in bolls collected from experimental cotton on March 7 at Chapman Field, about 13 miles south of Miami, were identified as pink bollworm. Upon this discovery and the immediate finding that wild cotton was infested, a program was undertaken to determine the distribution of the insect and this host in the State and to eradicate both.

On June 3 pink bollworms were found on an isolated cotton plant about 5 miles north of Chapman Field. Other immediate findings showed that heavy infestations already existed in wild cotton at other places in the southern extremity of the State. Infestation in cultivated cotton was found and eradicated in seven counties of northern Florida and two counties of southern Georgia during 1932–36 and has not recurred since then. At present the pink bollworm population in southern Florida, existing in wild cotton only, has been brought to a very low level.

Wild and dooryard cotton.—The wild cotton in Florida is a form of *Gossypium hirsutum*. It grows on higher ground than does mangrove, but it is seldom found more than 5 miles from the shoreline. The initial surveys showed that wild cotton was distributed in many of the Florida Keys beginning at Key West, at numerous locations along the west coast as far north as Hudson in Pasco County, and in a small area on the east coast at Grant in Brevard County. Dooryard cotton plants, or cultivated varieties used as ornamentals, were common in the southern half of the State.

The initial survey for pink bollworm in wild cotton showed that infestations were generally distributed in the Keys of Florida Bay and along the west coast in all counties as far north as Manatee County. On the east coast, infestations north of Miami were found only in dooryard cotton at Lake Worth, Palm Beach County.

Work to eradicate wild and dooryard cotton in southern Florida has been carried out since 1932 except from July 1, 1947, through June 30, 1949, when Federal funds were not available for the project. Unavoidably a few plants are missed. The seed may remain viable in nature for many years. The various areas are surveyed at least once yearly to destroy existing plants from late September to May, when weather conditions permit work in the junglelike areas where the plants grow. The procedure has been effective in suppressing the pink bollworm.

Although the aim to eradicate wild cotton from southern Florida has not been attained, the program has been successful in reducing the pink bollworm population so that spread to cultivated hosts has been prevented. Since the initial cleanup, the insect has not been found in wild cotton north of Lee County.

Commercial cotton and other cultivated hosts.—Initial findings of pink bollworms where cultivated cotton became infested in northern Florida were in Alachua and Columbia Counties in 1932, Madison County in 1933, and Hamilton, Jackson, Levy, and Suwannee Counties in 1934. In southern Georgia, infestations were found at Enigma in Berrien County and at Brookfield in Tift County, both in 1933. Eradication was commenced immediately after the insect was discovered in these areas. Infestation was not found in Georgia after 1933 and the quarantine of that State was lifted on December 5, 1935. After negative inspections in northern Florida during 1935–36, the quarantine was lifted on October 14, 1936.

In southern Florida where the former Bureau of Plant Industry had experimental cotton plantings infested by the pink bollworm in the Plant Introduction Garden at Chapman Field (first finding of pink bollworm in the State), the infestation was eradicated without destroying all the plants, some of which were rare breeding stocks. At that time cotton was cultivated south of Alachua County only on small acreages in Sumter, Pasco, and Hillsborough Counties. Florida law currently prohibits the growing of cotton from Tampa south, including Pinellas, Hillsborough, Hardee, Highlands, Okeechobee, and St. Lucie Counties.

Okra is currently grown on 800 to 1,000 acres in Dade County, more than 20 miles from the nearest known wild cotton. Okra may volunteer from seeds, or new plants may grow from old roots and thus give rise to wild okra for several years after a planting has been grown under cultivation. Wild okra is fairly common in southern Florida, particularly around old home sites. Such okra was found heavily infested by the pink bollworm on Plantation Key, where it was growing near infested wild cotton early in 1954.

Kenaf, another attractive host for the pink bollworm, is also grown in Dade County for local use as bean poles on several thousand acres of runner beans. The pink bollworm has never been found in these plantings. For bean poles, kenaf is planted broadcast in a thick stand to prevent branching. Seed pods fall to the ground when the plants are cut by hand and tied in bundles. Planting seed is not grown locally.

Research Laboratories

In February 1918, the U.S. Department of Agriculture 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 from late in 1919 until early 1921 and then resumed at Tlahualilo, Durango, where it was continued until April 1925. The Tlahualilo laboratory was closed at that time, 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 U.S. Department of Agriculture were established at El Paso, Tex., and since that time all subsequent Federal laboratories have been in Texas and have conducted research in cooperation with the Texas Agricultural Experiment Station, Texas A&M University.

The first experiment conducted with the insect in this country was begun 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, 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 was 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 during 1953–56. 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 during 1954–57 and 1954–62, respectively. A new laboratory at Phoenix, Ariz., will conduct research on the pink bollworm.

Pink bollworm research programs were expanded in the early 1950's as a result of increased intensity of infestations in southern Texas, associated with northerly and easterly spread that caused an alarming threat to the States bordering Texas on the east. The increase resulted from laxity on the part of growers to carry out control recommendations and from adverse weather conditions, which prevented proper execution of the compulsory cultural control program requiring early stalk destruction in southern Texas. Infestation in the area showed an upward trend during the years immediately preceding 1952.

Because of very heavy rain in the fall of 1951, the harvest and stalk-destruction activities were greatly delayed. Much of the rain-damaged seed cotton infested with potential overwintering pink bollworms was left in the field, and the larval population was increased by reproduction in green bolls, which were abundant in many fields as late as November. This high fall population with a dry period in the winter and spring favorable for a high winter survival resulted in a population explosion in 1952.

After this outbreak the Pink Bollworm Advisory Committee was formed to coordinate research and control efforts. It was composed of representatives of the Agricultural Research Service, the Texas and Mississippi Agricultural Experiment Stations, cotton growers, and the National Cotton Council.

The Entomology Research Division and the Texas Agricultural Experiment Station expanded their research programs on control of the pink bollworm in 1952. The Brownsville laboratory was enlarged to serve as a center for this research. The Pink Bollworm Advisory Committee arranged for funds and personnel to be furnished to the Brownsville laboratory by Alabama, Arkansas, Georgia, Mississippi, and the Oscar Johnston Cotton Foundation to assist the expanded research program. The Louisiana Agricultural Experiment Station located a staff member at the Texas Agricultural Experiment Station at College Station as its contribution to the pink bollworm research.

The Pink Bollworm Technical Research Committee was organized in 1955. It consisted of a representative from each cooperating cotton-growing State, the Entomology Research and Plant Pest Control Divisions, and the National Cotton Council. The primary function of the committee was to formulate plans for a cooperative regional research project. This committee was the forerunner of the Technical Committee for Regional Project S–37.

In January 1956, Regional Research Project S–37, entitled "Pink Bollworm Control," was planned. The project was revised in 1959 and the title changed to "Basic Factors Involved in Pink Bollworm Control," and again in 1964 with the title changed to "Factors Involved in the Control and Eradication of the Pink Bollworm." State and Federal agencies that obtained approval of projects contributing to Regional Project S–37 were the Arizona, Arkansas, Puerto Rico, and Texas Agricultural Experiment Stations and the Entomology Research, Agricultural Engineering Research, and Crops Research Divisions. In addition, the Plant Pest Control Division, the Cooperative State Research Service, and the Louisiana and California (since 1965) Agricultural Experiment Stations actively participated in the work of the S–37 Technical Committee. Research under this regional project continues; however, Arkansas discontinued its contributing project in 1963 and Puerto Rico withdrew in 1966.

Research Achievements

Pink bollworm populations in Texas were at their highest peak in 1952, and the insect caused very heavy losses in southern Texas that year. Control methods developed by research and control agencies were effective in reducing the infestation to a low level by the late 1950's. Since that time the populations in Texas have remained low and crop losses have been confined to a relatively small acreage in the southern and southwestern parts of the State.

Factors responsible for reducing the infestation in Texas after 1952 were (1) research that provided effective control methods; (2) regulatory requirements by the Plant Pest Control Division and the Texas State Department of Agriculture, and the educational campaign of the Texas Agricultural Extension Service to convince cotton growers of the necessity for following the recommended control programs; and (3) the wide-scale application of recommended control practices by growers, particularly in compliance with cultural control requirements, on a community-wide basis. Also, favorable weather was conducive for the effectiveness of the program in reducing the peak infestation. Because of the effectiveness of the cultural control practices employed, the growers had to apply relatively small amounts of insecticides solely to control the pink bollworm.

In the lower Rio Grande Valley, where the highest infestation occurred during the 1952 outbreak, a serious problem with the bollworm (*Heliothis zea* (Boddie)) and the tobacco budworm (*H. virescens* (F.)) has developed, resulting in increased use of insecticides for their control. This intensive insecticide program in addition to cultural practices is currently holding pink bollworm damage in the area below the economic level.

The recommended pink bollworm control program is also an excellent cotton-production program. Almost all practices in cotton production from seedbed preparation to harvest can be carried out to the disadvantage of the pink bollworm in Texas without adversely affecting yields or profits.

The outstanding achievements brought about by the concerted efforts of research and regulatory agencies have been as follows:

(1) Development of highly effective cultural and insecticide control methods.

(2) Development of the "community-action" concept in insect control programs.

(3) Evaluation of stalk-shredding machines for killing the potential overwintering insects; incorporating the use of shredders in a pink bollworm control program.

(4) Development of specifications for fans that will kill pink

bollworm larvae in gin trash; finding that nearly all larvae in infested seed will be killed during the ginning in modern saw gins and the processing in oil-mill plants. As a result of these findings the States with regulations requiring heat treatment of cottonseed as a continuous process of ginning have rescinded this requirement and thus effected savings to the ginning and oil-mill industry that have more than paid for the entire research program.

(5) Development of synthetic diets and techniques for rearing pink bollworms and other insects in the laboratory for experimental purposes so that scientists can study the physiology, biology, nutrition, and other basic aspects of insect research heretofore impossible.

(6) Basic research findings that have shown promise for controlling or eradicating the pink bollworm through male annihilation or sterile-insect release methods, including discovery and synthesis of a chemical in the female that is attractive to the male; development of methods for sterilizing the insect with a radioactive material or chemosterilant.

(7) Development of survey and detection tools such as the gin trash machine, argon light and blacklight traps, sex-lure traps, and lint cleaner inspection and field inspection techniques.

BIOLOGY AND BEHAVIOR

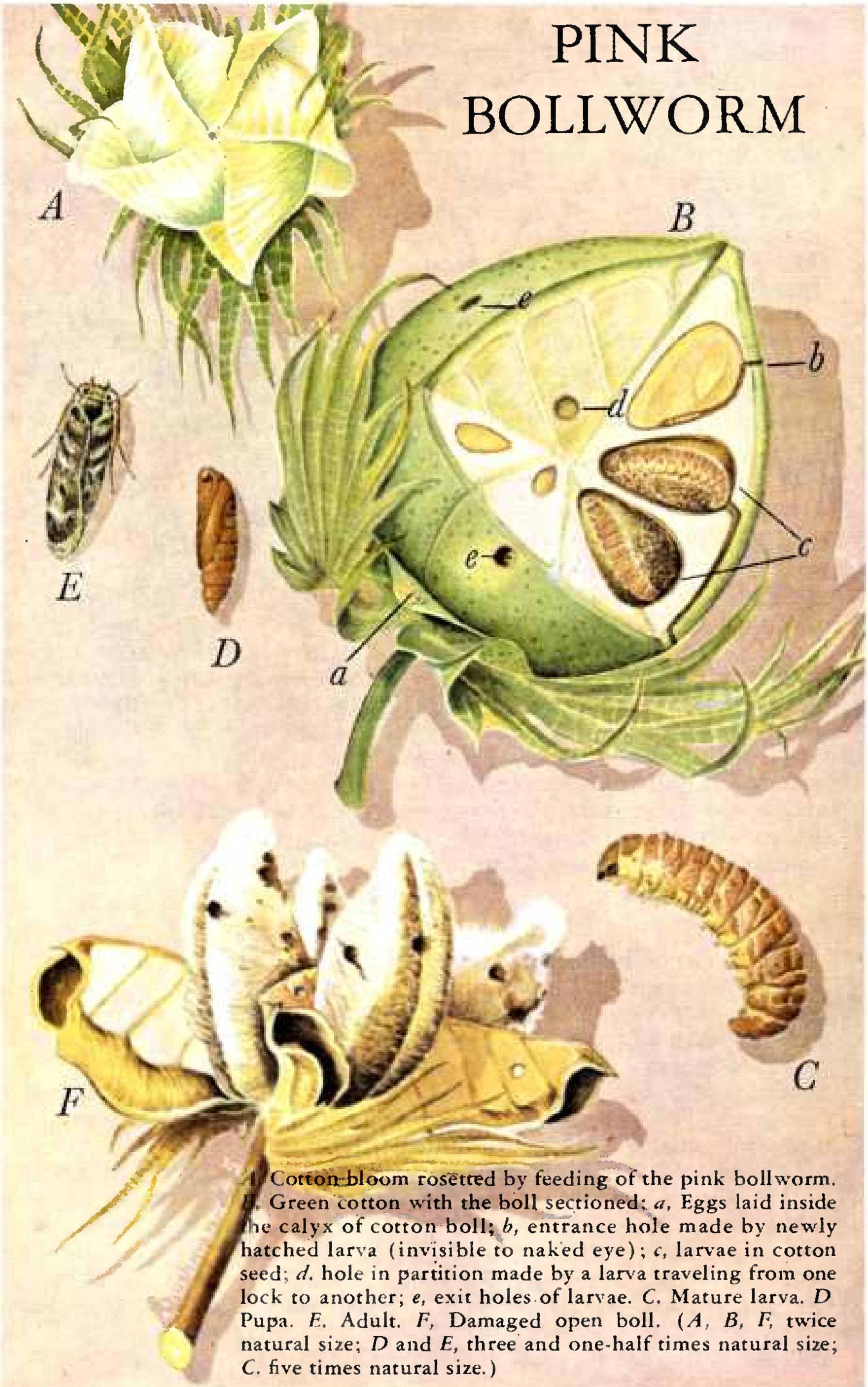
The pink bollworm is best adapted to areas with low rainfall and a long growing season. Development from egg to adult requires about 25 to 30 days in midsummer. There may be as many as four to six generations a year where long growing seasons occur. Diapause larvae pass the winter in seeds, old bolls, and trash in the fields or at gins and seed-storage facilities.

Developmental Stages

Adult

The pink bollworm adult (pl. 1, *E*) is a grayish-brown moth with a wingspread of 15 to 20 mm. The moths emerge early in the spring and summer from overwintered larvae. They live 10 days to 2 weeks during midsummer and longer during cooler weather. The female may lay about 100 to 200 eggs, depending on the food on which the immature stages develop and the age of the larva from which the adult emerges. Moths emerging from overwintered larvae and larvae developing in squares have a lower fecundity than do those of the summer generations developing in bolls. The moths may feed on nectar or honeydew in the field. In the laboratory, moths supplied with simulated nectar and other sugar solutions laid significantly more eggs than did those given water only. The moths hide under objects on the soil or in soil cracks during the day and become active for mating and laying eggs at night.

The greatest mating activity takes place after midnight, probably because of a biological clock that determines the time when



A. Cotton bloom rosetted by feeding of the pink bollworm. B. Green cotton with the boll sectioned; *a*, Eggs laid inside the calyx of cotton boll; *b*, entrance hole made by newly hatched larva (invisible to naked eye); *c*, larvae in cotton seed; *d*, hole in partition made by a larva traveling from one lock to another; *e*, exit holes of larvae. *C*, Mature larva. *D* Pupa. *E*, Adult. *F*, Damaged open boll. (*A*, *B*, *F*, twice natural size; *D* and *E*, three and one-half times natural size; *C*, five times natural size.)

the female releases a sex attractant. Males in the laboratory respond to the sex attractant at any time of day when exposed to an extract from the females. Mating may occur the first night after emergence and one or more times thereafter. Males mated an average of 4.2 times and females 2.3 times when the respective sexes were caged with a greater number of the opposite sex in the laboratory. Actual frequency of mating in the field, however, is probably much less than that observed in the laboratory. Examination of females collected from the field in light traps showed they had mated from one to six times, with an average of 1.1 times.

Oviposition begins on the second night and the daily number of eggs laid is at a peak on the third night after emergence. More than 80 percent of the eggs are laid before midnight. Below 70° F. moth activity and egg deposition are sharply reduced. Oviposition practically ceases at 60°.

Egg

The pink bollworm egg is pearly white when laid. It changes to a light reddish orange late in the incubation period. Incubation lasts 4 to 5 days in midsummer. Hatching occurs during approximately 3 hours from 8 to 11 a.m. Eggs may be distributed over all parts of the cotton plant, but most are laid on the fruiting forms of cultivated varieties. Early in the cotton season before bolls are present, eggs are laid singly on squares, stems, and terminal buds. Bolls become the preferred place for oviposition when they are 15 days old or older. Eggs laid on bolls are deposited singly and in clusters, rarely exceeding four or five per cluster. Usually the single eggs on bolls are laid on the apex or above the calyx and the clusters at the base. Most are laid at the base between the glovelike calyx and carpel, where they are considerably protected from predators. (Pl. 1, *B*.)

Larva

The pink bollworm has four larval instars. The first instar, except its brown head, has very little color when hatched and becomes glossy white after entering the square or boll. Late instars acquire a cream color, with the dorsal side having transverse bands of mottled pink that darken with age until the fully grown fourth instar has the deep pink appearance for which the insect is named. The cylindrical fully grown larva is about 2.5 mm. in diameter and 11 to 13 mm. long. (Pl. 1, *C*.)

Larvae that hatch on squares or bolls usually enter that form within about one-half hour after hatching and therefore are exposed to predators for a very short time. Those hatching under the calyx may enter at that place, thus escaping exposure to predators and insecticide residues. Those that hatch on parts of the plant other than squares and bolls are subject to some mortality resulting from failure to find a fruiting form as well as greater exposure to their natural enemies and insecticides. Once the larvae enter fruiting forms, where they feed for 10 to 15 days, they are fully protected from predators and insecticides. They complete their development in a single square or boll and never move to a second one for feeding. The fully developed fourth-instar larvae drop to the ground to pupate. Most of the overwintering ones remain in the seeds in which they developed.

Infestation in squares.—A larva developing in a square spins a web, which usually keeps the bloom from opening fully, and thus forms a rosette (pl. 1, *A*). Rosette blooms are easily detected on the plant, and they afford a convenient means of counting infestations for measuring the early spring larval population. Larvae enter and develop in squares that are over 10 days old. Squares infested before that age shed from the plant and the larvae do not survive. Larval development in squares is faster than in bolls. The rate of development increases with age of the square, and thus larvae are more likely to complete feeding by the flowering stage. Most larvae complete feeding by the time the bloom forms and then drop to the ground, either from the live bloom or with the dead bloom. A few feed on the young boll that is just beginning to form when the bloom unfolds, and thereby they destroy the boll.

Infestation in bolls.—Pink bollworm larvae usually infest bolls 20 days old or older. They may enter and develop in bolls about 10 days old, usually when older bolls are absent or scarce or the moth population is high relative to the number of older bolls present. Bolls over 4 weeks old give a better criterion of the degree of infestation. Larval development is faster in the older bolls.

The larval entrance hole, which may occur at any place on the surface, is barely discernible with the naked eye. The mines (fig. 1) visible on the inner carpel wall are easily discernible, and a count of these is the most convenient means of determining the degree of infestation. In watery, young bolls the larva may tun-

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FIGURE 1.—Interior carpel wall of green boll with locks removed, showing mines (darker areas) made by tunneling of small larvae when entering the boll.

nel directly through the carpel, leaving only a small discolored spot inside similar to that resulting from punctures of certain other insects. In older bolls when the lining has hardened, the larvae tunnel along the outer surface of the lining before cutting through it and thus leave lengthy mines that cannot be confused with the sign of other cotton insects. (Pl. 1, *B* and *F*.)

After completing feeding, the nondiapause larva cuts a round exit hole in the carpel, through which it crawls and drops to the ground. Some diapause larvae exit in this manner and form cocoons to pass the winter. These exit holes too are easily differentiated from the sign of other cotton insects, but they represent a small part of the larvae present of different ages and therefore should not be used as a criterion for determining when to apply insecticides. Nearly all larvae that stay in bolls after they finish feeding have entered diapause and do not cut an exit hole. They usually remain in a single seed, but sometimes they spin a cocoon tying two seeds or hulls together, which resembles a double seed.

Cocoon and Pupa

The nondiapause larva spins an elongate, loose-fitting cocoon in which it pupates. The diapause larva may spin a slightly elongate cocoon, but usually it spins a closely woven, tight-fitting spherical cocoon, which it abandons before pupating, and then may either spin a loose elongate one or pupate naked. The pupa is about 6 to 8 mm. long by 2.5 mm. at the widest part and is a shiny brown. (Pl. 1, *D*.)

Diapause

The pink bollworm has inhabited a wide geographical range, undoubtedly because it enters diapause before the seasonal onset of unfavorable environmental conditions. Moisture helps to break the diapause or to stimulate pupation. Diapause larvae have been reported to live as long as 2½ years under dry seed-storage conditions, but there are no data on fecundity or even a record that the insect can reproduce after such a long period. Larvae in seed stored from fall until late the next summer showed some mortality and the survivors produced moths of very low fecundity. The insect has never been found to survive a second winter in the field. Larvae in bolls buried in November in an arid climate showed stragglers that emerged as adults in September of the next year. This emergence was stimulated by rain after limited summer irrigation.

A few pink bollworm larvae may enter diapause in the first bolls formed in the crop season. At Waco and Brownsville, Tex., the seasonal initiation of pink bollworm diapause occurs in the generation hatching the last part of June. However, only a small percentage of the population enters diapause before September. Beginning with the generation hatching about the first of September, the incidence of diapause increases rapidly until the middle of October, when about 95 percent of the larvae developing in bolls are in diapause. Diapause in larvae developing in squares is not initiated until cool fall temperatures prevail. At Waco a few diapause larvae occur in the first bolls formed, whereas at Brownsville, because of warmer climate and earlier planting, the cotton crop is well advanced when the first diapause larvae appear, although the date of initiation of diapause in the two areas is about the same.

In the early research on the pink bollworm a greater proportion of diapause larvae found in old bolls than in young bolls was attributed to nutritional differences between boll ages. The rapid increase in proportion of larvae entering diapause as the season advanced in late summer and fall was attributed to seasonal change in temperature. Data from different regions of the world, however, indicated that diapause involved some factor in addition to diet and temperature, and when considered in relation to latitudes of the different regions, the data suggested a response of the insect to photoperiod.

Experiments carried out under controlled photoperiods and temperatures showed that diapause in pink bollworm is controlled by photoperiod, with diet and temperature exerting a secondary effect. The proportion of the population entering diapause may be increased by a diet such as that furnished by a nearly mature cotton boll and by low developmental temperature, both operative only under photoperiods that induce diapause.

In latitudes from 26° to 32° the seasonal diapause in pink bollworm is initiated shortly after the summer solstice (June 22), when daylengths have begun to decrease, as demonstrated at Waco and Brownsville. The proportion of larvae entering diapause increases as the days become shorter, and the increase is accelerated by seasonal drop in temperature and maturity of the crop. Reports from tropical latitudes between 10° and 22° indicate that diapause is initiated there in September, and the proportion of larvae in diapause increases until December. A concerted search reported by six authors failed to disclose the presence of pink bollworm diapause in the equatorial region between north and south 10° latitudes, where daylength continues unchanged throughout the year.

HOST PLANTS

Gossypium is the preferred host of the pink bollworm. Plants of worldwide distribution representing seven families, 24 genera, and 70 species have been recorded as alternative hosts. Most of the hosts belong to the family Malvaceae. Of these mallows, the genus *Hibiscus* ranks high in the insect's preference. Six cultivated plants are attacked. The ornamental and wild host plants (43 species) found in the Southwestern United States and northern Mexico exert a negligible effect on the pink bollworm population in the generally infested area because of their sparsity or lack of attractiveness to the insect. However, some may perpetuate the insect in small numbers and become important in an eradication program. A problem with eradication of an isolated infestation exists in southern Florida, where the insect maintains itself in wild cotton. The insect has also been found on *Gossypium thurberi* in Arizona.

The cultivated plants attacked are okra, kenaf, jute, roselle, muskmallow, and castorbean. Okra is the only one currently produced extensively in the United States, but some of the others have been considered as potential crops for this country. A few larvae developed when moths were caged on flax, but this cultivated plant was not found infested under natural conditions.

Okra is probably preferred next to cotton and must be considered in the same category with regard to cultural control measures and quarantine regulations. High populations develop on plants grown for a seed crop or abandoned during the growing season after an edible-crop harvest, and the residues of such crops carry a high potential overwintering population. A new infestation may be established from a shipment of infested edible okra if all is not consumed and the remaining pods are discarded where the larvae can complete development in them. First-instar larvae have completed development when placed on pods as young as 1 day. When infested edible pods were removed from the plants and caged, the larvae readily completed development and emerged as adults in the cage.

Kenaf was found heavily infested in experimental plantings in the lower Rio Grande Valley. When grown extensively, this plant, like okra, may cause control problems. Similar problems may be caused by jute, roselle, and muskmallow. The castorbean, although found infested, does not appear sufficiently attractive to be of any appreciable consequence as a host.

Plant species in the genus *Gossypium* are excluded from the list given here because they are considered as preferred hosts of the pink bollworm. A few other recorded hosts may have been missed in the review of literature. The known alternative hosts are listed here with their common name, if available. The location, when given, indicates that the species was found infested under natural conditions in the United States, Mexico, or both. Species on which diapause larvae were found to survive the winter in seed pods are marked with an asterisk.

Malvaceae (mallow family)

Abutilon amplum Benth.
A. hirtum G. Don; Texas
A. hypoleucum Gray (*A. jacquinii* Don); Mexico
**A. incanum* (Link) Sweet (*A. texense* T. & G.)—Indian-mallow; Texas
A. indicum (L.) Sweet (*A. americanum* (L.) Sweet)
**A. lignosum* (Cav.) Don (*A. berlandieri* Gray); Texas
A. otocarpum F. Muell.
A. trisulcatum (Jacq.) Urban (*A. triquetrum* (L.) Sweet); Texas, Mexico
**Althaea rosea* (L.) Cav.—hollyhock; Texas, Mexico
Callirhoe involucrata var. *lineariloba* (T. & G.) Gray—poppy-mallow; Texas
Fugosia australis (F. Muell.) Benth.
Hibiscadelphus hualalaiensis Rock
**Hibiscus abelmoschus* L. (*Abelmoschus moschatus* Medic.)—muskmallow; Texas
**H. aculeatus* Walt.; Texas, Mexico
H. bifurcatus Cav.

H. brasiliensis L.; Texas, Mexico
H. cannabinus L.—kenaf; Texas
H. cardiophyllus Gray; Texas, Mexico
H. coccineus Walt. (*H. speciosus* Ait.)—Texas-star, scarlet-rosemallow; Texas, Mexico
H. coulteri Harv.—desert-rosemallow; Mexico
H. dasycalyx Blake & Shiller; Texas
H. denudatus Benth.—paleface-rosemallow; Mexico
H. divaricatus Grah.
H. drummondii Turcz
H. esculentus L.—okra, gumbo; Texas, Mexico
H. furcellatus Lam. var. *youngianus* (Gaud.) Hochr.
H. heterophyllus Vent.—yellow-flowered variety
H. incanus Wendl.; Texas
H. lambertianus HBK. (*H. cubensis* Rich.); Texas
H. lasiocarpus Cav.—woolly-rosemallow; Texas
H. leucophyllus Shiller; Texas
H. ludwigii Eckl. & Zeyh. (*H. macranthus* Hochst. ex Rich.)
H. militaris Cav.—rosemallow; Texas, Mexico
H. mutabilis L.—cotton-rose, confederate-rose; Texas, Mexico
H. panduraeformis Burm. f.
H. rosa-sinensis L.—rose-of-china; Texas
H. sabdariffa L.—roselle
H. syriacus L.—rose-of-Sharon, shrubby althea; Texas, Mexico
H. tiliaceus L.
H. trilobus Aubl.
H. tubiflorus DC. (*H. pilosus* (Sw.) Fawc & Rendle); Texas, Mexico
H. vitifolius L.
Kosteletzkya althaeifolia (Chapm.) Gray; Texas
K. virginica (L.) Gray—saltmarsh mallow; Mexico
Malachra capitata L. (*M. palmata* Moench); Texas
Malva parviflora L.; Texas
M. sylvestris L.—high-mallow; Texas
Malvastrum coromandelianum (L.) Garcke (*M. americanum* (L.) Torr.) (*M. tricuspidatum* (Ait. f.) Gray)—false-mallow; Texas, Mexico
Malvaviscus arboreus Cav.—Turks-cap, South American waxmallow; Texas
M. drummondii T. & G.—waxmallow, Texas-mallow; Texas, Mexico
Pseudabutilon lozani (Rose) Fries (*Wissadula lozani* Rose)—false-abutilon; Texas, Mexico
Sida cordifolia L.; Texas
S. corrugata Lindl.
S. spinosa L.—prickly-sida; Texas
S. virgata Hook
Thespesia danis Oliv.
T. grandiflora DC. (*Montezuma speciossima* Sesse & Moc. in DC.)
T. lampas (Cav.) Dalz. & Gibs.
T. populnea (L.) Soland. ex Correa—tulip tree, portia tree; Texas

Euphorbiaceae (spurge family)

Croton capitatus Michx.—croton, goatweed; Texas
C. texensis (Klotzsch) Muell. Arg.—croton, goatweed; Texas
Ricinus communis L.—castorbean; Texas

Leguminosae (pea family)

Acacia wrightii Benth.—tree cat's-claw; Texas
Daubentonia punicea (Cav.) DC. (*Sesbania punicea* (Cav.) Benth.)—coffeebean, purple-sesban; Texas
Gleditsia triacanthos L.—honeylocust; Texas
Prosopis juliflora (Sw.) DC. var. *glandulosa* (Torr.) Cockerell (*P. glandulosa* Torr.) (*P. chilensis* (Molina) Stuntz)—mesquite; Texas

Convolvulaceae (morning-glory family)

Ipomoea crassicaulis (Benth.) Robinson (*I. fistulosa* Mart.; *I. texana* Coulter)—Texas bush morning-glory; Texas

Tiliaceae (linden family)

Corchorus olitorius L.—jute

Bombacaceae (bombax family)

Bombax munguba Mart. & Zucc.

Cochlospermaceae (cochlospermum family)

Cochlospermum regium (Mart.) Pilger (*C. insigne* St. Hil.)

MEANS OF SPREAD

Transportation of Larvae

After the pink bollworm became a pest of commercial cotton, it was carried long distances when infested cottonseed was transported in commerce. It rapidly invaded most major cotton-producing countries throughout the world. The insect lends itself to dispersal by man, because the diapause larva has the habit of remaining in the seed in which it developed. Besides the transport of bulk cottonseed, there is a hazard in moving the baled lint, mechanical cotton pickers, and vehicles that have been used to transport seed or seed cotton, oil-mill products, and other items subject to contamination by infested seeds. Larvae may be transported in okra and therefore are a hazard in marketing this crop (see Host Plants).

Moth Movement

Light traps generally show greater catches of pink bollworm moths in the spring before the cottonfields have produced squares than after fruiting forms become abundant, indicating moth flight in search of fruiting plants. Late in the season there is another much higher peak in number of moths trapped, indicating greater flight activity after seasonal population buildup and after crop maturity when green bolls are scarce.

Local Flight

Occurrence of early- and late-season local flight from field to field is reflected in the heavier infestations prevailing in early and late plantings compared with plantings of intermediate date. The spring generation developing in squares is higher in early than late plantings, even though some of the early cotton is in fields not planted to cotton the previous year and therefore is infested only by migrant moths. A heavy late-season local moth movement is shown in the sudden, sharp increased intensity of infestation in late plantings after the earlier plantings have matured.

Long-Distance Dispersal by Flight or Wind

Much evidence has been obtained that indicates pink bollworm flight activity is not restricted to local fields, because the moths may fly considerable distances or may be carried by the wind. They have been caught in light traps at least 25 miles from infested fields.

Moths collected by airplane.—Possibility of long-distance dispersal of adults was recognized when moths were collected as high as 3,000 feet on airplane flights over the heavily infested Torreón area of Mexico in 1928. Moths were taken at altitudes of 100 to 1,000 feet on similar flights 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 the northeastern (Arkansas-Louisiana) fringe of the quarantined area. The insect-collecting screens were exposed for a total of 99 hours in central Texas and 40 hours in the fringe area. Sixteen moths were taken in the flights over central Texas: 3 at 200 feet, 7 at 500 feet, 4 at 1,000 feet, and 2 at 2,000 feet; none were trapped at 3,000 feet. Two pink bollworm moths were collected in the lightly infested Arkansas-Louisiana fringe area, one at 500 feet and the other at 2,000 feet above ground.

During the flights in central Texas the near-surface wind was mostly from a southerly direction. Small hydrogen-filled balloons released at Waco and College Station drifted to the north and northeast for distances up to 195 miles, as indicated by a small number recovered. In previous studies, separate from pink bollworm investigations, other workers found that during May and June balloons drifted as far as 375 miles from south-central Texas, with prevailing winds to the north and northeast. It is thus evident that pink bollworm moths, aided by the wind, may drift from the more heavily infested areas of central Texas to outlying areas on the north and northeast, and similar spread may occur in other areas.

Isolated infested plantings.—Early experiments in Mexico showed that isolated plantings of cotton as far as 40 miles from the nearest source of infestation readily became infested where chances of man's carrying the insect were meager. Small plots of cotton became infested from 35 to 65 miles from the nearest cotton in an arid section of western Texas where other host plants were not a factor in the spread. These plots were planted over a 6-year period with a total of 90 plantings. Of the 90 plantings, 18 became infested; none were found infested before the last part of September. A planting 35 miles from cottonfields became infested in 4 of the 6 years.

Surveys showing spread.—During the surveys to determine spread of the pink bollworm in this country, many new infestations found at long distances from the nearest previously known infestations could be accounted for only by moth movement. In 1947, for example, new infestations were found in 30 counties in northern Texas and in Oklahoma, covering an area extending northward for about 170 miles from the nearest previously known infested county. Allowing for any doubt as to some undetected spread into this area before 1947, despite surveys made in the area, still the findings that year certainly demonstrate widespread dispersal of the moth.

COTTON CROP DAMAGE

Square Injury

Most infested squares develop to flowering stage with normal pollination and boll formation. A few shed because of infestation at an unusually early age or injury to the young boll after flowering. This loss in number of squares produced is minor. Any measures used to control the spring population developing in squares are necessary only to reduce the potential population that would attack bolls later in the season.

Boll Injury

Larval feeding in bolls results in lowered quality of lint and seed as well as reduced yield in weight. Reduction in quantity of seed cotton produced is the more important loss in high infestations, but reduction in quality may be of considerable importance at a degree of infestation too low to appreciably reduce the yield.

Loss in yield of seed cotton consists of the bolls and locks that are nonpickable either because of destruction of the seeds and lint resulting from heavy larval feeding or development of boll-rot organisms introduced into the boll through larval exit holes. A lightly infested boll may develop a fungal growth resulting in hard locks, as opposed to fluffy locks, which are nonpickable and may range from one lock to the entire content of the boll.

The quality of lint is lowered because of discoloration and reduced fiber length and strength. Loss in lint value resulting from injury is greatest when climatic and agronomic factors are favorable for production of a high quality fiber. Many of the seeds in pickable cotton have been consumed and the quality of those ginned is lowered because of reduced protein and oil content and increased free fatty acids.

Effect of Boll Age

Greatest damage occurs in the younger bolls where more seeds are consumed and lint injury is greater than in older bolls. A larva infesting an old boll may complete development in a single seed. The proportion of bolls becoming infested at a young age increases with buildup of the insect population in a field. Upon maturity of the early plantings, the fields with late cotton may receive a sudden influx of moths when many of the old bolls are still free of infestation. Under these conditions in a dry climate as many as 29 larvae have been found to develop in an old boll that opened when fully mature with fluffy pickable locks. However, the younger bolls fail to open under such conditions, or they open prematurely with the locks so badly damaged that they are nonpickable.

Effect of Rain and Humidity

A given degree of infestation causes greater damage in an area with heavy rainfall and high humidity, resulting in greater boll rot, than in a dry area. The entrance of rot organisms into green bolls through larval exit holes is aided by rain, and the moisture is favorable for development of the organisms. As a result, many infested bolls do not open and the number of hard locks in those that open is increased in a wet area.

Loss in Yield and Quality

Reductions in yield and quality of cotton due to pink bollworm damage were determined at Brownsville, a high humidity area, with infestations introduced into cages at levels designated as light, medium, and heavy. The highest level resulted in a seasonal average of 60 percent of the bolls infested. At this intensity of infestation, crop value was reduced by 34 percent, and the losses were about equally distributed between reduced yield and reduced quality of lint and seed. The lower infestations resulted in losses due chiefly to reduced quality of lint and seed.

Estimates of losses to be expected due to nonpickable bolls and locks, without insecticide control of heavy infestations in a high humidity area, can be obtained from results of insecticide experiments conducted in the lower Rio Grande Valley in 1952, the year of peak infestation. The experiments were conducted in fields with infestations ranging from intermediate to high for the area that year. They showed reductions in yield ranging from about 50 percent, representative of many fields in the area, to as high as 80 percent in some fields. Losses in quality of the seed and lint harvested were not determined. The total loss from pink bollworm damage was in addition to that caused by the boll weevil (*Anthonomus grandis* Boheman). The cotton rendered nonpickable due to pink bollworm injury was determined by comparing the yield from plots treated for control of both insects with that from plots treated only for the boll weevil.

BIOLOGICAL CONTROL

Native Parasites

At least 18 parasitic insects native to the United States and Mexico have been found to attack the pink bollworm. The prevailing low parasitization observed was of minor importance in controlling the pest. All the parasites were hymenopterous species except one tachinid fly (*Erynnia* sp.) reared from larvae collected in cotton blooms. All attacked the larva except four egg parasites—*Chelonus texanus,* two new *Chelonus* spp., and *Trichogramma minutum.* The species giving the highest parasitization were *Bracon gelechiae, B. mellitor,* and *B. platynotae.* A list of the species found to parasitize the pink bollworm is given here. Several other species emerged from caged bolls infested with both this host and the boll weevil and possibly were parasitic on the pink bollworm.

Bethylidae

Epyris californicus (Ashmead)—western Texas
Parasierola emigrata (Rohwer)—Durango, Mexico
Parasierola punctaticeps Kieffer—Mexico and Texas

Braconidae

Apanteles pholisorae Riley—southern Texas
Bracon gelechiae Ashmead—Durango, Mexico
Bracon mellitor Say—Mexico and Texas
Bracon platynotae (Cushman)—Mexico and Texas
Chelonus texanus Cresson—Texas
Chelonus n. spp.—southern Texas
Opius dimidiatus (Ashmead)—southern Texas
Orgilus gelechiaevorus Cushman—southern Texas

Chalcididae

Spilochalcis flavopicta (Cresson)—western Texas

Elasmidae

Elasmus setosiscutellatus Crawford—western Texas

Pteromalidae

Heterolaccus hunteri (Crawford)—Durango, Mexico
Zatropis incertus (Ashmead)—western Texas

Tachinidae

Erynnia sp.—Durango, Mexico

Trichogrammatidae

Trichogramma minutum Riley—western Texas

Introduced Parasites

Eleven species of foreign parasites were reared in the laboratory and released in large numbers in Texas and Mexico. The work was begun at the Presidio laboratory in 1932 and discontinued there in 1944 before the rapid spread of the pink bollworm to the northeast beginning about 1950. Work was resumed at the Brownsville laboratory in 1952 and continued through 1955. Besides the 11 species released, four others were received, but the stocks died in the laboratory: *Bracon greeni* Ashmead from India, *B. vulgaris* Ashmead and *Calliephialtes dimorphus* Cushman from Brazil, and *Elasmus platyedrae* Ferriére from Egypt.

Investigations at Presidio

Most of the parasites reared at Presidio were released in local areas with limited releases in Mexico near Las Delicias, Chihuahua, and Torreón, Coahuila. Texas releases were restricted to the Presidio Valley because of the prevailing low pink bollworm infestation in other parts of the State at that time. The species released and origins of the breeding stocks were as follows: *Bracon brevicornis* Wesmael—southern Europe, *B. kirkpatricki* (Wilkinson)—east-central Africa, *B. mellitor* Say—Hawaii, *B. nigrorufum* (Cushman)—Japan, *Chelonus blackburni* Cameron—Hawaii, *C. pectinophorae* Cushman—Japan, and *Exeristes roborator* (F.)—southern Europe.

All species were recovered in field collections made in the current summers of the releases and, with the exception of *Bracon brevicornis* and *B. kirkpatricki,* all overwintered in hibernation cages. None of the species became established in this country or Mexico. Their failure to become established in the arid sections where all were released was apparently due to early spring emergence with a lack of other hosts for their propagation before pink bollworms became available in cotton squares.

Investigations at Brownsville

When work was resumed at the Brownsville laboratory, the recent spread of the pink bollworm and a buildup in southern Texas were believed to afford more favorable conditions for parasites to maintain themselves than at the time of the previous releases. Five species imported from India were reared and released in southern Texas and northeastern Mexico. They were *Apanteles angaleti* Muesebeck, *Bracon brevicornis, B. gelechiae, Chelonus heliopae* Gupta, and *C. narayani* Rao. None of these parasites were recovered in collections made at 170 liberation sites. Apparently contributing to failure of the parasites to maintain themselves were the intensive use of insecticides and the cultural control program directed against the pink bollworm, which reduced the parasites as well as their host.

Predators

Little work has been done to determine the predators that attack the pink bollworm and to evaluate their effectiveness in controlling the pest. Undoubtedly many of the arthropods that prey on other lepidopterous cotton insects also feed on eggs and larvae of the pink bollworm but to a less degree because of protective mechanisms. Eggs laid under the calyx are protected from predators. Newly hatched larvae are exposed for a very short time before they enter the square or boll where they are protected during their feeding period.

A predacious mite, *Melichares* (*Blattisocius*) *tarsalis* (Berlese), was observed feeding on pink bollworm eggs from moths caged in the laboratory. This mite was also found on cotton growing on the laboratory grounds, indicating that it may contribute to natural control of the pink bollworm. Other mites—*Glycyphagus destructor* (Schrank), *Parasitus* sp., and *Tyrophagus putrescentiae* (Schrank)—are known to feed on larvae in stored cottonseed.

The lacewing *Chrysopa rufilabris* Burmeister is reported to feed on newly hatched larvae and the larger larvae in flowers. The checkered beetle *Enoclerus quadrisignatus* (Say) was frequently found feeding on larvae in blooms. Several unidentified spiders and ants were observed attacking larvae in blooms and larvae that had left the fruiting forms for pupation. Also, unidentified spiders were seen attacking moths on the cotton plant at night. Further evidence of moth attack was obtained in a pink bollworm dispersal study, in which moths tagged with P^{32} were released, and spiders found near the release point by means of a Geiger counter had been secondarily tagged by feeding on the radioactive insects.

Pathogens

Bacillus thuringiensis Berliner was investigated in the laboratory and in field-cage and small-plot tests, in which the organism was applied against overwintering and summer populations of the pink bollworm. This pathogen was effective in reducing the populations but at application rates too high for use as a practical control measure. A nematode with an associated pathogen (nematode DD–136) was similarly tested, and it too was effective but not sufficiently to warrant its use for pink bollworm control.

Several bacteria, fungi, and a cytoplasmic virus have been found in diseased pink bollworm larvae from laboratory cultures and field collections. Their effect on field populations has not been studied. A disease observed among fourth-instar larvae being used to rear parasites was named "pink bollworm septicemia," and the bacterial species causing the disease was named *Bacillus pectinophorae* White. Of the different pathogens found in pink bollworms, the cytoplasmic virus has attracted greatest attention. It has a wide range of insect hosts and has caused concern through contamination of cultures reared for experimental purposes. Although it is not highly pathogenic, it appears to warrant investigation as a possible agent for controlling the pink bollworm and other insects.

CHEMICAL CONTROL

Recommendations on the chemical control of the pink bollworm are subject to frequent change and are not given in this publication. For such recommendations, see U.S. Department of Agriculture Farmers' Bulletin 2207, "Controlling the Pink Bollworm on Cotton."

Foliar Applications

Only those contact insecticides causing mortality of the adult pink bollworm as well as newly hatched larvae have given satisfactory control of the insect. DDT was the first one found to be highly effective. When DDT became available for field testing in 1945, all the insecticides then commonly known had proved inadequate for practical control of the insect. New insecticides, including systemics, were tested as they became available. Of the many compounds screened in the laboratory, relatively few gave results warranting further testing in the field. Of those showing promise in laboratory tests, many failed to give satisfactory control when tested in the field. None of the systemic insecticides have been effective against the pink bollworm.

Methods were developed to control the pink bollworm with azinphosmethyl, carbaryl, or DDT, applied at 5-day intervals. Methoxychlor, EPN (*O*-ethyl *O*-*p*-nitrophenyl phenylphosphonothioate), and Dilan (a mixture of one part 1,1-bis(*p*-chlorophenyl)-2-nitropropane and two parts of 1,1-bis(*p*-chlorophenyl)-2-nitrobutane) were also shown to be effective, but for several reasons they were not developed for control of this insect.

Experiments showed that early-season application of insecticides, begun before the occurrence of squares susceptible to attack, was effective in reducing the spring pink bollworm population found in blooms compared with that in untreated fields. However, such early application is not required for economic control of the insect. Good control of the pink bollworm can be obtained with insecticides applied when needed, based on infestation counts (fig. 2).

Although the spring generation developing in squares does not cause economic damage, a high population found in early blooms may require immediate insecticide application to prevent serious damage to the first bolls formed. Therefore, infestation counts made to determine when insecticides should be applied involve the early square generation as well as the later generations developing in bolls. (See Surveys for description of bloom and boll inspection methods.)

Treatment with an insecticide should begin immediately in a field where a spring count shows 350 or more larvae per acre in blooms. When less than 350 larvae per acre are found, further inspection may be delayed until the first bolls are 4 weeks old. After that time treatment should be started when 10 to 15 percent of the bolls are infested. Once treatment is begun, the scheduled applications should be continued until most bolls are open.

Resistance to Insecticides

The pink bollworm has acquired a high resistance to DDT in the Torreón area of Mexico, and laboratory data have shown

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FIGURE 2.—Results from controlling pink bollworm with insecticides: Treated plot on right produced 2,702 pounds of seed cotton per acre compared with 668 pounds for untreated plot on left.

less resistance in varying degrees at several localities in Texas. Many cotton growers of the Torreón area reported poor control of the pink bollworm with DDT in 1958–60 after its extensive use in the area since 1947. In 1960, laboratory tests at Brownsville showed that the dosage of DDT for 50-percent mortality (LD_{50}) of moths originating near Torreón was 13.6 times greater than that for the LD_{50} of moths originating at El Paso. Susceptibility of moths from the Brownsville area was not significantly different from that of the El Paso moths. Appreciable pink bollworm resistance to DDT in Texas was first indicated in laboratory tests with moths from the 1962 crop at Coyanosa (near Pecos) and Presidio. The greatest resistance (6.6-fold) was in moths from Presidio.

Field experiments conducted near Torreón in 1961 showed that DDT alone was no longer effective against the pink bollworm in that area. Azinphosmethyl, carbaryl, and a mixture of azinphosmethyl and DDT gave excellent control and were slightly more effective than a mixture of benzene hexachloride-DDT. Laboratory tests indicated that the toxic effects of the last mixture were more than additive and may be classified as synergistic, because benzene hexachloride alone is only slightly effective.

In a study of increased resistance to DDT in pink bollworm adults, a laboratory culture was propagated with moths that survived topical application of DDT. Such selection, continued through 21 generations with a DDT dosage estimated to kill about one-third of the moths, resulted in an eighteenfold increase in resistance. The increase was very rapid during the last five generations.

Soil Treatment

Results of experiments at the Brownsville laboratory indicate that the overwintering pink bollworm population can be greatly reduced by soil treatment with fumigants and organic insecticides but at dosages too expensive for use as a practical control measure. In these experiments, bolls infested with diapausing larvae were buried in cages, and evaluation of the treatments was based on records of moth emergence from the treated bolls compared with nontreated bolls. Examples of the dosage and larval mortality obtained are as follows:

Chemical	*Pounds per acre*[1]	*Larval mortality (percent)*
Endrin	8	94
Parathion	10	92
DDT	20	53
Nemagon[2]	250	96
D–D[3]	25	43
	50	83

[1] Dosage in gallons per acre for D–D.
[2] 1,2-Dibromo-3-chloropropane.
[3] Dichloropropane-dichloropropene mixture.

CONTROL BY PLANT RESISTANCE

Use of plant varieties resistant to insect attack is a highly desirable way to control the pests. In India, where the pink bollworm is believed to have originated, imported commercial cottons were more susceptible to attack by the insect than were the indigenous cottons. None of the commercial cottons grown in this country have shown resistance to pink bollworm attack. Early-fruiting, quick-maturing varieties escape some damage from the late-season buildup in population, and an open-type variety has less boll rot from pink bollworm infestation than does a dense-foliage type.

A long-range breeding program directed toward developing a commercially accepted variety resistant to pink bollworms was undertaken in the early 1950's. Approximately 150 cottons have been screened for resistance to the insect and further studies made of certain plant characteristics. A cotton possessing both resistance and desirable agronomic characters has not as yet been developed.

Some of the cottons tested apparently were more preferred than others by the pink bollworm moth. Of all the cottons observed, *Gossypium thurberi* was the least attractive for oviposition.

Two species and a cross with a third species exhibited properties detrimental to pink bollworm larvae. This was evidenced by a reduction in number of surviving larvae on *Gossypium thurberi* and a *G. tomentosum* × *G. hirsutum* (Stoneville 2B) cross and by a lengthening of the larval developmental period on *G. arboreum*. The mechanism of resistance in the cross appeared to be a physiological response of the seed to insect injury. When the seeds were attacked, large masses of cells were proliferated and they engulfed and killed many larvae.

Morphological characters of certain cottons were found to affect the oviposition sites selected by the pink bollworm, with a greater percentage of the eggs being laid away from the bolls as compared with other cottons. As a result, there was greater exposure of the eggs and of newly hatched larvae to insecticides, parasites, and predators. Greater larval mortality was due to failure of the wandering larvae to find bolls. The studies showed that oviposition on bolls decreased when the boll had a very tight-fitting calyx without well-defined lobes, flared bracts, or both. The moths were attracted to vegetative parts having heavy, coarse pubescence and leaves with heavy veins for oviposition. In a field-plot experiment, however, the number of larval mines in bolls of hirsute and glabrous strains was not significantly different.

The studies suggest that it may be possible to increase the resistance of cotton to the pink bollworm and other insects by breeding for a higher gossypol content of the plant. The presence of gossypol in the seed, however, renders the cottonseed meal poisonous as feed to nonruminant animals, and in cottonseed oil it hinders the oil-refining process for oleomargarine and salad dressing.

In cage experiments a cotton without extrafloral nectaries reduced pink bollworm reproduction, presumably because of lack of nectar as food for the moths. However, field experiments were unsuccessful in demonstrating the effect of nectarless cotton on pink bollworm infestation.

KILL AT GIN AND OIL MILL AND IN PLANTING-SEED TREATMENT

Kill of pink bollworms in cottonseed and seed cotton is necessary for local insect control in a generally infested area. This is in addition to the quarantine requirement that infested materials be treated to render them free of live larvae before they are moved out of an infested area. Soon after the insect became established in this country, Federal and State governments adopted regulations requiring that gins and oil mills in quarantined areas be provided with special equipment for killing the larvae.

Such equipment consists of heat sterilizers for treating cottonseed as a continuous process of ginning, fumigation equipment and steel rollers for treating lint and linters, and incinerators or other special equipment for burning or treating gin trash. Installing and operating this equipment in infested territory have cost farmers and processors many millions of dollars.

As more and more gin machinery came into use with improved harvest and ginning practices, it became evident that increasing percentages of pink bollworms brought to gins in seed cotton were killed by the operation of the gins themselves. Beginning in 1953, investigations were conducted to determine the pink bollworm mortality resulting from modern gin and oil-mill processing and, if possible, to find ways of increasing it. Also, investigations were made on larval kill by delinting and hot-water treatments of cottonseed intended for planting.

Kill in Ginning Operation

In the ginning laboratory at Mesilla Park, N. Mex., results of tests on infested snapped cotton indicated that ginning with the simplest saw-gin setup possible for handling this kind of cotton had killed 84 percent of the pink bollworms in seed taken at the gin stand. With gradual addition of machinery to make an elaborate gin setup, the kill increased to more than 99 percent. Results with infested handpicked cotton showed a similar trend. Further kill was caused by the seed-blow system. In tests at commercial gins similar results were obtained regarding pink bollworm mortality in the ginning operation. The large number of live pink bollworms found in gin trash, despite the high kill in seed, confirmed the need for treating this material to kill the larvae.

Pink bollworm kill in seed cotton ginned with a roller gin is lower than that resulting from a saw gin. When infested cotton passed through the gin stand alone, bypassing all other equipment, the larval mortality was 6 percent for a roller gin compared with 32 percent for a saw gin operated at 570 r.p.m. and 77 percent at 865 r.p.m.

Survey of Gins in Quarantined Area

A survey was made of the cleaning and ginning equipment of all the saw gins in the pink bollworm quarantined area of Texas, New Mexico, Oklahoma, and regulated areas of Arizona, Arkansas, and Louisiana, and a record was kept of the number of bales ginned by each in 1955. The machinery in the respective gins was coded as in the ginning experiments. The effectiveness of each gin in killing pink bollworms was then estimated, based on results of the ginning experiments.

Of the 2,340 saw gins in the quarantined area in 1955, equipment estimated to kill less than 90 percent of pink bollworms was found in only 47, and less than 1 percent of the cotton produced in the area was ginned at these 47 plants. Some of these gins showing low kill have been taken out of service since the 1955 survey. Gins classified as equipped to kill at least 95 percent of pink bollworms numbered 2,019, and their output of cotton made up 94 percent of the year's total for the area. Roller gins used for American-Egyptian varieties numbered only 16 in the quarantined area in 1955.

Fan Treatment of Gin Trash and Oil-Mill Byproducts

Fractions of samples of seed cotton used in the ginning experiments showed that waste material per bale averaged 70 pounds in handpicked cotton and 689 pounds in snapped cotton, both containing many live pink bollworms. There is a demand for this material, which is used profitably for soil improvement and as stock feed when it is free of live pink bollworms. The alternative for disposing of the material is burning it. Besides the cost of using incinerators to dispose of gin trash, serious problems have been created in some localities because of the smoke and disagreeable odors.

Preliminary work to determine the effectiveness of oil-mill processes in killing pink bollworms showed that 26 percent of the larvae in seed survived the first delinting and 1.8 percent survived the second. Large numbers of live larvae were found in the shaker waste.

Tests were made with fans of the kinds commonly used for moving trash to an incinerator as it occurs in the ginning operation and for moving motes and linters to the press at oil mills. Gin trash used in the tests originated with the ginning of heavily infested cotton and contained many live pink bollworms in seed in waste locks as well as free larvae. Infested seed was added to the oil-mill byproducts used in the tests. Fans tested, whether their housings were unlined or had rubber linings, were found to kill all pink bollworms in gin trash and in linters, motes, and hulls if designed and operated according to specifications developed as a result of the experiments conducted. The fans at both the gin and oil mill are installed in the duct system.[2]

Treatment of Planting Seed

Investigations of treatments commonly used for cottonseed intended for planting showed that 100 percent of the larvae in infested seed were killed by the standard acid or mechanical-flame delinting process. Also, the hot-water treatment sometimes used to hasten germination of the American-Egyptian variety was effective in killing the larvae in infested seed. Immersion of the seed for 45 seconds at 150° F. or higher resulted in 100-percent kill. At 140°, 80 to 120 seconds was required for 100-percent kill.

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[2] For information on specifications and installation of the fans, consult the Plant Pest Control Division, Agricultural Research Service, Federal Center Building, Hyattsville, Md., 20782, its field offices, or the State regulatory agencies in the States where the fans are used.

Changes in Quarantine Requirements

The research conducted at the gin and oil mill has brought about several changes in the pink bollworm quarantine requirements. These changes are now saving cotton growers and processors more than $3 million a year.

The high pink bollworm kill in the normal ginning operation and the further kill in oil-mill processing or planting-seed treatment have led to the conclusion that under present practices the survival in cottonseed is of little, if any, importance when the seed is used within the generally infested area. As a result of this conclusion, based on research conducted in the mid-1950's, Texas, New Mexico, Arizona, Arkansas, and Louisiana promptly abolished their regulations requiring heat treatment of cottonseed as a continuous process of ginning. Oklahoma has never required it nor do the recently infested States of California and Nevada. Because of the danger of pink bollworm spread from the fringe of the infested areas, however, seed returned to the farm from gins with low pink bollworm-killing capacity in these areas is required to be treated. Although fumigation usually is the preferred treatment, a few gins in Arkansas and Louisiana still operate heat sterilizers for the benefit of farmers who want to take their seed home.

Planting seed that is delinted at approved acid or mechanical-flame delinting plants or that receives approved heat treatment may now be certified for movement out of the pink bollworm quarantine area without further treatment.

Fans meeting approved specifications may now be used instead of more expensive treatments formerly required for killing pink bollworms in linters, motes, and hulls at the oil mill. They also may be used to kill the larvae in gin trash and thus free this material for local use rather than burning it. There are occasions when gin trash is still burned to get rid of it, although it has been passed through an approved fan at places where it is not in sufficient demand and where local regulations do not prohibit burning.

CULTURAL CONTROL

During the many years before effective insecticides were available for controlling the pink bollworm, research was directed primarily toward developing cultural control methods. Even with the present-day insecticides, practical control of the insect still is dependent mainly on cultural practices. Mandatory cultural control zones are in effect in the southern, central, and eastern sections of Texas, in regulated areas of Arkansas, and certain regulated areas in Louisiana, Arizona, and California.

The pink bollworm is the only major cotton insect that passes the winter in crop residue in the field in which it developed. Because of this habit it is especially susceptible to destruction by mechanical and cultural means. Although the most effective cultural control measures are aimed at destroying the overwintering larvae, certain practices during the crop-production season help to reduce crop damage and buildup of the potential overwintering population.

Planting Date and Early Crop Maturity

The main objective to be accomplished by cultural practices during the cotton-production season is to shorten the season in order to minimize pink bollworm damage and still permit maximum yield and profit. This objective involves planting date and practices to hasten crop maturity.

Planting Date

Many pink bollworm moths from overwintered larvae emerge early in the spring and die before cotton squares become available for their reproduction (suicidal emergence). At Waco, Tex., for example, about 65 percent of the emergence from overwintered larvae is suicidal if cotton is planted the first of April. Suicidal emergence increases with delay in planting; however, a delay past the optimum planting date may increase the larval population in diapause at harvesttime.

Planting-date experiments were conducted for 4 years at Presidio, Tex. The plantings were started at different dates on caged plots to prevent moth movement from plot to plot. The 4-year average data indicate that delay in planting caused a decrease in pink bollworm population during the early blooming and early boll period; however, at harvesttime the diapause larval population was much greater in the late than in the early plantings.

A wide range in planting dates in an area extends the cotton production season and reproduction period of the pink bollworm. Extremely early, scattered plantings attract early emerging moths from surrounding fields and thus the spring population developing in squares is increased. Because of this concentration of spring emergence, heavy damage may occur in the early plantings. When early plantings mature, the moths emerging in them move to later fruiting, more attractive cotton. Extremely late plantings may be severely damaged because moths move into them in large numbers after the early and intermediate plantings have matured. Thus a long planting period results in greater damage by the pink bollworm, and because of the longer growing season with abundant late bolls, a greater buildup occurs in the insect population compared with a short planting period. Therefore planting in a community should be completed in the shortest period possible.

Reports by agronomists show that cotton should not be planted until the daily minimum soil temperature at an 8-inch depth averages 60° F. or above for 10 days preceding planting. At lower temperatures, germination and seedling growth are retarded, the incidence of seedling disease is increased, and the young plants are exposed to early-season insects such as thrips for a longer period.

Under good conditions for plant growth, first squares are formed on upland cotton within 40 to 50 days of planting and first blooms within 60 to 70 days. The crop will mature sufficiently under these conditions for chemical defoliation within 125 to 150 days of planting and may be harvested within 160 days. Thus there is ample time for maturing and harvesting a crop in advance of stalk-destruction deadlines, and there is little reason for planting to begin extremely early or to continue for a long period.

The reports show that the best stands, highest yields, and lowest production costs occur when cotton is planted at the optimum date based on soil temperature (recommended average of 60° F.). Where American-Egyptian (long staple) varieties are grown, they should be the first plantings in a community because they are later and slower fruiting than upland varieties.

Early Crop Maturity

Production of an early crop in the shortest period possible, with early harvest, prompt stalk destruction, and deep plowing, is most important in reducing the overwintering population of the pink bollworm. (See Survival Under Different Practices and Climatic Conditions.) Bolls formed in the first part of the season escape severe damage because they mature before the pink bollworm infestation builds up to its seasonal maximum intensity. Crop production in a short period decreases the seasonal buildup of the insect and may result in fewer larvae entering diapause to live through the winter.

Late irrigation in order to produce a late top crop of bolls after the plants have matured an early crop tends to foster a tremendous population of pink bollworms and boll weevils, if they are present. 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. Tests conducted at Presidio showed that withholding late irrigation speeded up maturity of the cotton and reduced the overwintering pink bollworm population.

A serious problem has been created by an outbreak of the pink bollworm in the Far West, where the climate is favorable for a high winter survival of the insect and cotton growers are accustomed to very high yields resulting from a long growing season with favorable weather for a late harvest. The growers think they cannot afford to eliminate the late top crop of bolls produced there. It appears that this late crop will soon become very expensive, even in the absence of the boll weevil. Certainly the intensive use of insecticides will be required or the pink bollworm will take the late crop, and growers may find it is to their advantage to shorten the production and harvest period, unless research improves or develops other ways of handling the insect in the immediate future.

Prefrost stalk destruction.—Early destruction of stalks before frost may decrease pink bollworm reproduction by two or three generations in areas with a long growing season. Prefrost stalk destruction may stop reproduction before many larvae have entered diapause, and winter mortality of those in diapause is increased when they are plowed under early.

Experiments in the lower Rio Grande Valley, simulating stalk destruction on August 15, September 15, and October 15 with the infested bolls buried 1½ inches on these dates, showed that winter survival of the diapause larvae increased greatly with delay in stalk destruction. Based on moth emergence after March 15, with squares available for reproduction by moths emerging at that time, the survival was 55 times greater for September and 400 times greater for October than for August stalk destruction. This increase in winter survival with delay in stalk destruction is in addition to seasonal buildup of the larval population and the increase in the proportion entering diapause as the season advances.

Use of preharvest chemicals.—In the lower Rio Grande Valley a mandatory stalk destruction deadline of August 31, when less than 20 percent of the pink bollworm larvae are in diapause, has been very effective in controlling the insect. Occasionally weather conditions require extending the deadline. Farther north where later stalk destruction usually is necessary, a greater percentage of the larval population enters diapause.

The time of harvest and stalk destruction may be hastened and the diapause larval population reduced by using chemical defoliants or desiccants. Preharvest chemicals do not prevent larvae that develop in bolls from entering diapause. However, they stop plant fruiting and make the plant unattractive to pink bollworm moths for oviposition, besides hastening maturity of the bolls present.

Certain hazards are involved in using desiccants or defoliants. The principal danger is if the chemical is applied too early, serious yield losses may occur with additional losses in quality of the lint and seed. Defoliation is not recommended until 60 percent of the bolls are open.

Stub Cotton

Where the winters are not cold enough to kill cotton roots, the land may be left unplowed after the stalks are shredded, and the old plant stubs will grow new sprouts for producing the next crop (stub cotton). In a program to control the pink bollworm, the production of stub cotton should be prohibited.

Stub cotton results in a higher winter survival of larvae, because the infested crop residue left in the field after harvest of the previous crop is not plowed under. It decreases the spring suicidal moth emergence, because it produces squares before any are formed on the earliest possible spring planting, and thus the moth population at the beginning of the cotton fruiting season is further increased. It increases the length of the plant fruiting and insect reproduction season, adding at least an extra generation to those possible on cotton planted at the optimum time, and thereby increases the seasonal population buildup, crop damage, and potential overwintering population to attack the next crop.

Shredding and Field Cleanup

Pink bollworms in bolls and locks remaining in the field after harvest are the main source of carryover to the next crop. Diapause larvae in cocoons in the soil are very common in the West, but this free-cocoon population is less important. Data obtained during a period of several years at Presidio showed that the cocoon population accounted for only 16 percent of the total diapause larvae present in the fields after harvest, though the percentage was much higher in some fields. Also, the winter survival of larvae in cocoons is lower than in bolls. (See Survival Under Different Practices and Climatic Conditions.)

Pink bollworms in the harvested crop carried to the gin are killed during the ginning and oil-mill processing and by the planting-seed treatment. Clean harvesting of the crop by hand or mechanical picker and using a cotton gleaner if appreciable cotton is left on the ground help to reduce the crop residue. Snapping the bolls by hand or with a machine stripper, where practical, is very effective in removing infested bolls from the field.

Stalk Cutting and Shredding Equipment

Great progress has been made in the development of stalk cutting and shredding equipment since the days when horsedrawn equipment was commonly used. The early stalk cutting equipment used with tractors, generally an adaptation of the horsedrawn rolling cutter, was of little value in killing pink bollworms except to cut the stalks in pieces that could be plowed under. The appearance of power-driven shredders was hailed as a promising means of killing larvae in crop residue. Tests showed that they were effective. A shredder also cuts the stalks in finer pieces and spreads them over the ground so that they can be plowed under more thoroughly than when the stalks are cut with a rolling cutter.

Different makes of shredders and new models were tested as they became available to evaluate their effectiveness in killing pink bollworms in crop residue. From information gained in these tests, adaptations or improvements of the commercial machines were made and evaluated. Some of the adaptations found to improve the killing efficiency have been incorporated in present-day commercial shredders.

Stalk shredders are of two types—one with a vertical shaft and a horizontal rotating blade (horizontal rotary type) and the other with a horizontal shaft and many free-swinging, vertical rotating knives (flail type). Experiments have shown that the flail shredder is more effective in killing pink bollworms than the horizontal rotary shredder.

The flail shredder will kill about 85 percent of the pink bollworms in crop residue compared with 55 percent for the horizontal rotary type. Experiments have revealed no significant difference in kill between different makes of the same type. Although killing efficiency of the flail shredder is higher with a correspondingly higher degree of stalk shredability, the power requirement is greater than for the horizontal rotary shredder.

A part of the crop residue containing pink bollworms may be found on the ground before shredding or may be shattered from the plants during the shredding operation. An improvement in the horizontal rotary shredder was to shape the blades so as to create a suction to lift the shattered bolls and expose them to shredding action. The flail shredder creates a tremendous suction and the bolls are exposed to greater shredding action (fig. 3) than with the horizontal rotary type. In one experiment prefrost shredding with a flail shredder resulted in 98-percent larval mortality where 4 percent of the population was on the ground before shredding.

Burning and Grazing Stalks

During the early existence of the pink bollworm in this country, Federal and State regulatory agencies and growers had no choice but to cut and burn cotton stalks or graze the fields to reduce the pink bollworm population in crop residue before plowing. Although both methods are effective, they have serious disadvantages and have never been used to any appreciable extent for practical pink bollworm control.

In a field cleanup program conducted by the Plant Pest Control Division for 9 years in the Presidio area, the effectiveness of burning stalks for pink bollworm control was evaluated. Approximately 90 percent of the larvae in bolls and locks were destroyed when the stalks were cut by hand, piled with a pitchfork, and the shattered bolls picked up or raked by hand and burned with the stalk piles. The remaining 10 percent of the larvae were accounted for in bolls and locks that were missed in the cleanup process. The amount of bolls shattered from the stalks was greater and efficiency of the cleanup process decreased when stalks were cut with a tractor mower and piled with a push rake or dump rake. Besides the high cost of cutting and burning stalks with the crop residue, it is desirable to retain this material in the field for soil improvement.

Investigations on pasturage of infested fields for pink bollworm control were made during a period of several years at Presidio. Where fields were heavily pastured with cattle or goats, over 90 percent of the overwintering pink bollworms were destroyed. To be highly effective, large numbers of livestock must be kept in the fields. Food value of the cotton plant for animals is poor, and also grazing fields that have been treated with insecticides is hazardous.

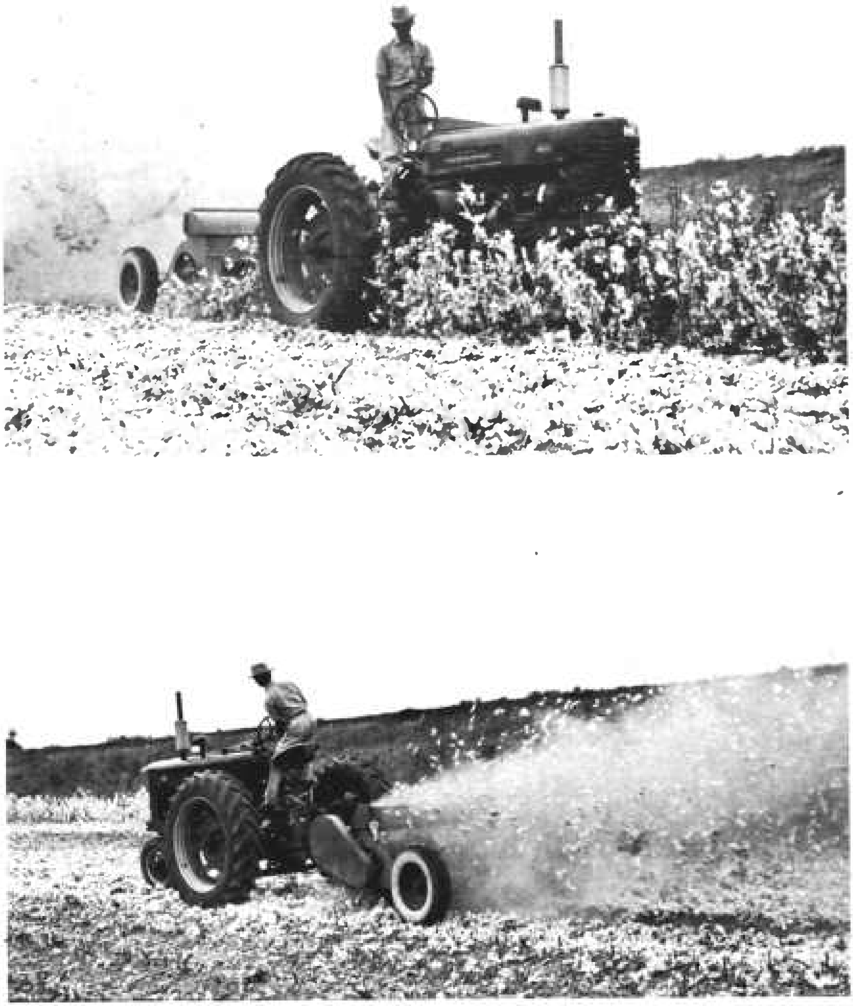

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FIGURE 3.—Stalk shredding with flail shredder (top) and machine lifting bolls from ground and shredding them (bottom).

Survival Under Different Practices and Climatic Conditions

Experiments conducted with the pink bollworm in bioclimatic cabinets simulating temperatures and rainfall at representative localities outside the infested area indicate that the insect can survive an average winter throughout the Cotton Belt. Work performed in arid sections of southwestern Texas and northern Mexico has shown that a heavy larval mortality occurs when infested bolls are buried in the fall, especially if the soil remains thoroughly moistened for a considerable time.

Data from experiments in central Texas show that plowing the land to a 6-inch depth in November with a moldboard plow, followed by listing in February, will give better pink bollworm control than any other winter cultural methods that have been practiced in the area. These experiments indicate that when a winter grazing or cover crop follows cotton, the land should be plowed before planting, especially if the crop is to be left for harvest, instead of plowing it under in the spring.

Investigations of winter survival of the pink bollworm in field cages (fig. 4) at several localities in Texas and Oklahoma have furnished data to help determine the effects of fall and winter cultural practices, rainfall, and winter temperature on survival of the insect, although other factors such as soil type probably had considerable effect in the experiments. Climatic conditions at the localities in which the experiments were conducted ranged from subtropical and humid at Brownsville to cold and arid in western Texas to cold and wet at Heavener, Okla.

Results of these widely separated experiments, simulating four winter cultural practices under natural rainfall conditions, showed

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FIGURE 4.—Cages used to study survival of overwintering larvae of pink bollworm.

that the cultural practices affected pink bollworm survival and that this effect varied in different localities and was largely due to climatic conditions. Variation in survival due to climatic conditions can be seen by comparing the average survival (percent for the four treatments) at eight localities in Texas and two in Oklahoma as follows: Brownsville 1.1, El Paso 12.8, Greenville 3.9, Lubbock 3.2, Mt. Pleasant 10.2, Port Lavaca 2.9, Vernon 2.1, Waco 11.9, Chickasha 3.8, and Heavener 1.1.

Fall burial of infested bolls greatly decreased survival over that for bolls that remained on the soil surface until buried in the spring except at localities in a dry climate. The highest survival occurred in bolls that remained on the soil surface throughout the experiments at all localities except Brownsville, where the highest survival occurred in bolls exposed above ground, simulating standing stalks. Where the temperature dropped to 15° F. or lower, the lowest survival occurred in bolls exposed above ground until buried in the spring. Under farm practice, however, where much of the cotton has shattered to the ground, it is not advisable to leave the land unplowed to take advantage of this mortality on standing stalks resulting from low air temperature.

Time and Depth of Burial and Winter Irrigation

Experiments to furnish data on this subject were conducted on a clay soil in arid climate at Presidio. An irrigation on March 15 was included in all treatments, simulating the preplanting irrigation practiced in the area.

Winter burial of infested bolls followed by winter irrigation greatly decreased pink bollworm survival and two irrigations were more effective than one. Survival where the soil was not irrigated during the winter was three to seven times greater than that in soil receiving two winter irrigations. The earlier in the winter the bolls were buried and irrigated, the lower the survival was. However, when bolls were not irrigated, there was no marked difference in survival between burial dates.

As the depth of burial increased, the survival decreased from 15.1 at 2 inches to 3.1 percent at 6 inches. Of the total number of moths that emerged from the experiments, 61, 26, and 13 percent came from the 2-, 4-, and 6-inch depths, respectively. It is therefore apparent that early deep plowing with high soil moisture is a major factor in pink bollworm control. In extremely cloddy soil it may be necessary to use a disk harrow before irrigation to adequately cover the infested bolls.

Winter and Spring Rainfall

Dry weather during the fall and winter is favorable for a high survival of pink bollworms, as shown in the experiments at Presidio previously discussed. Also, the higher survival in the cold climate of El Paso, as compared with warmer localities having higher rainfall, is attributed to the aridity of the climate there. In the El Paso experiment, however, spring and summer irrigations were favorable for pupation and may partly account for the higher survival there than at Lubbock. The effect of spring moisture to stimulate pupation and moth emergence was shown in a 2-year experiment at Presidio, in which spring irrigation compared with nonirrigation increased survival from 2.8 to 7.1 percent in one year and from 6.8 to 12.3 percent in the other year.

Effects of rainfall were evident in the yearly fluctuations of survival at several localities in Texas where yearly rainfall varied considerably during the 5-year experiments. Increases in survival for 2 years at Lubbock, a low rainfall area, were attributed to higher spring rainfall that was more favorable for spring pupation than in the other years. At Waco, a higher rainfall area, survival was decreased in 2 drought years, in which low spring rainfall was unfavorable for pupation. However, the fall moisture in these years was sufficient to cause a high mortality in bolls buried on November 15. A similar instance occurred at Greenville in one winter. Unusually high rainfall in one winter at Waco reduced survival in buried bolls to less than that in any other year; however, it was rather favorable for survival in bolls on the soil surface.

Undoubtedly winter rainfall was the major cause for the low survival at Greenville compared with Waco. In one year at Greenville, a rainfall of 57 inches from November through June accounted for an extremely low survival in both buried and surface bolls. Not only did the winter rain produce adverse conditions for the larvae but 19 inches of rain in April and 14 inches in May certainly exceeded the amounts favorable for moth emergence.

Fall and Winter Temperature

Survival of the pink bollworm under winter temperatures with a minimum below 0° F. was demonstrated in the arid El Paso area. Winter temperatures there are characterized by wide fluctuations, with daily highs above 50° except during extremely cold periods, which always last for only a few days. Laboratory studies and an experiment conducted in a bioclimatic cabinet simulating the climate at Malden, Mo., indicate the survival is not only affected by the extreme minima but greatly reduced by long periods in which the maxima are about 40°. Diapause larvae stored for experimental use may be held for a long period under dry conditions at about 55°. At a refrigerator temperature of approximately 38° a high mortality will occur within a month.

The wide fluctuation in winter survival during 8 years of experiments at El Paso, averaging from 4 to 21 percent, was attributed to low temperatures. Unusually cold weather occurred in three consecutive winters. In January 1947 the temperature remained below freezing for 136 hours, with a low of 4° F. A low of −6° occurred in January 1948, an alltime low for the area. The temperature dropped to −2° in January 1949. During each of these winters survival decreased compared with that in the milder winters. This low survival was reflected in greatly decreased field infestations in the area during the 3 years.

The effect of temperature and level of soil moisture on survival of diapause pink bollworms in buried bolls was studied in bioclimatic cabinets that were programed to simulate the December 1960–March 1961 temperatures at Waco and Heavener, areas of generally high and low winter survival of the insect, respectively. At the moderate Waco soil temperatures (mean 51.7° F.), moderate soil moisture (16 percent) reduced larval survival compared with that obtained at a low level of moisture (8 percent). At Heavener soil temperatures (mean 44.1°), survival was very low at both 8- and 16-percent soil moisture, with no significant difference between these levels.

Sudden fall freeze.—In the fall, pink bollworm mortality in green bolls is negligible if light frosts persist for several days before subfreezing temperature, whereas a sudden drop in temperature sufficient to freeze succulent bolls results in almost 100-percent mortality. Such sudden freezes occur in the colder climates of the infested area where many bolls are green at frost date. When these bolls are frozen, the pink bollworm population is greatly reduced.

High soil temperature.—A high larval mortality resulting from high temperatures may occur in bolls on the soil surface after prefrost shredding of the stalks. From August 19 to September 15, when maximum soil-surface temperatures ranged from 123° to 155°F. at Brownsville, mortality was 100 percent in open bolls held in direct contact with the soil surface for 14 days and nearly 100 percent for 7-day exposures. In the field where some of the bolls were protected by debris after shredding, the mortality was slightly lower. In later exposures the mortality progressively decreased with seasonal decrease in temperature after heavy rainfall on September 11. In the lower Rio Grande Valley there is danger in delaying plowing to take advantage of the larval kill from soil temperature because of the fall rainy season, which may result in plant regrowth and a very late plowing if not done before the rains begin.

Winter Survival in Clay and Sandy Soils

Winter survival of the pink bollworm was two to three times greater in a heavy clay soil than in sandy soil in experiments conducted during the winters of 1928–30 and 1938 at Presidio. In the 1928–30 experiments, survival in nonirrigated bolls buried 4 inches was 3.1 percent in clay soil and 1.4 percent in sandy soil. In the 1938 experiments, survival in bolls buried 2 to 6 inches and irrigated on March 15 was 7.9 and 2.5 percent for the respective soils.

Winter Survival in Bolls and Free Cocoons

Pink bollworms in free cocoons and in blooms at Brownsville pupated and emerged in the fall and winter; consequently, none were left to infest the next crop in the subtropical lower Rio Grande Valley. There was no winter carryover during 1 of 2 years in which experiments with cocoons were conducted at Port Lavaca, where mild weather induced fall and winter pupation.

Larval survival in bolls was greater than in free cocoons under identical treatments in experiments at Presidio, El Paso, and Waco. In nonirrigated treatments survival in bolls was approximately 15 times greater than that in cocoons at Presidio, eight times greater at El Paso where the weather was colder, and 12 times greater at Waco where the weather was milder but rainfall greater than at the other two localities. Winter burial and irrigation at Presidio were more effective in reducing survival of larvae in free cocoons than in bolls. Because of the high larval mortality in cocoons and the smaller number present, compared with the population in bolls, the overwintering cocoon population is considered to be of minor importance, especially in areas of high rainfall or where the land is irrigated during the winter.

Recommendations for Cultural Control

Recommended practices for controlling the pink bollworm as given here are based on the foregoing discussions. Every cotton grower in pink bollworm-infested areas should follow recommended control practices for the benefit of himself and other growers of his community.

For the most effective cultural control of the pink bollworm, the cotton crop should be produced and harvested in the shortest period possible, with stalk shredding and deep plowing performed immediately after harvest. There is sufficient time for producing and harvesting a crop before stalk-destruction deadlines if planting is done at the optimum time and recommended practices to hasten crop maturity are carried out. Recommended control practices are as follows:

(1) Shorten the planting period and plant at the optimum time for a given locality. Use seeds of an early-maturing variety that have been culled, treated with a fungicide, and tested for germination.

(2) Leave as thick a stand as has been recommended for the section and type of soil.

(3) Use practices during the cotton-production period that promote early maturity. Early-season control of certain insects has proved advantageous in some States but not in others. Practice early-season control where recommended by controlling the cotton aphid (*Aphis gossypii* Glover), the boll weevil, the cotton fleahopper (*Pseudatomoscelis seriatus* (Reuter)), cutworms, thrips, and any other insects that may retard the growth and fruiting of young plants. Protection of early fruit may make possible an early harvest.

(4) Withhold late irrigation. Use defoliants or desiccants to hasten opening of the bolls remaining after 60 percent have opened.

(5) Harvest cleanly. Use strippers where practicable. In areas where spindle pickers are used, final scrapping with a stripper

is desirable. Use a cotton gleaner if appreciable cotton is left on the ground after harvest.

(6) Shred and plow under the stalks and debris as soon as possible after harvest. The flail-type shredder is recommended over the horizontal rotary type for pink bollworm control. Okra stalks and debris should be shredded and plowed under at the same time because this plant is a preferred secondary host. In arid areas where the crop debris is plowed under in the late fall or early winter, the fields should be irrigated in the winter to increase pink bollworm mortality. Fields left fallow or unplowed in the fall or winter should be plowed early in the spring.

(7) The production of stub cotton, possible only in the warmer areas, should not be practiced. Early prefrost shredding and plowing decrease reproduction of the insect and increase mortality of the overwintering larvae. All sprouting and seedling cotton and okra developing after plowing should be destroyed before fruiting to create a host-free period between crops.

OTHER METHODS OF CONTROL

Light Traps

The pink bollworm moth is attracted to light radiated in the near ultraviolet range of the spectrum. The blacklight fluorescent (mercury vapor) and argon glow (mixture of gases) are examples of lamps that radiate strongly in the near ultraviolet region. A 15-watt blacklight lamp was highly attractive to the pink bollworm and a 2-watt argon glow was almost as attractive to this insect but was much less attractive to orders other than Lepidoptera. Traps equipped with blacklight and argon bulbs attract and catch pink bollworm moths. Males and females are equally attracted.

Finding that the argon lamp is selective led to the design of a special argon light trap. It is commonly used for pink bollworm surveys, because the time required to examine the trap collections is shorter than that for the larger volume of other insects in blacklight traps. A comparison of collections from blacklight and argon light traps during May and June at Brownsville showed that the ratios of pink bollworm moths caught by the blacklight trap to those by the argon light trap varied from 1.7:1 in May to 3.2:1 in June.

Light traps of the electric-grid type with two 15-watt blacklight fluorescent bulbs were used by growers for insect control on cotton, corn, and vegetable crops at Batesville, Tex., in 1955. There were 142 traps operated on five adjacent farms comprising approximately 3,000 acres. Infestation counts in representative fields of cotton in the trap area and check fields outside the area indicated that these traps were of no benefit in controlling the pink bollworm. Counts at 100, 450, and 800 feet from traps showed that the infestation did not vary appreciably with distance from the traps.

At Brownsville, cotton infested with the pink bollworm was grown in a screened cage partitioned into two sections, 40 by 60 feet each, and an insect-collecting type of trap with four 15-watt blacklight bulbs was operated in one section while the other was used as a check. Although the trap caught a large number of pink bollworm moths during 8 weeks, there was no appreciable difference in buildup of infestation between the light trap and check sections. The bolls infested reached 100 percent in both sections within the same week. This lack of reduced infestation in the trap section, despite the high moth catch, indicates that the moths deposit eggs before being trapped.

Release of Sterile Males

Experiments indicate that the pink bollworm may be controlled or eradicated by releasing sterile males to prevent fertilization of the female population in nature. Before this method of control can be undertaken, problems are still to be solved, such as the development of practicable techniques for mass rearing and sterilizing the moths for release. Utilization of this method should take advantage of winter mortality, cultural control, and possibly insecticide applications to reduce the natural population to a low level before the sterile-male releases are begun.

Sterilization by Gamma Radiation

Experiments were conducted to determine the optimum sterilizing dosage for pink bollworms treated as pupae with gamma radiation from cobalt–60. Pupal sensitivity to gamma radiation was dependent on age at time of treatment—the older the pupae, the less susceptible they were. When 1- and 3-day-old pupae were irradiated, dosages inducing complete sterility also caused some pupal mortality and appreciable moth damage. However, irradiation of 5- to 7-day-old pupae induced almost complete sterility without pupal mortality or adult malformation.

When males from irradiated 7-day-old pupae were mated with untreated females, complete sterility was achieved at 55 kr. At dosages of 30 to 60 kr no more than 3 percent of the oviposited eggs hatched for any one exposure dosage. Exposure at 40 kr was sufficient to sterilize females. Longevity of males from 7-day-old pupae treated with 35 through 90 kr was significantly shorter than that of untreated moths. Also, the males sterilized by gamma radiation did not fully compete with nonsterile males for the females.

Work on sterilization of the adult pink bollworm by irradiation is in progress.

Sterilization With Metepa

Metepa was found to sterilize pink bollworm males, without impairing their competitiveness for females, when applied topically at 15 μg. per moth or when the moths are exposed to residues on glass at 26 μg. per square centimeter for 15 minutes. Further work is needed to develop techniques for mass treating the moths; however, the topical treatment has been satisfactory for experimental purposes. When metepa was received from different production batches and was used by workers with other insects, difficulties were encountered because of variation among the different batches.

Eradication of Confined Population With Sterile-Male Releases

Male pink bollworm moths treated with 15 μg. of metepa per moth were released in field cages with normal moths of both sexes to determine the effects of sterile-male releases on the F_1 generation. A single release in each cage at a ratio of nine sterile to one normal male reduced the F_1 population an average of 81 percent compared with that in untreated check cages. Despite this reduction, the F_1 population increased 2.6 times the parent population. Data on pink bollworm population dynamics indicate that in the lower Rio Grande Valley an increase of fivefold to sevenfold per generation is required to overcome winter mortality, including that resulting from cultural practices, and yet maintain a steady population from year to year.

An experiment conducted in a large field cage during 1964 and 1965 demonstrated that a pink bollworm population can be eradicated through effects of sterile-male releases combined with mortality from winter cultural practices. A screen partition divided the cage into two equal sections, into which equal populations of overwintered pink bollworms were introduced in the spring of 1964. Sterile males were introduced into the natural population of one section and the other section was used as an untreated check.

In 1964 the treated population was reduced 80 to 90 percent, compared with the check, by an estimated seasonal release ratio of 7:1 sterile males to normal males. However, the treated population continued to increase slightly during the growing season. In 1965 an estimated higher seasonal release ratio of sterile to normal males (probably more than 25:1) reduced the population 98 percent, despite some entry of moths from the check section. No larvae were found in the cage from June 20 to July 27, and the population is believed to have been eradicated before this entry of moths from the check section.

Chemical Attractants

Work was undertaken in the 1950's to find a chemical highly attractive to pink bollworm moths that might be used for detecting incipient infestations, for measuring insect abundance in the generally infested area from year to year, and for increasing the effectiveness of insecticide applications. Such a chemical could be used to attract the moths to a poison bait or possibly to treated plants where only parts of a field would be treated with the attractant and an insecticide and thus reduce the amount of insecticide needed.

Olfactory tests were conducted in the laboratory to screen compounds for attractancy to pink bollworm moths. The *m*-isopropoxybenzyl ester of chrysanthemumic acid was soon found to have greater attractancy than the cotton boll and was adopted as a standard for evaluating other materials. Of nearly a thousand compounds tested, none were found to be more attractive than the standard. Several compounds related to the standard were about equal to it but not sufficiently attractive for any practical purpose.

Sex Lure

Discovery in 1962 of a substance extracted from female pink bollworm moths that is highly attractive to the male has resulted in new methods for detecting and controlling the insect. The sex attractant occurs in the terminal two to three segments of the female abdomen. It can be extracted from clipped abdomens with methylene chloride or other solvents. Insect traps baited with this extract will attract and catch male pink bollworm moths. A component of the sex attractant has been isolated in pure form, identified, and synthesized. The synthetic material (propylure) produced and tested to date is not as effective as the crude natural extract, and work is in progress to improve its effectiveness.

A trap has been developed for utilizing the pink bollworm sex attractant to catch and kill the male moth. Calcium cyanide used as a killing agent does not affect the number of moths caught. This trap has been used to detect the pink bollworm in areas not previously known to be infested. In an experiment comparing different kinds of traps, light traps baited with the sex attractant caught more males than did untreated light traps.

One of the most exciting potential uses of the pink bollworm sex attractant is control of the insect population through male annihilation. This method of insect control reduces the male population to such an extent that the number of mated females is reduced and likewise the number of fertile eggs. A study to develop this method of control was undertaken during the 1964 cotton-production season.

Traps baited with pink bollworm sex attractant failed to reduce the infestation in the 1964 experiment though the moth catch in 6 months averaged 1,341 males per trap. Movement of moths into the field, due to lack of field isolation, and too few traps were probably responsible for the failure. The study poses many questions for further investigations: To what extent must the male:female ratio be reduced to achieve a reduction in population? What is the range of the sex attractant at different concentrations, and what factors affect the attractive radius? What is the behavior of the moths in the field, and how does this vary with the season and stage of plant growth? Can the design of the traps be improved, or is there a more effective way to use the sex attractant? Studies are underway to answer some of these questions.

Another use of the pink bollworm sex attractant, provided practicable techniques could be developed, would be to attract males to a chemosterilant, where they would be sterilized and then released back into the field population to mate with the normal females.

REARING

Development of an artificial diet and rearing techniques has made possible the rearing of the pink bollworm in the laboratory for experimental use. Larvae may be reared individually on the medium in small vials stoppered with cotton. Although this method is expensive, there are no difficulties other than the tedious task of dispensing the rearing medium into the vials, introducing the larvae, and inserting the cotton stoppers.

Difficulties encountered in early attempts to rear large numbers of pink bollworms in a container involved measures to prevent the larvae from wandering away from the medium and escaping. Using a tightly closed container to prevent escape of newly hatched larvae resulted in condensation of moisture and drowning of the larvae. Later it was found that newly hatched larvae could be confined on the medium when they were placed on ¼-inch cubes of the medium spread in layers interspersed between layers of cotton fibers.

Preparation of Rearing Medium

The rearing medium is prepared in batches of approximately 1 gallon in a blender of the Waring type. The ingredients for such a batch in the order in which they are added to the blender are as follows:

Material	*Amount*
Water (distilled)	880 ml.
Potassium hydroxide (4M)	18 ml.
Casein (vitamin free)	126 grams
Salts, Wesson's	36 grams
Sucrose	126 grams
Wheat germ	108 grams
α-Cellulose	18 grams
Choline chloride (10 percent v/v in water)	36 ml.
Formaldehyde (10 percent v/v in water)	13 ml.
Methyl *p*-hydroxybenzoate (15 percent w/v in 95 percent alcohol)	36 ml.
Vitamin stock[1]	6 ml.
Agar (dissolved in 2,200 ml. of boiling distilled water)	90 grams

[1] Contains 300 mg. riboflavin, 150 mg. pyridoxine, 150 mg. thiamine, 150 mg. folic acid, 600 mg. niacin, and 600 mg. calcium. The mixture should be stored under refrigeration.

When preparing a batch of this size, the potassium hydroxide and casein are blended in 880 ml. of water. All solids are then added and blended. The choline chloride, formaldehyde, methyl *p*-hydroxybenzoate, and vitamin stock are successively added with continuous blending. The hot dissolved agar is added and the entire mixture blended for about 2 minutes or until a homogeneous color is obtained.

After blending, the hot medium may be dispensed into vials with a plastic "squeeze" bottle of the type used to eject mustard or catsup, or it may be poured into a tray to solidify as a cake about one-fourth inch thick. The cake is cut into cubes by pressing it through a ¼-inch mesh hardware cloth mounted on a wooden frame.

Equipment and Rearing Procedure

During the early rearing of the pink bollworm, considerable difficulty was experienced in getting the moth to lay eggs where they could be recovered without using parts of the cotton plant as an egg-laying site. Later it was found that the female can be induced to insert her ovipositor through a screen to deposit eggs on a rough-surface paper pressed against the screen if all other surfaces of the oviposition cage are smooth and therefore offer no alternative egg-laying site. A 1-quart cylindrical ice cream carton will serve as such a cage if it is treated inside with paraffin and the cardboard disk in the lid is replaced with a screen disk. It will accommodate about 50 pairs of moths.

Eggs adhering to laying pads from several oviposition cages are held for incubation in a 250-cc. Erlenmeyer flask stoppered with cotton. The flasks are inverted in a holding rack until hatching takes place and the larvae are ready for transfer to rearing containers. Since newly hatched larvae are attracted to light, proper exposure to a 40- or 60-watt light bulb will cause them to crawl to the lip of the flask, where they may be removed with a camel's hair brush or small tuft of cotton and placed in the rearing vials or cups.

A 9-ounce waxed paper cup with a plastic snap-on lid has been found convenient for rearing large numbers of larvae. A thin layer of sterile plucked cotton is placed at the bottom of the cup followed with a layer of medium consisting of about twenty-five ¼-inch cubes. About 25 newly hatched larvae collected on a small tuft of cotton are placed on this medium, and another layer of cotton, which serves as a barrier, is added. Successive layers of medium and cotton, with 25 larvae per layer of medium, are added until the cup is filled. Usually four to five layers of medium per cup are used. After a layer of cotton is applied to the top layer of medium, the lid is placed on the cup. Eggs instead of larvae may be placed in the cups. However, better yields have been obtained from newly hatched larvae implanted on the medium.

SURVEYS

Need for Surveys

Surveys for the pink bollworm are made by both the cotton producers and quarantine regulatory agencies. When the population control resulting from cultural practices and natural factors fails to hold the infestation below the economic damage level, growers must make infestation counts to determine when insecticide control is needed. Fall, winter, and spring surveys are useful as an index to the potential infestation of the next season's crop.

Regulatory agencies conduct surveys to detect the pink bollworm in areas not previously known to be infested and to determine when an isolated infestation has been eradicated. Also, they make surveys to provide information that may be used in planning control or suppressive programs for retarding or preventing spread, and to evaluate the effectiveness of these programs.

Survey Methods

Surveys to determine the degree of pink bollworm infestation in individual fields may be made early in the season by inspecting blooms and later by inspecting bolls. Bloom infestation ceases to be a reliable index of the larval population after bolls form, because the insect then attacks bolls in preference to squares and very few larvae are found in blooms.

Bloom Inspection

The spring pink bollworm population developing in squares reaches a peak 2 weeks after blooms first appear and then decreases rapidly. In an experiment with two planting dates during a 3-year study, all blooms on a measured acreage were inspected daily during the first 3 weeks after blooming commenced.

The daily number of infested blooms found on this acreage increased from three on the first day to 186 on the seventh day, reached a peak of 347 on the 14th day, and decreased to 125 on the 21st day. The daily counts showed that the most reliable time to estimate the larval population is from about the eighth through the 17th day. However, the larger plants and greater number of blooms present during the last part of this period make the inspection more difficult. The number of blooms opening daily increased from 11 to 1,059 the first week, to 3,904 the second week, and to 5,321 the third week. The percent of blooms infested decreased continuously from 27 to 18, to 9, and to 2 during the respective weeks. Therefore a count to determine the percentage of blooms infested is a less reliable index than one showing the number of blooms infested on a measured sample area.

A survey for detecting a light pink bollworm infestation is easiest accomplished early, when the plants are small and the larval population is concentrated in a few blooms. Also, at that time persons fully familiar with the insect can estimate fairly accurately the potential seasonal infestation from a count made to determine the percentage of blooms infested. However, a better criterion for comparing yearly early-season populations in blooms, or to determine when early insecticide applications are needed, is obtained when inspections are made to estimate the number of larvae per acre.

Recommended method.—Five days after the first blooms appear, but not later than 15 days, check the number of larvae per acre as follows: Step off 300 feet of row (100 steps) and count the number of rosetted blooms at five representative locations in a field (1,500 feet). Add the number of rosetted blooms from the five locations and multiply by 10 to obtain the number of larvae per acre. To increase the sample size, two rows may be inspected simultaneously instead of one row and the number of rosetted blooms multiplied by 5 instead of 10.

Boll Inspection

In most field investigations of the pink bollworm, it is desirable to count boll infestations so as to estimate the larval population per acre. The timing of late-season insecticide applications is based on the percentage of bolls infested. A count of pink bollworm exit holes in green bolls should not be used as an index to abundance of the insect, because the larvae that have emerged represent only a small proportion of the population present. Also, the timing of insecticide applications based on exit holes is dangerous, because this may result in serious population buildup before the treatment begins.

Recommended methods.—When determining the time to apply insecticides, walk diagonally across the field and collect at random 100 firm bolls. Crack the bolls or cut each section of the carpel (hull) lengthwise so that the locks can be removed, and examine the inside of the carpel for mines made by the young larvae when entering the boll. Record the number of bolls infested on a percentage basis.

When it is desirable to know the larval population, the number of mines in each infested boll should also be recorded for determining the total mines in the sample or average number per boll. The number of bolls per acre at the time the sample is collected may be estimated by counting the firm bolls on 10 row-feet at representative points in the plot or field sampled. The average number of bolls per row-foot multiplied by 13,000 equals approximately the number of bolls per acre, and this figure multiplied by the average mines per boll equals the larval population per acre.

Other Inspection Techniques

Other inspection methods are helpful in directing control activities against the pink bollworm. They make possible the detection of infestations in previously uninfested areas and the evaluation of increases or decreases as they occur in infested areas. They are also used to determine the population of larvae in hibernation and their carryover to infest the new cotton crop.

Inspection of gin trash.—Arrange with ginners to install traps where possible to procure freshly ginned "first cleaner" trash, which has not been passed through a fan, from as many gins as possible in the area. Maintain the identity of each sample. A gin trash machine is used to separate mechanically all parts of the trash larger and all parts lighter than the pink bollworm. A small residue is left, which must be examined by hand. This method is very efficient for detecting the presence and abundance of the pink bollworm in any given area. One may locate the exact field by taking a separate trash sample from each grower's cotton.

Inspection of lint cleaner.—During the ginning process the free larvae remaining in the lint are separated in the lint cleaners, and a substantial number of them are smashed against the glass inspection plates where they stick on the glass and may be counted. For constant examination at a single gin, wipe off the plates and examine after each bale is ginned. In this way the individual field that is infested may be determined. For a general survey, examine periodically to detect the presence of the pink bollworm in a general area.

Examination of debris.—Between January and the time squares begin to form in the new crop, examine old bolls or parts of bolls from the soil surface in known infested fields. Examine the cotton debris from 50 feet of row at five representative points in the field for the number of living pink bollworms. Multiply by 50 to determine the number of living larvae per acre. Such records when maintained from year to year provide comparative data that may be used in determining appropriate control measures.

Use of light traps.—Light traps containing argon bulbs or mercury vapor (blacklight fluorescent) bulbs will attract pink bollworm moths. Such traps may be used to discover new infestations and to compare yearly population trends. The argon trap is generally used in pink bollworm surveys because it is more selective than the blacklight. Although it attracts smaller numbers of pink bollworms, the collections of orders other than Lepidoptera are decreased compared with those by the blacklight, and thus the argon trap reduces the time required for examining the collections.

Use of sex-lure traps.—Traps containing the sex attractant extracted from the tips of abdomens of female pink bollworm moths have been highly effective in trapping male moths. Such traps are being used in surveys for detecting insect spread. Propylure is sometimes mixed with the natural attractant; however, the synthetic material currently available is of questionable value in the mixture.

PRESENT STATUS

The cotton-producer reaction to the pink bollworm in the United States has varied from panic to apathy. In the extreme eastern cotton area, growers have been lulled into a state of apathy because for many years they have anticipated an invasion that has not materialized. Growers in Texas, New Mexico, and Oklahoma have become accustomed to the pink bollworm and find its presence not so bad as they feared in the beginning so long as they follow recommended cultural and other control methods. Arizona growers have reappraised the insect they had begun to consider as a minor pest in their area; now they know its potential demands a great deal of concern. Growers in California know they have a serious new pest in their midst, but they have not had time to experience the full impact of its invasion into their area.

The dynamics of pink bollworm populations is governed by an interacting complex of environmental factors over which man has considerable influence. In the eastern part of the infested area of this country man has the upper hand on this insect with his effective winter cultural practices and his intensive insecticide program for control of other insects. A great danger looms in the Far West, where the winter environment is favorable to the species, insecticides are used in less quantity than in the East, and production of high yields resulting from a long growing season with a late harvest is customary. Apparently man's ultimate goal concerning this insect should be to eliminate it completely.

REFERENCES

ADKISSON, P. L.
1959. THE EFFECT OF VARIOUS HUMIDITY LEVELS ON HATCHABILITY OF PINK BOLLWORM EGGS. Kans. Ent. Soc. Jour. 32: 189–190.

——— 1960. THE EFFECT OF PINK BOLLWORM INFESTATION ON COTTON PRODUCED UNDER HIGH MOISTURE CONDITIONS. Tex. Agr. Expt. Sta. Prog. Rpt. 2156, 7 pp.

——— 1961. EFFECT OF LARVAL DIET ON THE SEASONAL OCCURRENCE OF DIAPAUSE IN THE PINK BOLLWORM. Jour. Econ. Ent. 54: 1107–1112.

——— 1961. FECUNDITY AND LONGEVITY OF ADULT FEMALE PINK BOLLWORMS REARED FROM NATURAL AND SYNTHETIC DIETS. Jour. Econ. Ent. 54: 1224–1227.

——— 1962. TIMING DEFOLIANTS AND DESICCANTS TO REDUCE OVERWINTERING POPULATIONS OF THE PINK BOLLWORM. Jour. Econ. Ent. 55: 949–951.

——— 1963. TIME-MEASUREMENT IN THE PHOTOPERIODIC INDUCTION OF DIAPAUSE IN THE PINK BOLLWORM. Tex. Agr. Expt. Sta. Prog. Rpt. 2274, 4 pp.

——— 1964. ACTION OF THE PHOTOPERIOD IN CONTROLLING INSECT DIAPAUSE. Amer. Nat. XCVIII: 357–374.

———— 1964. LIGHT-DARK REACTIONS INVOLVED IN INSECT DIAPAUSE. *In* Aschoff, J., ed., Circadian Clocks, pp. 344–350. Amsterdam.

———— 1964. RELATIVE SUSCEPTIBILITY OF VARIOUS GEOGRAPHICAL RACES OF THE PINK BOLLWORM TO CERTAIN INSECTICIDES. Tex. Agr. Expt. Sta. Prog. Rpt. 2300, 4 pp.

———— 1965. BIOLOGICAL CLOCKS AND INSECT PHOTOPERIODISM. Cotton Impr. Conf., Atlanta, Ann. Proc. 17: 99–104.

———— 1966. ACTION OF LIGHT IN CONTROLLING INSECT GROWTH AND DEVELOPMENT. Internatl. Cong. on Electromagnetic Radiation in Agr., Roanoke, Va., Proc. 1965: 30–33.

———— 1966. INTERNAL CLOCKS AND INSECT DIAPAUSE. Science 154: 234–241.

———— BAILY, C. F., and NILES, A.
1962. A LIST OF COTTON STOCKS SCREENED FOR RESISTANCE TO THE PINK BOLLWORM, 1960–1961. Tex. Agr. Expt. Sta. Misc. Pub. 606, 7 pp.

———— BELL, R. A., and WELLSO, S. G.
1963. ENVIRONMENTAL FACTORS CONTROLLING THE INDUCTION OF DIAPAUSE IN THE PINK BOLLWORM, PECTINOPHORA GOSSYPIELLA (SAUNDERS). Insect Physiol. Jour. 9: 299–310.

———— BRAZZEL, J. R., and GAINES, J. C.
1963. YIELD AND QUALITY LOSSES RESULTING FROM PINK BOLLWORM DAMAGE TO COTTON. Tex. Agr. Expt. Sta. Misc. Pub. 632, 8 pp.

———— BULL, D. L., and ALLISON, W. E.
1960. A COMPARISON OF CERTAIN ARTIFICIAL DIETS FOR LABORATORY CULTURES OF THE PINK BOLLWORM. Jour. Econ. Ent. 53: 791–793.

———— and GAINES, J. C.
1960. PINK BOLLWORM CONTROL AS RELATED TO THE TOTAL COTTON INSECT CONTROL PROGRAM OF CENTRAL TEXAS. Tex. Agr. Expt. Sta. Misc. Pub. 444, 7 pp.

———— ROBERTSON, O. T., and FIFE, L. C.
1962. PLANTING DATE AS A FACTOR INVOLVED IN PINK BOLLWORM CONTROL. *In* Martin, D. F., and Lewis, R. D., A Summary of Recent Research Basic to the Cultural Control of the Pink Bollworm. Tex. Agr. Expt. Sta. Misc. Pub. 579, pp. 16–20.

———— VANDERZANT, E. S., BULL, D. L., and ALLISON, W. E.
1960. A WHEAT GERM MEDIUM FOR REARING THE PINK BOLLWORM. Jour. Econ. Ent. 53: 759–762.

———— and WELLSO, S. G.
1962. EFFECT OF DDT POISONING ON THE FECUNDITY AND LONGEVITY OF THE PINK BOLLWORM. Jour. Econ. Ent. 55: 842–845.

———— WILKES, L. H., and COCHRAN, B. J.
1959. RELATIVE EFFICIENCIES OF CERTAIN SPRAY NOZZLES FOR COTTON INSECT CONTROL. Jour. Econ. Ent. 52: 985–991.

———— WILKES, L. H., and COCHRAN, B. J.
1960. STALK DESTRUCTION AND PLOWING AS MEASURES FOR CONTROLLING THE PINK BOLLWORM. Jour. Econ. Ent. 53: 436–439.

———— WILKES, L. H., and JOHNSON, S. P.
1958. CHEMICAL, CULTURAL, AND MECHANICAL CONTROL OF THE PINK BOLLWORM. Tex. Agr. Expt. Sta. Bul. 920, 16 pp.

ANKERSMIT, G. W., and ADKISSON, P. L.
1967. PHOTOPERIODIC RESPONSES OF CERTAIN GEOGRAPHICAL STRAINS OF PECTINOPHORA GOSSYPIELLA (LEPIDOPTERA). Insect Physiol. Jour. 13: 553–564.

BARRY, B. D., and ADKISSON, P. L.
1966. CERTAIN ASPECTS OF THE GENETIC FACTORS INVOLVED IN THE LARVAL DIAPAUSE OF THE PINK BOLLWORM. Amer. Ent. Soc. Ann. 59: 122–125.

BECKMAN, H. F.
1953. LABORATORY CULTURE OF THE PINK BOLLWORM ON CHEMICALLY DEFINED MEDIA. Jour. Econ. Ent. 46: 627–630.

BELL, R. A., and ADKISSON, P. L.
1964. PHOTOPERIODIC REVERSIBILITY OF DIAPAUSE INDUCTION IN AN INSECT. Science 144: 1149–1151.

BERGER, R. S., MCGOUGH, J. M., MARTIN, D. F., and BALL, L. R.
1964. SOME PROPERTIES AND THE FIELD EVALUATION OF THE PINK BOLLWORM SEX ATTRACTANT. Amer. Ent. Soc. Ann. 57: 606–609.

BIBBY, F. F., and MORENO, I.
1941. SECONDARY HOSTS OF THE PINK BOLLWORM IN THE LOWER RIO GRANDE VALLEY OF TEXAS AND MEXICO. Jour. Econ. Ent. 34: 736–737.

BISHOPP, F. C.
1956. INSECTS LOWER THE QUALITY OF COTTON LINT AND SEED. Jour. Econ. Ent. 49: 172–175.

BOTTGER, G. T., CHAPMAN, A. J., MCGARR, R. L., and RICHMOND, C. A.
1958. LABORATORY AND FIELD TESTS WITH SEVIN AGAINST COTTON INSECTS. Jour. Econ. Ent. 51: 236–239.

——— SHEEHAN, E. T., and LUKEFAHR, M. J.
1964. RELATION OF GOSSYPOL CONTENT OF COTTON PLANTS TO INSECT RESISTANCE. Jour. Econ. Ent. 57: 283–285.

BRAZZEL, J. R.
1955. THE PINK BOLLWORM AS A FACTOR IN COTTON BOLL ROT. U.S. Agr. Res. Serv. Plant Dis. Rptr. 39: 583–584.

——— and GAINES, J. C.
1956. THE EFFECTS OF PINK BOLLWORM INFESTATIONS ON YIELD AND QUALITY OF COTTON. Jour. Econ. Ent. 49: 852–854.

——— and GAINES, J. C.
1957. COTTON YIELD AND QUALITY LOSSES CAUSED BY VARIOUS LEVELS OF PINK BOLLWORM INFESTATIONS. Jour. Econ. Ent. 50: 609–613.

——— and GAINES, J. C.
1959. THE TOXICITY OF SEVERAL INSECTICIDES TO THE EGGS AND LARVAE OF THE PINK BOLLWORM. Jour. Econ. Ent. 52: 301–303.

——— and MARTIN, D. F.
1955. BEHAVIOR OF PINK BOLLWORM LARVAE. Jour. Econ. Ent. 48: 677–679.

——— and MARTIN, D. F.
1956. RESISTANCE OF COTTON TO PINK BOLLWORM DAMAGE. Tex. Agr. Expt. Sta. Bul. 843, 20 pp.

——— and MARTIN, D. F.
1957. OVIPOSITION SITES OF THE PINK BOLLWORM ON THE COTTON PLANT. Jour. Econ. Ent. 50: 122–124.

——— and MARTIN, D. F.
1959. WINTER SURVIVAL AND TIME OF EMERGENCE OF DIAPAUSING PINK BOLLWORMS IN CENTRAL TEXAS. Jour. Econ. Ent. 52: 305–308.

——— and MARTIN, D. F.
1959. PINK BOLLWORM RESISTANCE IN COTTON. Jour. Econ. Ent. 52: 385–390.

BULL, D. L., and ADKISSON, P. L.
1960. CERTAIN FACTORS INFLUENCING DIAPAUSE IN THE PINK BOLLWORM. Jour. Econ. Ent. 53: 793–798.

——— and ADKISSON, P. L.
1962. FAT CONTENT OF THE LARVAL DIET AS A FACTOR INFLUENCING DIAPAUSE AND GROWTH-RATE OF THE PINK BOLLWORM. Amer. Ent. Soc. Ann. 55: 499–502.

——— and ADKISSON, P. L.
1963. ABSORPTION AND METABOLISM OF C^{14}-LABELED DDT BY DDT-SUSCEPTIBLE AND DDT-RESISTANT PINK BOLLWORM ADULTS. Jour. Econ. Ent. 56: 641–643.

BUSK, A.
1917. THE PINK BOLLWORM, PECTINOPHORA GOSSYPIELLA. Jour. Agr. Res. 9 (10): 343–370.

CHAPMAN, A. J., and CAVITT, H. S.
1934. THE INFLUENCE OF SOIL MOISTURE UPON THE SURVIVAL OF THE PINK BOLLWORM. Jour. Econ. Ent. 27: 820–827.
——— and CAVITT, H. S.
1938. POSSIBILITIES OF REDUCING OVER-WINTERING PINK BOLLWORM POPULATION IN THE SOIL AS SHOWN BY STRIPPING TESTS. Jour. Econ. Ent. 30: 837–838.
——— and COFFIN, L. B.
1964. PINK BOLLWORM RESISTANCE TO DDT IN THE LAGUNA AREA OF MEXICO. Jour. Econ. Ent. 57: 148–150.
——— FIFE, L. C., SMITH, G. L., and CLARK, J. C.
1950. DDT FOR CONTROL OF PINK BOLLWORM IN MEXICO IN 1946. Jour. Econ. Ent. 43: 491–494.
——— and HUGHES, M. A.
1941. FACTORS INFLUENCING THE FORMATION OF RESTING PINK BOLLWORM LARVAE. Jour. Econ. Ent. 34: 493–494.
——— and LOWRY, W. L.
1941. CONTROL OF THE PINK BOLLWORM WITH INSECTICIDES. Jour. Econ. Ent. 34: 490–492.
——— and MORENO, I.
1945. FURTHER OBSERVATIONS ON HOST PLANTS OF THE PINK BOLLWORM IN THE LOWER RIO GRANDE VALLEY OF TEXAS AND MEXICO. Jour. Econ. Ent. 38: 583–584.
——— and NOBLE, L. W.
1954. HIBERNATION EXPERIMENTS ON THE PINK BOLLWORM IN TEXAS AND OKLAHOMA. U.S. Bur. Ent. and Plant Quar. E-879, 3 pp.
——— NOBLE, L. W., ROBERTSON, O. T., and FIFE, L. C.
1960. SURVIVAL OF THE PINK BOLLWORM UNDER VARIOUS CULTURAL AND CLIMATIC CONDITIONS. U.S. Dept. Agr. Prod. Res. Rpt. 34, 21 pp.
——— NOBLE, L. W., ROBERTSON, O. T., and SMITH, G. L.
1963. EARLY-SEASON APPLICATION OF DDT FOR PINK BOLLWORM CONTROL. Jour. Econ. Ent. 56: 900–901.
——— ROBERTSON, O. T., and NOBLE, L. W.
1961. EVALUATION OF STALK SHREDDERS AND CUTTERS FOR PINK BOLLWORM CONTROL. Jour. Econ. Ent. 54: 791–792.
CLARK, E. W.
1957. THE EFFECT OF THE HOT WATER TREATMENT FOR HARD COTTONSEED ON A PINK BOLLWORM INFESTATION. Jour. Econ. Ent. 50: 795–796.
———
1960. A COMPARATIVE STUDY OF THE FREE AMINO ACIDS AND CARBOHYDRATES OF PECTINOPHORA GOSSYPIELLA (SAUND.). Amer. Ent. Soc. Ann. 53: 439–441.
——— and CHADBOURNE, D. S.
1960. THE HAESMOCYTES OF NONDIAPAUSE AND DIAPAUSE LARVAL AND PUPAL PINK BOLLWORM (PECTINOPHORA GOSSYPIELLA (SAUND.)). Amer. Ent. Soc. Ann. 53: 682–685.
——— and CHADBOURNE, D. S.
1962. A COMPARATIVE STUDY OF THE WEIGHT, AND LIPID AND WATER CONTENT OF THE PINK BOLLWORM, PECTINOPHORA GOSSYPIELLA (SAUND.). Amer. Ent. Soc. Ann. 55: 225–228.
——— and GLICK, P. A.
1961. SOME PREDATORS AND SCAVENGERS FEEDING UPON PINK BOLLWORM MOTHS. Jour. Econ. Ent. 54: 815–816.
——— and LUKEFAHR, M.
1956. A PARTIAL ANALYSIS OF COTTON EXTRAFLORAL NECTAR AND ITS APPROXIMATION AS A NUTRITIONAL MEDIUM FOR THE ADULT PINK BOLLWORM. Jour. Econ. Ent. 49: 875–876.
——— and RICHMOND, C. A.
1961. THE EFFECT OF CENTRIFUGAL FORCE ON PINK BOLLWORM LARVAE. Jour. Econ. Ent. 54: 1262–1263.
——— and RICHMOND, C. A.
1962. THE EFFECT OF AQUEOUS SUBMERSION ON LARVAL AND PUPAL PINK BOLLWORM. Jour. Econ. Ent. 55: 167–169.

CLARK, E. W., and RICHMOND, C. A.
1964. CHANGES IN WEIGHT OF ABRADED AND UNABRADED LARVAL PINK BOLLWORM UNDER SUBMERSION AND DESICCATION. Jour. Econ. Ent. 57: 14–16.

——— RICHMOND, C. A., and MCGOUGH, J. M.
1961. ARTIFICIAL MEDIA AND REARING TECHNIQUES FOR THE PINK BOLLWORM. Jour. Econ. Ent. 54: 4–9.

——— WILLIAMSON, A. L., and RICHMOND, C. A.
1959. A COLLECTING TECHNIQUE FOR PINK BOLLWORMS AND OTHER INSECTS USING A BERLESE FUNNEL WITH AN IMPROVED HEATER. Jour. Econ. Ent. 52: 1010–1012.

COAD, B. R.
1929. ORGANIZATION AND PROGRESS OF PINK BOLLWORM INVESTIGATIONS. Jour. Econ. Ent. 22: 743–750.

——— and FENTON, F. A.
1928. PRELIMINARY REPORT OF STUDIES CARRIED ON IN 1928 ON THE MIGRATION OF MOTHS OF THE PINK BOLLWORM. Mex. Sec. de Agr. y Formento Bol. Mens. 2:878–893.

COCHRAN, B. J., WILKES, L. H., and ADKISSON, P. L.
1961. PRIMARY TILLAGE PRACTICES FOR PINK BOLLWORM CONTROL. Tex. Agr. Expt. Sta. Prog. Rpt. 2194, 3 pp.

CURL, L. F.
1938. PINK BOLLWORM CONTROL IN SOUTHEASTERN STATES. Jour. Econ. Ent. 31: 652–656.

ENKERLIN, D., and HANNA, R. L.
1956. THE DILUTION OF DUST CONCENTRATES IN PINK BOLLWORM CONTROL. Jour. Econ. Ent. 49: 560.

FENTON, F. A.
1929. BIOLOGICAL NOTES ON THE PINK BOLLWORM IN TEXAS. 4th Internatl. Cong. Ent., Ithaca, Trans. 1928 (2), pp. 439–447.

——— and OWEN, W. L., JR.
1931. HIBERNATION OF PECTINOPHORA GOSSYPIELLA IN TEXAS. Jour. Econ. Ent. 24: 1197–1207.

——— and OWEN, W. L., JR.
1953. THE PINK BOLLWORM OF COTTON IN TEXAS. Tex. Agr. Expt. Sta. Misc. Pub. 100, 39 pp.

——— and WAITE, W. W.
1932. DETECTING PINK BOLLWORMS IN COTTONSEEDS BY THE X-RAY. Jour. Agr. Res. 45: 347–348.

FIFE, L. C.
1934. TEMPERATURE STUDIES IN A COTTON FIELD, PRESIDIO, TEXAS, 1932. Ecology 15: 298–305.

———
1937. NUMBER OF INSTARS OF PINK BOLLWORM COLLECTED IN SQUARES AND IN BOLLS OF COTTON. Amer. Ent. Soc. Ann. 30: 57–63.

———
1937. THE PINK BOLLWORM OF COTTON IN PUERTO RICO DURING 1936 AND RECOMMENDATIONS FOR ITS CONTROL. Puerto Rico Agr. Expt. Sta. Agr. Notes 81, 9 pp.

———
1938. ALTERNATE HOST PLANTS OF THE PINK BOLLWORM, PECTINOPHORA GOSSYPIELLA (SAUND.) IN PUERTO RICO. Puerto Rico Univ. Jour. Agr. XXII: 483–492.

———
1949. STUDIES OF THE DIAPAUSE IN THE PINK BOLLWORM IN PUERTO RICO. U.S. Dept. Agr. Tech. Bul. 977, 26 pp.

———
1956. SEASONAL OCCURRENCE OF RESTING LARVAE OF THE PINK BOLLWORM IN CENTRAL TEXAS. Jour. Econ. Ent. 49: 562–563.

———
1961. FACTORS INFLUENCING PINK BOLLWORM PUPATION AND MOTH EMERGENCE FROM OVERWINTERING LARVAE IN CENTRAL TEXAS. Jour. Econ. Ent. 54: 908–913.

——— COWAN, C. B., JR., and DAVIS, J. W.
1957. FACTORS INFLUENCING PINK BOLLWORM WINTER CARRYOVER IN CENTRAL TEXAS. Jour. Econ. Ent. 50: 642–644.

——— and GRAHAM, H. M.
1965. SEASONAL ACTIVITY OF BURIED OVERWINTERING PINK BOLLWORM LARVAE IN CENTRAL TEXAS. Jour. Econ. Ent. 58: 688–690.

——— and GRAHAM, H. M.
1966. INFLUENCE OF MOISTURE ON WINTER SURVIVAL OF THE PINK BOLLWORM. Jour. Econ. Ent. 59: 430–432.

——— and MORENO, I.
1943. ADDITIONAL NOTES ON HOST PLANTS OF THE PINK BOLLWORM IN TEXAS AND MEXICO. Jour. Econ. Ent. 36: 478–479.

——— ROBERTSON, O. T., and GRAHAM, H. M.
1963. WINTER CARRYOVER OF THE PINK BOLLWORM UNDER VARIOUS CULTURAL PRACTICES IN CENTRAL TEXAS. Jour. Econ. Ent. 56: 172–175.

——— SHILLER, I., and CHAPMAN, A. J.
1947. PINK BOLLWORM CARRYOVER FROM ONE COTTON CROP TO THE NEXT IN THE LOWER RIO GRANDE VALLEY. Jour. Econ. Ent. 40: 540–545.

———WILKES, L. H., and COCHRAN, B. J.
1962. WINTER CULTURAL PRACTICES FOR PINK BOLLWORM CONTROL. *In* Martin, D. F., and Lewis, R. D., A Summary of Recent Research Basic to the Cultural Control of the Pink Bollworm. Tex. Agr. Expt. Sta. Misc. Pub. 579, pp. 25–28.

FLITTERS, N. E., MESSENGER, P. S., and HUSMAN, C. N.
1956. BIOCLIMATIC CABINETS USED IN STUDIES ON THE MEXICAN FRUIT FLY AND THE PINK BOLLWORM. U.S. Agr. Res. Serv. ARS–33–33, 12 pp.

GLICK, P. A.
1939. THE DISTRIBUTION OF INSECTS, SPIDERS, AND MITES IN THE AIR. U.S. Dept. Agr. Tech. Bul. 673, 150 pp.

———
1955. PINK BOLLWORM MOTH COLLECTIONS IN AIRPLANE TRAPS. Jour. Econ. Ent. 48: 767.

———
1957. COLLECTING INSECTS BY AIRPLANE IN SOUTHERN TEXAS. U.S. Dept. Agr. Tech. Bul. 1158, 28 pp.

———
1967. AERIAL DISPERSAL OF THE PINK BOLLWORM IN THE UNITED STATES AND MEXICO. U.S. Dept. Agr. Prod. Res. Rpt. 96, 12 pp.

——— and GRAHAM, H. M.
1961. EARLY-SEASON COLLECTIONS OF THREE COTTON INSECTS BY ARGON-GLOW LAMP AND BLACK LIGHT TRAPS. Jour. Econ. Ent. 54: 1253–1254.

——— and GRAHAM, H. M.
1965. SEASONAL LIGHT TRAP COLLECTIONS OF LEPIDOPTEROUS COTTON INSECTS IN SOUTH TEXAS. Jour. Econ. Ent. 58: 880–882.

——— GRAHAM, H. M., and BILLINGSLEY, C. H.
1964. EVALUATION OF A BLOWER ATTACHMENT FOR LIGHT TRAPS. Jour. Econ. Ent. 57: 169–170.

——— and HOLLINGSWORTH, J. P.
1954. RESPONSE OF THE PINK BOLLWORM MOTH TO CERTAIN ULTRAVIOLET AND VISIBLE RADIATION. Jour. Econ. Ent. 47: 81–86.

——— and HOLLINGSWORTH, J. P.
1955. RESPONSE OF MOTHS OF THE PINK BOLLWORM AND OTHER COTTON INSECTS TO CERTAIN ULTRAVIOLET AND VISIBLE RADIATION. Jour. Econ. Ent. 48: 173–177.

——— HOLLINGSWORTH, J. P., and EITEL, W. J.
1956. FURTHER STUDIES ON THE ATTRACTION OF THE PINK BOLLWORM MOTH TO NEAR ULTRAVIOLET AND VISIBLE RADIATION. Jour. Econ. Ent. 49: 158–161.

——— and LATTIMORE, W. B., JR.
1954. THE RELATION OF INSECTICIDES TO INSECT POPULATIONS IN COTTON FIELDS. Jour. Econ. Ent. 47: 681–684.

GLICK, P. A., and NOBLE, L. W.
1961. AIRBORNE MOVEMENT OF THE PINK BOLLWORM AND OTHER ARTHROPODS. U.S. Dept. Agr. Tech. Bul. 1255, 20 pp.
GRAHAM, H. M., FIFE, L. C., and BRYAN, D. E.
1965. DYNAMICS OF CAGED PINK BOLLWORM POPULATIONS IN TEXAS AND OKLAHOMA. Amer. Ent. Soc. Ann. 58: 658–663.
——— FIFE, L. C., ROBERTSON, O. T., and ADKISSON, P. L.
1962. PINK BOLLWORM POPULATION DYNAMICS. *In* Martin, D. F., and Lewis, R. D., A Summary of Recent Research Basic to the Cultural Control of the Pink Bollworm. Tex. Agr. Expt. Sta. Misc. Pub. 579, pp. 5–10.
——— GLICK, P. A., and HOLLINGSWORTH, J. P.
1961. EFFECTIVE RANGE OF ARGON GLOW LAMP SURVEY TRAPS FOR PECTINOPHORA GOSSYPIELLA (SAUND.) ADULTS. Jour. Econ. Ent. 54: 788–789.
——— GLICK, P. A., and MARTIN, D. F.
1964. NOCTURNAL ACTIVITY OF ADULTS OF SIX LEPIDOPTEROUS PESTS OF COTTON AS INDICATED BY LIGHT TRAP COLLECTIONS. Amer. Ent. Soc. Ann. 57: 328–332.
——— GLICK, P. A., and OUYE, M. T.
1967. TEMPERATURE EFFECT ON REPRODUCTION AND LONGEVITY OF LABORATORY-REARED ADULT PINK BOLLWORM (LEPIDOPTERA: GELECHIIDAE). Amer. Ent. Soc. Ann. 60: 1211–1213.
——— GLICK, P. A., OUYE, M. T., and MARTIN, D. F.
1965. MATING FREQUENCY OF FEMALE PINK BOLLWORMS COLLECTED FROM LIGHT TRAPS. Amer. Ent. Soc. Ann. 58: 595–596.
——— MCGOUGH, J. M., and JACOBSON, M.
1966. INFLUENCE OF SOLVENTS ON EFFECTIVENESS OF SEX LURE FOR PINK BOLLWORM. Jour. Econ. Ent. 59: 761–763.
——— and MARTIN, D. F.
1963. USE OF CYANIDE IN PINK BOLLWORM SEX-LURE TRAPS. Jour. Econ. Ent. 56: 901–902.
——— MARTIN, D. F., OUYE, M. T., and HARDMAN, R. M.
1966. CONTROL OF PINK BOLLWORMS BY MALE ANNIHILATION. Jour. Econ. Ent. 59: 950–953.
——— ROBERTSON, O. T., ADKISSON, P. L., and WILKES, L. H.
1961. FURTHER TESTS OF THE EFFECTIVENESS OF COTTON STALK SHREDDERS FOR CONTROLLING THE PINK BOLLWORM. Jour. Econ. Ent. 54: 1057–1058.
——— ROBERTSON, O. T., and MARTIN, D. F.
1964. RADIOGRAPHIC DETECTION OF PINK BOLLWORM LARVAE IN COTTONSEED. Jour. Econ. Ent. 57: 419–420.
——— ROBERTSON, O. T., and STEDRONSKY, V. L.
1967. A METHOD OF EVALUATING COTTON GINS FOR PINK BOLLWORM KILL. U.S. Agr. Res. Serv. ARS–33–121, 5 pp.
——— and STEPHENSON, B. C.
1966. INFESTATION OF PINK BOLLWORMS IN OKRA. Jour. Econ. Ent. 59: 756.
GUERRA, A. A., and OUYE, M. T.
1967. CATCH OF MALE PINK BOLLWORMS IN TRAPS BAITED WITH SEX ATTRACTANT. Jour. Econ. Ent. 60: 1046–1048.
HEINRICH, C.
1921. SOME LEPIDOPTERA LIKELY TO BE CONFUSED WITH THE PINK BOLLWORM. Jour. Agr. Res. 20: 807–836.
HOLLINGSWORTH, J. P., BRIGGS, C. P., III, GLICK, P. A., and GRAHAM, H. M.
1961. SOME FACTORS INFLUENCING LIGHT TRAP COLLECTIONS. Jour. Econ. Ent. 54: 305–308.
HUNTER, W. D.
1926. THE PINK BOLLWORM WITH SPECIAL REFERENCE TO STEPS TAKEN BY THE DEPARTMENT OF AGRICULTURE TO PREVENT ITS ESTABLISHMENT IN THE U.S. U.S. Dept. Agr. Bul. 1397, 30 pp.
IGNOFFO, C. M.
1962. THE SUSCEPTIBILITY OF PECTINOPHORA GOSSYPIELLA (SAUNDERS) TO INTRAHEMOCOELIC INJECTIONS OF BACILLUS THURINGIENSIS BERLINER. Insect Path. Jour. 4: 34–40.

———
1962. THE EFFECTS OF TEMPERATURE AND HUMIDITY ON MORTALITY OF LARVAE OF PECTINOPHORA GOSSYPIELLA (SAUNDERS) INJECTED WITH BACILLUS THURINGIENSIS BERLINER. Insect Path. Jour. 4: 63–71.

——— and ADAMS, J. R.
1966. A CYTOPLASMIC POLYHEDROSIS VIRUS, SMITHAVIRUS PECTINOPHORAE N. SP. OF THE PINK BOLLWORM, PECTINOPHORA GOSSYPIELLA (SAUNDERS), LEPIDOPTERA: GELECHIIDAE. Invertebrate Path. Jour. 8: 59–66.

——— and GARCIA, C.
1965. INFECTION OF THE CABBAGE LOOPER, BOLLWORM, TOBACCO BUDWORM, AND PINK BOLLWORM WITH SPORES OF MATTESIA GRANDIS MCLAUGHLIN COLLECTED FROM BOLL WEEVILS. Invertebrate Path. Jour. 7: 260–262.

——— and GRAHAM, H. M.
1967. LABORATORY AND FIELD CAGE TESTS WITH BACILLUS THURINGIENSIS AGAINST PINK BOLLWORM LARVAE. Invertebrate Path. Jour. 9: 390–394.

ISLER, D. A., and FENTON, F. A.
1931. PRELIMINARY REPORT ON CONTROLLING PINK BOLLWORM IN TEXAS BY WINTER CULTURAL METHODS. Jour. Econ. Ent. 24: 795–807.

IVY, E. E., BRAZZEL, J. R., SCALES, A. L., and MARTIN, D. F.
1955. TWO NEW PHOSPHATE INSECTICIDES FOR COTTON INSECT CONTROL. Jour. Econ. Ent. 48: 293–295.

JOHNSON, A. C., BECKER, G. G., and HAWKINS, L. A.
1938. FUMIGATION OF BALED COTTON WITH HYDROCYANIC ACID FOR THE PINK BOLLWORM. U.S. Dept. Agr. Tech. Bul. 623, 45 pp.

JONES, W. A., JACOBSON, M., and MARTIN, D. F.
1966. SEX ATTRACTANT OF THE PINK BOLLWORM MOTH (PECTINOPHORA GOSSYPIELLA): ISOLATION, IDENTIFICATION, AND SYNTHESIS. Science 152: 1516–1517.

LEIGH, T. F.
1958. THE PINK BOLLWORM IN ARKANSAS. Ark. Farm Res. VII, No. 2, p. 5.

LINCOLN, C. A., and HILL, T.
1961. THE PINK BOLLWORM PROGRAM IN ARKANSAS. State Plant Bd., Fayetteville, Ark., Mimeo. Rpt., 22 pp.

LOFTIN, U. C., MCKINNEY, K. B., and HENSON, W. K.
1921. REPORT ON INVESTIGATIONS OF THE PINK BOLLWORM OF COTTON IN MEXICO. U.S. Dept. Agr. Bul. 918, 64 pp.

LOWRY, W. L.
1966. PRESERVATION OF LARVAE OF THE PINK BOLLWORM. Jour. Econ. Ent. 59: 1300-1301.

——— and BERGER, R. S.
1964. JOINT ACTION OF DDT-CONTAINING INSECTICIDE MIXTURES AGAINST DDT-RESISTANT PINK BOLLWORMS. Jour. Econ. Ent. 57: 181–182.

——— and BERGER, R. S.
1965. INVESTIGATIONS OF PINK BOLLWORM RESISTANCE TO DDT IN MEXICO AND THE UNITED STATES. Jour. Econ. Ent. 58: 590.

——— CHAPMAN, A. J., WRATTEN, F. T., and HOLLINGSWORTH, J. P.
1954. TESTS ON DIELECTRIC TREATMENT OF COTTON SEED FOR DESTROYING PINK BOLLWORMS. Jour. Econ. Ent. 47: 1022–1023.

——— OUYE, M. T., and BERGER, R. S.
1965. RATE OF INCREASE IN RESISTANCE TO DDT IN THE PINK BOLLWORM. Jour. Econ. Ent. 58: 781–782.

——— and TSAO, C. H.
1961. INCIDENCE OF THE PINK BOLLWORM RESISTANCE TO DDT. Jour. Econ. Ent. 54: 1209–1211.

LUKEFAHR, M. J., FIFE, L. C., and ADKISSON, P. L.
1962. PINK BOLLWORM DIAPAUSE STUDIES. *In* Martin, D. F., and Lewis, R. D., A Summary of Recent Research Basic to the Cultural Control of the Pink Bollworm. Tex. Agr. Expt. Sta. Misc. Pub. 579, pp. 11–13.

LUKEFAHR, M. J., and FRYXELL, P. A.
1967. CONTENT OF GOSSYPOL IN PLANTS BELONGING TO GENERA RELATED TO COTTON. Econ. Bot. 21: 128–131.
——— and GRIFFIN, J. A.
1956. THE EFFECTS OF FOOD ON THE LONGEVITY AND FECUNDITY OF PINK BOLLWORM MOTHS. Jour. Econ. Ent. 49: 876–877.
——— and GRIFFIN, J. A.
1957. MATING AND OVIPOSITION HABITS OF THE PINK BOLLWORM MOTH. Jour. Econ. Ent. 50: 487–490.
——— and GRIFFIN, J. A.
1962. PINK BOLLWORM DEVELOPMENT IN RELATION TO AGE OF SQUARES AND BOLLS WITH NOTES ON BIOLOGY. Jour. Econ. Ent. 55: 158–159.
——— and MARTIN, D. F.
1963. EVALUATION OF DAMAGE TO LINT AND SEED OF COTTON CAUSED BY THE PINK BOLLWORM. Jour. Econ. Ent. 56: 710–713.
——— MARTIN, D. F., and MEYER, J. R.
1965. PLANT RESISTANCE TO FIVE LEPIDOPTERA ATTACKING COTTON. Jour. Econ. Ent. 58: 516–518.
———NOBLE, L. W., and MARTIN, D. F.
1964. FACTORS INDUCING DIAPAUSE IN THE PINK BOLLWORM. U.S. Dept. Agr. Tech. Bul. 1304, 17 pp.
——— and RHYNE, C.
1960. EFFECTS OF NECTARILESS COTTONS ON POPULATIONS OF THREE LEPIDOPTEROUS INSECTS. Jour. Econ. Ent. 53: 242–244.
MCDONALD, R. E.
1931. THE PRESENT STATUS OF THE PINK BOLLWORM IN THE SOUTHWEST. Jour. Econ. Ent. 24: 790–795.
——— and LOFTIN, U. C.
1935. DISPERSAL OF THE PINK BOLLWORM BY FLIGHT OR WIND CARRIAGE OF THE MOTHS. Jour. Econ. Ent. 28: 745–755.
——— and SCHOLL, G. J.
1922. DISINFECTING COTTON SEED TO PREVENT SPREAD OF THE PINK BOLLWORM. Tex. Dept. Agr. Bul. 71, 38 pp.
MCGARR, R. L.
1953. COMBINATIONS OF INSECTICIDES FOR CONTROL OF THE PINK BOLLWORM AND OTHER COTTON INSECTS IN THE LOWER RIO GRANDE VALLEY. Jour. Econ. Ent. 46: 1103–1105.
———
1955. WEEKLY APPLICATIONS OF INSECTICIDES FOR CONTROL OF PINK BOLLWORM AND BOLL WEEVIL. Jour. Econ. Ent. 48: 95–96.
———
1957. TESTS WITH INSECTICIDES FOR CONTROL OF COTTON INSECTS IN THE LOWER RIO GRANDE VALLEY. Jour. Econ. Ent. 50: 632–634.
———
1957. INSECTICIDES FOR PINK BOLLWORM AND BOLL WEEVIL CONTROL IN THE LOWER RIO GRANDE VALLEY IN 1955 AND 1956. Jour. Econ. Ent. 50: 672–674.
——— and CHAPMAN, A. J.
1958. GUTHION AND A DDT-ENDRIN MIXTURE FOR CONTROL OF THE PINK BOLLWORM. Jour. Econ. Ent. 51: 673.
——— and CHAPMAN, A. J.
1963. CONTROL OF THREE IMPORTANT COTTON INSECTS IN THE LOWER RIO GRANDE VALLEY IN 1960. Jour. Econ. Ent. 56: 902–903.
———CHAPMAN, A. J., and LOWRY, W. L.
1961. FIELD TESTS WITH INSECTICIDES FOR PINK BOLLWORM CONTROL IN 1958. Jour. Econ. Ent. 54: 972–974.
——— CHAPMAN, A. J., and MARTIN, D. F.
1965. FIELD TESTS WITH SEVERAL INSECTICIDES FOR CONTROL OF THE PINK BOLLWORM, BOLL WEEVIL, AND BOLLWORM. Jour. Econ. Ent. 58: 693–694.
MCGOUGH, J. M., and NOBLE, L. W.
1955. COLONIZATION OF IMPORTED PINK BOLLWORM PARASITES IN THE UNITED STATES AND MEXICO, 1937-54. Jour. Econ. Ent. 48: 626–627.