Population Growth of the Pink Bollworm

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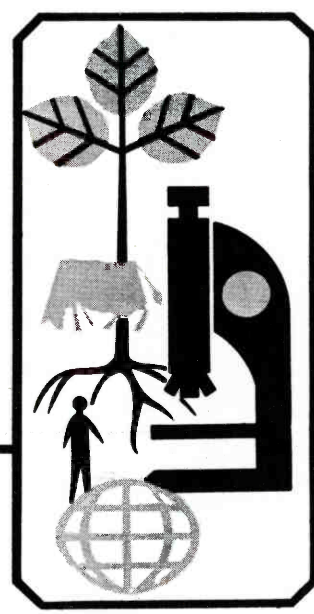

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Population Growth of the Pink Bollworm[1]

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INTRODUCTION

A population growth study of the pink bollworm, **Pectinophora gossypiella** (Saunders), was conducted during the 1968 and 1969 cotton growing seasons (Slosser 1971). This insect has been sporadically present in Arizona since 1926 and in Maricopa County since 1929 (Wene et al. 1965). Because federal and state agencies have conducted several successful suppression programs since the initial infestations, the pink bollworm did not become widespread until 1965; and economic losses have occurred regularly since 1966 (Wene et al. 1965, Spears 1968). Noble (1969) has reviewed the spread of the pink bollworm in the United States and the nature of pink bollworm injury to the cotton crop.

Loftin, McKinney, and Hanson (1921) noted that initial pink bollworm infestations in squares and blooms were very light; but, as the season progressed and bolls became available, the populations increased rapidly and culminated in a 100% boll infestation. Due to this characteristic pattern of population increase, the pink bollworm generally causes little early-season damage and can be considered a mid- to late-season cotton pest.

The study of pink bollworm populations has been approached through observations of natural field infestations, through studies of field populations confined in cages, and through theoretical studies of laboratory populations. Most of the investigations of natural populations were conducted before World War II and the advent of modern pesticides. Loftin et al. (1921), Ohlendorf (1926), Rude and Smith (1932), and Fenton and Owen, whose studies were conducted between 1928 and 1931 but published in 1953, studied general trends of population increase as revealed by the degree of crop damage and number of larvae per fruiting structure as the growing season progressed. Darling (1951) studied population development in bolls and reported percent infestation and number of larvae per acre in the top and bottom crops.

A more recent approach to the study of pink bollworm populations has been to artificially infest caged cotton plants with moths. Graham, Fife, and Bryan (1965) used this technique to determine rates of increase and number of generations per season at Brownsville and Waco, Texas, and Stillwater, Oklahoma. Tsao and Lowry (1963) divided a 1/6-acre cage into two units and compared rates of population increase between DDT-treated and untreated sections.

A third approach to the study of pink bollworm population dynamics has been through laboratory investigations. Graham, Glick, and Ouye (1967) and Philipp and Watson (1971) constructed life-fecundity tables in order to calculate and compare intrinsic rates of

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increase, net reproduction rates, and mean generation times of laboratory populations reared under different temperature regimes. These studies isolated the effects of temperature, one of many variables which affect pink bollworm populations. Graham et al. (1962) have outlined the variables involved and reviewed several studies concerning pink bollworm population dynamics.

The study of populations in modified environments has several disadvantages. Fye, Bonham, and Leggett (1969) reported that temperatures within cages are modified, and Graham et al. (1962) noted that cages minimize the influence of other animals, cultural practices, and dispersal. The disadvantage of laboratory studies is that all conditions are ideal, or nearly so, except for the one or two variables under investigation, and the results only apply to the conditions of the study because the influence of interaction between variables is reduced. The major problems associated with the field study of natural pink bollworm populations involve sampling methods and the difficulty of isolating and assessing the influence of the environmental variables. Even though all the methods have inherent disadvantages, each contributes a component necessary to form an integrated picture of population dynamics.

The present study was undertaken because detailed information on natural pink bollworm populations is generally lacking, especially for the arid Southwest. The major objective in 1968 and 1969 was to determine the larval population in squares, blooms, and bolls throughout the growing season. In 1968, an additional objective was to compare two methods of boll sampling.

METHODS AND MATERIALS

The population growth studies were conducted at The University of Arizona Experiment Station at Mesa, Arizona, in fields isolated by several miles from other cotton. The cotton was grown by farm personnel following routine agronomic practices. No insecticides were applied for the control of any insect during the growing season. In both years the cotton was grown in eight-row borders oriented north and south. Spacing was 40" between rows and 80" between borders. The study field was planted with Acala 44 on March 28, 1968, and with Delta Pine 16 on April 4 in 1969.

The sources of the pink bollworm infestation each year were probably adjacent fields on the University Farm where cultural control experiments were conducted. Infestations were thus initiated from overwintering larval populations in nearby fields planted with cotton the preceding season. Moth emergence from the adjacent fields began in early March and continued well into the summer each year.

For sampling purposes, the cotton plants were divided into upper and lower halves. The mid-point of each plant was estimated visually at each observation, and its distance above the soil surface increased as the plant grew. When fruiting began, square samples were taken initially from the bottom half and later from both plant halves. Only squares with buds approximately 3/16" in diameter (pea-size) or larger were sampled. Mature squares were not sampled. Boll sampling was initiated on each plant-half at the appropriate time. Bolls which were slightly spongy when squeezed between the thumb and fingers were collected. This procedure helped to standardize the maturity of the samples. The pink bollworm population density in squares and bolls was estimated for each plant-half and for the total plant. Population estimates in blooms were made for the total plant only.

Calculation of Population Density

To calculate pink bollworm larval density, four variables were estimated each year: (1) the mean number of plants per row foot; (2) the mean number of fruiting structures (squares, blooms, and bolls) per plant-half; (3) the percent infestation in each type of fruiting structure; and (4) the mean number of larvae per infested fruiting structure. The number of plants per row foot was estimated only once each year; the other variables were estimated each time samples were taken.

Plants per acre were estimated by multiplying the average number of plants per row foot by 13,081, the row feet per acre for a 40" row spacing. The plants per acre times the mean number of squares, blooms, or bolls per plant gave an estimate of each fruiting structure per acre, which when multiplied by the percent infestation, gave an estimate of the number of infested fruiting structures per acre. Multiplying this last estimate by the mean number of larvae per infested fruit gave the number of pink bollworm larvae per acre. This procedure was used only to calculate larval populations in squares and bolls for each plant-half and in blooms for the total plant.

When considering the larval population on the total plant, two of the estimates must be adjusted, or weighted, to account for differences in the number of fruiting structures on each plant-half. These estimates are the percent of squares or bolls infested and the mean number of larvae per infested square or boll. Weighting these estimates and then calculating the total larval population gave the same result as adding the larval population estimates of each plant-half. Therefore, when both plant-halves were sampled, the total population was calculated by simply adding the estimates for each half.

A different procedure was used to calculate the total population when only one plant-half was sampled, as occurred early and late in the season when fruiting structures were not readily available from one of the plant-halves. To assume that the population estimate for the half sampled was also the estimate for the total plant would disregard any population present in the half not sampled.

The alternative employed was to use the estimate for the number of squares or bolls per total plant with the data for percent infestation and mean number of larvae per infested fruiting structure from the plant-half sampled for pink bollworms. The total population was then calculated from these data. This technique assumes a population to be present on the half not sampled. It undoubtedly overestimates the total population since equal weight is given to each half. There is no method for estimating a weighted percent or mean when only one plant-half was sampled.

There are two types of infestation means per fruiting structure. One is the mean number of larvae per square or boll. These data were not used in the calculation of population density but are presented to give additional information on population change. The second is the mean number of larvae per infested square or boll. This second mean was used to calculate population density. The two means become equal only when 100% of the squares or bolls are infested.

The average percent infestation and standard error of the mean in squares, blooms, and bolls were calculated on a sampling station basis in 1968 and 1969 because these fruiting structures were sampled in clusters. Cochran (1963) indicates that variance calculations for proportions are likely to be inaccurate if binomial theory is used in conjunction with cluster sampling. Therefore, the sampling station basis provided a means for treating the percentage data as a continuous variate.

In the following tables, data for percent of fruiting structures infested and mean number of larvae per fruiting structure and per infested fruiting structure for the total plant are nonweighted figures and are not appropriate for calculating the total population. They are nevertheless included because if future samples should be taken without regard to population differences on each plant-half, the resulting estimates would be similar to those presented here for the total plant. The means and standard error of the means for total plant were calculated by considering the top- and bottom-half sample data to be one sample of the whole plant.

The data for total squares and bolls per plant are appropriate for calculating total populations present in these two types of fruiting structures.

Sampling Methods

The 1968 study field contained 2.29 acres and comprised 14, eight-row borders, each 268′ long. The study field contained 1.91 acres and comprised 12, eight-row borders, each 260′ long, in 1969. Samples were taken weekly from May 22 to September 26 in 1968 and biweekly from June 9 to September 2 in 1969.

Hygrothermograph and Thermocouple Records

Temperatures were recorded at midpoint of the plant height with a hygrothermograph (Bendix), starting June 11 and June 9 in 1968 and 1969, respectively. The daily temperature and relative humidity records thus obtained are referred to as those at one-half plant height.

A hygrothermograph which had been maintained at standard height, 5′ above ground, in the adjacent cultural control field was moved into the population study field on July 15, 1968. Similar recordings were made in 1969 with the exception that the instrument was not moved into the study field. Records from the second instrument are referred to as those obtained at standard height.

A 12-point, strip-chart potentiometer (Honeywell) was installed on June 9, 1969, adjacent to the hygrothermograph maintained at one-half plant height. Four thermocouples were used to measure temperatures inside top- and bottom-half squares and bolls throughout the season. The thermocouples were inserted perpendicularly into the sides of the developing fruiting structures. A new square was selected each sampling date, but bolls were replaced only when they became hard.

A fifth thermocouple was maintained at one-half plant height in the center of a 9″ x 4″ tubular screen enclosure. The top of this thermocouple was shaded by an additional piece of louvered screen and the entire enclosure was supported by a wooden dowel. The enclosure was maintained within the cotton foliage, not in the middle of the furrow.

Plant Density Estimates

Plant density counts were made on June 5 and June 16 in 1968 and 1969, respectively, approximately three weeks after the first squares had appeared on the plants. Stand density was determined by counting plants in randomly selected areas of equal size in each border. A total of 700 row feet in 1968 and 1248 row feet in 1969 formed the basis for calculating the mean number of plants per row foot and per acre.

Square and Boll Sampling

In 1968 the borders were divided into quarters, perpendicular to the direction of the rows, to form four sampling positions in each of the 14 borders. Each sampling position was eight rows wide, and each row within a position constituted a sampling station.

In 1969 the field was divided into four blocks (or replicates) of three borders per block. As in 1968 the borders were divided into sampling positions and sampling stations.

All samples were taken systematically in 1968. To obtain data for each plant-half and for each fruiting structure, one of the eight rows in the first border was randomly selected on each sampling date. That row and every eighth row thereafter across the field were sampled. Samples were taken from alternate positions only, possible selections being Positions 1 and 3 or 2 and 4. The alternate positions were selected randomly for sampling each fruiting structure in each plant-half; however, the same rows (stations) in both positions were sampled. Thus, only one-half of the field was represented in samples from each plant-half, but not necessarily the same half for the top- and bottom-half square and boll samples.

In 1969 the sampling stations were independently and randomly selected, without replacement, within each of the four blocks on each date. Separate randomizations were made for sampling squares and bolls, but top and bottom samples of each fruiting structure were taken from the same station.

The larval population in bolls was estimated by two methods in 1968. After the bolls were picked they were divided into two subsamples of unequal size. The smaller subsample was examined within 36 hours after collection. Infestation records were based on the presence of live larvae and exit holes. This method is subsequently referred to as the immediate examination method.

The larger subsample of bolls was examined three weeks after collection, and this procedure is subsequently referred to as the holding method. Infestation records were based on the numbers of fourth instar larvae and exit holes present. Exit holes were counted as mature larvae. The bolls were held in wood-frame, screen-bottomed trays measuring 6′ 11″ x 2′ 10.5″, and the bolls from each station were held separately, one station per section of tray. The trays were placed in a rack in a greenhouse maintained with a maximum temperature of approximately 70°F. The screen bottoms allowed air circulation through the rack; and this, in conjunction with relatively cool temperatures and adequate spacing between bolls in each section, prevented the bolls from rotting.

When samples of the fruiting structures were collected from the top and bottom halves of the plant, an equal number of squares or bolls was taken from each half. These records were maintained on a sampling station basis only in 1968.

In 1968 the pink bollworm larval population in squares on the top-half of the plant averaged 2.8 times greater than on the bottom-half. Based on this relationship three squares from the top-half of the plant were sampled for every bottom square in 1969.

In 1968 the bottom-half larval population in bolls was 5.6 times greater than the top-half population during July, but the top-half population averaged 6.3 times greater in August and September. Only the relationship between top and bottom bolls examined immediately after sampling was considered. The bolls in 1969 were therefore sampled initially in a ratio of 6:1 (bottom:top). This ratio was reversed after the top population became noticeably greater, which first occurred on July 31; and the sampling ratio was changed to 1:6 (bottom:top) on August 5.

The result of this ratio sampling technique is that estimates for the total plant are weighted. None of the estimates for the total plant are exactly correct because the sampling ratios used were not identical to the larval population ratios between each plant-half. However, the estimates given for the total plant are likely to be more accurate than those made in 1968 when equal sample sizes were taken from each plant-half.

Records were kept on each individual fruiting structure sampled in 1969, and the means and standard errors could be calculated on a fruiting structure basis. The instar of each larva, determined by visual inspection only, found in squares and bolls and the number of exit holes in each boll were also recorded.

In order to ensure that the samples came from the entire length of the station, the sampler walked two to three steps into each sampling station and picked a square or boll every third step thereafter. In 1969, a bottom-half square was picked after every third top square. One top boll was picked after the fourth and ninth bottom bolls, and vice versa when the sampling ratio was changed.

The sample sizes for squares and bolls in 1968 and 1969 are summarized in Tables 1 and 2, respectively. In 1968 squares were picked apart and examined under a dissecting microscope. The carpels of the bolls examined immediately were removed by cutting along the interlocular seams. The inner carpel wall was examined for the presence of warts or tunnels as a first clue to the presence of larvae. Next, the lint was examined in place for stains and then was carefully picked apart. In all cases, a square or boll classified as infested was one containing one or more live larvae or exit holes. Bolls showing only stained lint, warts, or tunnels were not considered infested.

All 1969 boll and square samples were examined within 36 hours after collection. Methods of examination were the same as in 1968 except that no bolls were held. The 1968 criteria for determining infestation were also used in 1969.

Bloom Sampling

For bloom counts the 1968 field was divided into north and south halves. Beginning June 17 and each sampling date thereafter a row was selected at random, and the middle 50′ section within that half-row and in every eighth row thereafter was examined for numbers of normal and rosetted (infested) blooms. The same row in each half was examined. Flags were placed at the sides of the field in order to delineate the area to be examined. Each rosetted bloom was inspected for the presence of a larva, but it was assumed that there was only one larva per infested bloom.

Because cultural control experiments, not a part of this study, were superimposed on the sampling field, two borders were eliminated on September 11 and 17, and an additional two eliminated on September 26. This explains the end-of-the-season reduction in square and boll sample sizes shown in Table 1.

In 1969 the sampling design used to collect squares and bolls was also employed to determine the number of normal and rosetted blooms. The entire length of each randomly selected sampling station was examined.

Biweekly sampling was initiated on June 19, 1969. Throughout June and on July 7 and 10, seven stations per block were examined. Because of time limitations, only four stations per block were examined after July 10. The only deviation from these two procedures occurred on July 3; only three stations per block were examined. The sample size was reduced because of recent irrigation and a maximum temperature that day of 115°F. As in 1968 it was assumed that there was only one larva per infested bloom.

Fruiting Structure Density Estimates

Square, bloom, and boll density estimates were made for the top and bottom halves of the cotton plants throughout the growing season in both years. A fruiting structure was considered as being on the top half of the plant if it extended above the mid-point, even

Table 1. Number of squares and bolls sampled for determination of pink bollworm infestation. Mesa, Arizona. 1968.

Date	No. Sampling Stations		Squares Sampled per Station			Bolls Sampled per Station					
	Squares	Bolls	Top-half of plant	Bottom-half of plant	Total plant	Top-half of plant		Bottom-half of plant		Total plant	
						A[a]	B[a]	A	B	A	B
May											
22	14	0	0	0	3	0	0	0	0	0	0
28	14	0	0	0	6	0	0	0	0	0	0
June											
5	28	0	15	0	15	0	0	0	0	0	0
11	28	0	15	15	30	0	0	0	0	0	0
17	28	0	15	15	30	0	0	0	0	0	0
24	28	28	15	15	30	0	0	0	15	0	15
July											
1	28	28	15	15	30	0	0	0	15	0	15
8	28	28	15	15	30	0	0	0	15	0	15
15	28	28	15	15	30	4	15	4	15	8	30
22	28	28	15	0	15	4	15	4	15	8	30
29	28	28	15	0	15	4	15	4	15	8	30
August											
9	0	28	0	0	0	4	15	4	15	8	30
15	0	28	0	0	0	4	14	4	15	8	30
23	0	28	0	0	0	4	15	4	15	8	30
28	0	28	0	0	0	4	15	4	15	8	30
September											
3	0	28	0	0	0	4	15	4	--[b]	8	19
11	24	24	15	0	15	4	15	0	0	4	15
17	24	24	15	0	15	4	15	0	0	4	15
26	20	20	15	0	15	4	15	0	0	4	15

[a] A = bolls examined immediately after collection. B = bolls examined three weeks after collection.

[b] Four bolls were sampled from 22 stations, 10 bolls from one station, and 15 bolls from five stations.

though it may have been on a fruiting branch arising from the lower half of the plant. Late in the season, when the branches were bending under the weight of the bolls, a fruiting structure was judged as being on the lower half of the plant if it did not project above the mid-point. All sizes of each fruiting structure were counted in the density estimates.

In 1968 the sampling design used to collect the boll and square samples was also used to obtain the fruiting structure density estimates except that top and bottom counts were made on the same plant.

The total number of plants examined each week, through September 3, was 112. On September 11 and 17, 96 plants were examined; and on September 26 only 80 plants were examined. This is approximately 50 plants per acre. The samples were divided into two groups and each group was examined by a different person. A group consisted of 28 stations with two plants examined at each station. The alternate positions of the field, the beginning row in each border, and the locations of the two plants in the selected row were determined randomly for each group on each date.

Fruiting structure density estimates were made biweekly in 1969 from June 9 to September 2. Top and bottom counts were made on the same plant.

Samples were taken systematically within each block. A row in the most western border of each block was randomly selected. The same row number was then sampled in the remaining two borders. Next, two plants were randomly located in the first position. The plants were located as in 1968 except that two adjacent plants were examined. The two plants in the selected location were then systematically sampled in all four positions in each of the three rows sampled per block. A total of 96 plants was examined each date. This is equivalent to 50 plants per acre.

Initially, each of two samplers examined two entire blocks. In mid-season, this procedure was changed such that two positions in each block were randomly assigned to each sampler.

Table 2. Number of squares and bolls sampled for determination of pink bollworm infestation. Mesa, Arizona. 1969.

Date	Blocks	Stations per Block		Squares Sampled per Station			Bolls Sampled per Station		
		Squares	Bolls	Top-half of plant	Bottom-half of plant	Total plant	Top-half of plant	Bottom-half of plant	Total plant
June[a]									
9-30	4	7	0	9	3	12	0	0	0
July									
3	4	7	3	9	3	12	0	12	12
7	4	7	4	9	3	12	0	12	12
10	4	7	7	9	3	12	0	12	12
14	4	3	7	9	3	12	0	12	12
17	4	3	7	9	3	12	0	12	12
21	4	3	7	9	3	12	2	12	14
25	4	3	7	12	0	12	2	12	14
28	4	3	7	12	0	12	2	12	14
31	4	3	7	12	0	12	2	12	14
August[b]									
5-21	4	3	7	12	0	12	12	2	14
25	4	3	4	12	0	12	12	2	14
Sept.									
2	4	3	4	12	0	12	12	0	12

[a] Samples taken June 9, 12, 16, 19, 23, 26 and 30.

[b] Samples taken August 5, 7, 11, 14, 18 and 21.

Insect Predator Sampling

To estimate the relative abundance of common predatory insects, sweep net samples were taken from June 23 through July 28, 1969, using a standard 15" net. Fifty net sweeps were taken within the middle border of each block. Collections of coccinellids, reduviids, **Geocoris** spp., **Orius** spp., **Collops** spp., **Chrysopa** spp., and **Nabis** spp. were tabulated as numbers per 100 sweeps on each sampling date.

A more detailed description of sampling procedures, with illustrations, was given by Slosser (1971).

RESULTS

In 1968, the mean number of plants per row foot ($\pm$ the standard error) was 1.154 $\pm$ 0.024. The estimate was 1.789 $\pm$ 0.053 in 1969. Therefore, the estimated number of plants per acre was 15,205 in 1968 for Acala 44 and 23,392 in 1969 for Delta Pine 16.

1968 Population Growth Studies

On April 26, 1968, when the plants in the sampling field were in the first true-leaf stage, 60 plants were pulled at random from among five of the borders. These plants were thoroughly examined under a dissecting microscope in the laboratory for pink bollworm eggs. A second sample of 50 plants was similarly examined on May 8. No eggs were found, and this type of sampling was discontinued.

Several volunteer cotton plants were found in the adjacent cultural control field. These nearby plants were squaring as early as May 8. Twenty-five squares were picked from these volunteer plants on May 8, 17, and 22. Five, six and eight squares, respectively, were infested on each date with pink bollworm larvae. Because there were so few volunteer plants, it is doubtful that this early infestation contributed significantly to the population in the study field. It does indicate, however, that a gravid female population was available in the area before May 8. This sampling was discontinued after May 22.

Population Growth in Squares

First squares in the population study field were found on May 20, and first samples were taken on May 22 when there was an average of 0.231 squares per plant. Each square was less than

⅓ the size of a pea. This sample was taken because of the infestation in the volunteer cotton in the adjacent field; however, no infested squares were found in the sampling field. On May 28, there was an average of 0.523 squares per plant. This second sample was taken even though only a few squares were "pea-size," and again, no infestation was found.

Beginning on June 5, the plants were examined individually. The mean number of squares and standard error on each plant-half and on the total plant are presented by sampling date in Table 3. The number of squares increased to a maximum in mid-July and then decreased to a minimum in late August. A second cycle of square production, of lower magnitude than the first, began in September. Generally, the standard error was within 10% of the mean when there were six or more squares per plant. The estimates were most variable at times of low square density, in early June, August, and early September.

The percentages of the squares infested are presented in Table 4. No square samples were taken in August or on September 3 because the square infestations never exceeded 1.5% during June and July, and the number of squares present during August represented less than 13% of the fruiting structures. It was felt, therefore, that the population in squares did not make a sufficient contribution to the overall picture to justify the time involved in collecting and evaluating the samples. Squares were sampled later in September when the number of available bolls became very low. As the data in Table 4 illustrate, almost 60% of the squares were infested on September 17. The standard errors were within 10% of the mean only after the 35% infestation level was reached.

The mean number of pink bollworm larvae per sampling station, $\overline{X}_1$ and standard error of $\overline{X}_1$ are shown in Table 5. The mean number of larvae per square, $\overline{X}_2$, is also shown; but a standard error could not be calculated for this mean because records were not kept for each individual square. In addition to the sample size, the only other information recorded was the number of infested squares and the number of larvae observed at each station. Thus, the exact number of larvae in each square could not be determined. The total plant $\overline{X}_1$ is the sum of the top- and bottom-half means; and the mean per square, $\overline{X}_2$, is the average of the two means.

Table 3. Mean number of squares per plant.[a] Mesa, Arizona. 1968.

Date	Top-half of plant $\overline{X}$[b]	Top-half of plant $S\bar{x}$[c]	Bottom-half of plant $\overline{X}$	Bottom-half of plant $S\bar{x}$	Total plant $\overline{X}$	Total plant $S\bar{x}$
June						
5	6.000	0.649	0.286	0.177	6.286	0.705
11	7.214	.781	2.107	.369	9.321	.878
17	8.750	.362	3.750	.270	12.500	.512
24	14.446	.528	6.652	.434	21.098	.721
July						
1	15.929	.536	6.714	.360	22.643	.690
8	17.312	.602	8.241	.440	25.554	.881
15	21.580	.990	7.072	.425	28.652	1.203
22	18.768	1.365	3.277	.309	22.044	1.594
29	13.366	.981	2.839	.290	16.205	.959
August						
9	2.616	.377	.178	.064	2.794	.400
15	0.866	.160	.054	.032	0.920	.168
23	.821	.572	.054	.033	.875	.196
28	1.303	.281	.241	.118	1.544	.343
Sept.						
3	2.214	.330	.892	.182	3.107	.489
11	4.125	.454	1.021	.170	5.146	.626
17	5.312	.481	1.958	.213	7.271	.601
26	5.325	.523	2.500	.253	7.825	.600

[a] The cotton, of the variety Acala 44, was planted on March 28.
[b] $\bar{y}$ = the mean.
[c] $S\bar{x}$ = the standard error of the mean.

Table 4. Percentage of squares infested by pink bollworm larvae. Mesa, Arizona. 1968.

Date	Top-half of plant $\overline{X}$	Top-half of plant $S\bar{x}$	Bottom-half of plant $\overline{X}$	Bottom-half of plant $S\bar{x}$	Total plant $\overline{X}$	Total plant $S\bar{x}$
May						
22	-	-	-	-	0.00	0.00
28	-	-	-	-	.00	.00
June						
5	0.00	0.00	-	-	.00	.00
11	1.43	.53	1.43	0.53	1.42	.35
17	.95	.45	0.71	.40	.83	.32
24	.71	.40	.71	.40	.71	.36
July						
1	.24	.24	.24	.24	.24	.16
8	.00	.00	.00	.00	.00	.00
15	.71	.40	.00	.00	.35	.19
22	.24	.24	-	-	.24	.24
29	.24	.24	-	-	.24	.24
Sept.[a]						
11	35.00	3.09	-	-	35.00	3.09
17	59.17	2.84	-	-	59.17	2.84
26	49.33	3.00	-	-	49.33	3.00

[a] No square samples taken during August or on September 3.

Table 5. Mean number of pink bollworm larvae per sampling station in squares. Mesa, Arizona. 1968.

Date	Top-half of plant $\bar{X}_1$ [a]	Top-half of plant $S\bar{x}$ [a]	Top-half of plant $\bar{X}_2$ [b]	Bottom-half of plant $\bar{X}_1$	Bottom-half of plant $S\bar{x}$	Bottom-half of plant $\bar{X}_2$	Total plant $\bar{X}_1$	Total plant $S\bar{x}$	Total plant $\bar{X}_2$
May									
22	-	-	-	-	-	-	0.000	0.000	0.000
28	-	-	-	-	-	-	.000	.000	.000
June									
5	0.000	0.000	0.000	-	-	-	.000	.000	.000
11	.214	.079	.014	0.214	0.079	0.014	.429	.108	.014
17	.143	.067	.010	.107	.060	.007	.250	.098	.008
24	.107	.060	.007	.107	.060	.007	.214	.107	.007
July									
1	.036	.036	.002	.036	.036	.002	.071	.050	.002
8	.000	.000	.000	.000	.000	.000	.000	.000	.000
15	.107	.060	.007	.000	.000	.000	.107	.060	.004
22	.036	.036	.002	-	-	-	.036	.036	.002
29	.036	.036	.002	-	-	-	.036	.036	.002
Sept. [c]									
11	5.917	.561	.394	-	-	-	5.917	.561	.394
17	9.708	.582	.647	-	-	-	9.708	.582	.647
26	8.450	.495	.563	-	-	-	8.450	.495	.563

[a] $\bar{X}_1$ and $S\bar{x}$ calculated on a sampling station basis since records were not kept on an individual square basis.

[b] $\bar{X}_2$ = mean number of larvae per square and was obtained by dividing $\bar{X}_1$ by station sample size. $S\bar{x}$ of $\bar{X}_2$ not available for reason cited in footnote a above.

[c] Square samples not taken in August or on September 3.

Table 6. Number of pink bollworm larvae, in squares, per acre. Mesa, Arizona. 1968.

Date	Squares: Top-half of plant	Squares: Bottom-half of plant	Squares: Total plant
June			
5	0	- [a]	0
11	1,568	459	2,027
17	1,264	405	1,669
24	1,560	718	2,278
July			
1	581	245	826
8	0	0	0
15	2,330	0	2,330
22	685	-	805
29	488	-	592
August [b]			
September			
3	-	-	-
11	24,776	-	30,910
17	52,072	-	71,292
26	45,490	-	66,867

[a] Dash indicates no samples were taken.

[b] No squares were sampled in August.

The means per sampling station were less than 1.000 through July because most stations contained no infested squares. In September a minimum of two infested squares was found at each station. On a sampling station basis, the standard error was within 10% of the mean in September only.

On those dates in June and July when infested squares were found (Table 4 or 5), the mean number of larvae per infested square was 1.000. On September 11, 17, and 26, the mean per infested square was 1.127, 1.094, and 1.142, respectively. These means (not those in Table 5) were used to calculate population density. The means in September apply to both the top-half and total squares.

The estimated larval populations in squares are presented in Table 6; and in June and early July, the population in the upper squares was two to three times greater than that in the lower-half. The population remained fairly constant during June.

Table 7. Pink bollworm population development in blooms on the total cotton plant. Mesa, Arizona. 1968.

Date	Blooms per plant $\bar{X}$	Blooms per plant $S\bar{x}$	Percent blooms infested $\bar{X}$	Percent blooms infested $S\bar{x}$	Population per acre
June					
17	0.170	0.037	1.95	1.10	50
24	.384	.062	2.06	0.59	119
July					
1	.393	.074	0.42	.27	24
8	.723	.087	.18	.03	20
15	1.794	.117	.76	.25	207
22	1.322	.122	.82	.25	164
29	1.196	.136	.12	.05	22
August					
9	1.232	.152	1.45	.39	271
15	.223	.054	.98	.54	33
23	.062	.025	6.67	2.38	61
28	.008	.010	.00	.00	0
Sept.					
3	.035	.017	17.95	3.47	109
11	.135	.040	15.00	6.27	319
17	.208	.059	45.79	4.78	1,462
26	.325	.065	63.47	4.51	3,088

The larval population in July was generally less than in June, but a definite peak occurred on July 15. Since there was no obvious peak in June and because no samples were taken in August, it is difficult to depict any trends in the population in squares. A striking increase occurred in September; this was probably due to a high population pressure caused by the low number of available bolls during late August and September.

Bottom-half squares were not sampled after July 15 because of the difficulty in locating them. The data in Table 5 indicate that there were very few squares on the bottom half after this date. Even when there were 15,000 to 30,000 bottom squares per acre (one to two squares per plant as in September), it was extremely time consuming to collect a sample. However, the population estimates for the top half of the plant during September indicated that a large population could have been present in the bottom-half squares. It therefore seemed justifiable to calculate the total population in the manner described previously. Even a 10% infestation in bottom squares during September would have contributed several thousand larvae to the total estimate.

Population Growth in Blooms

The first bloom samples were taken on June 17, 1968, and each week thereafter. The data used to calculate the population in blooms and the estimated larval populations are presented in Table 7.

The number of blooms per plant reached a peak on July 15 and then declined to a minimum on August 28. A second blooming cycle began in September. The standard error was within 10% of the mean only in mid-July. The blooming cycle corresponded with the squaring trend, and both reached maximum and minimum densities on about the same dates.

The percentage of blooms infested each date is also shown in Table 7. Definite peaks occurred on June 24, July 22, and August 23. The 63% infestation in blooms on September 26 may represent a fourth peak since the infestation in squares peaked on September 17 and then declined. The standard error was within 10% of the mean on September 26 only. These cyclic peaks may represent larval generation trends.

The percent infestation peaks in blooms correspond with the population peaks on June 24 only. The sharp increase in percent infestation on August 23 produced only a minor increase in a population which otherwise was declining. The small decrease in percent infestation on September 11 was not represented in the population trend. This indicates that percent bloom infestation is not a reliable index of the population trend in blooms. The small population in blooms during August indicates that the population in squares was also small during this month.

Population Growth in Bolls

The first bolls were observed on June 17, 1968, and weekly boll counts were made for the rest of the season. These data are presented in Table 8. The bottom bolls reached a peak on July 22 and then declined through mid-September. Top-half and total bolls reached a maximum on August 9 and then decreased until late September. The standard errors were within 10% of the mean during most of July and August. The boll counts in Table 8 were used in the population calculations for both methods of boll evaluation.

The percentages of infested bolls, as determined by the holding method and immediate examination method, are presented in Tables 9 and 10, respectively. Generally, the holding method indicated a higher percent infestation than the immediate examination method although both depict a similar trend in population increase.

The discrepancy between the two methods is probably a result of several factors. First instar larvae are difficult to locate, and it seems probable that some were overlooked. Errors of this type tend to lower the immediate examination estimates, especially early in the season when population density is low and only a few bolls are infested. On the other hand, exit holes are very obvious; and it is doubtful that any of the infested, held bolls were overlooked. The holding method may give an inflated estimate since any eggs on the bolls at sampling could have hatched and developed into mature larvae during the three-week holding period. It therefore appears that the holding method initially estimates a potential infestation rather than the actual infestation. Because samples were only taken weekly and because the infestation was not static, the potential infestation data may be of limited practical value.

Watson and Fullerton (1969) reported that control measures are not warranted until 20% of the green bolls become infested. The data in Tables 9 and 10 indicate that this level was not reached in 1968 until late in July.

The standard errors indicate that the holding method was less variable. Part of this is due to the fact that exit holes are easy to detect. The larger sample size (see Table 1) may also be a factor. The holding method has a major disadvantage in that infestation data are not available until several weeks after the bolls are collected. This makes the holding method impractical because decisions concerning control of the pink bollworm cannot be delayed for two or three weeks.

The mean number of pink bollworm larvae per sampling station, $\overline{X}_1$, the standard error of this mean, and the mean number of larvae per boll, $\overline{X}_2$, are presented in Table 11. These data are for the immediate examination method. Due to the manner in which the data were recorded comparable information for the holding method is not available. Total $\overline{X}_1$ represents the sum of the means for each half, and total $\overline{X}_2$ is the average of the $\overline{X}_2$ means for each half.

An average of one larva per boll was not reached until the latter half of August. The average increased to almost seven per boll by the end of September. Although not used in the calculation of population density, these data are presented because they indicate how rapidly the infestation increases in the latter part of the season.

The mean number of larvae per infested boll for both sampling methods is presented in Table 12. Some means are less than 1.000 for the bolls examined immediately because a few bolls had exit holes, and thus were counted as being damaged, but had no larvae. The means for the holding method had to be corrected for those exit holes which were present when the bolls were first collected from the field. The adjustment was made by subtracting the mean number of exit holes per boll, as determined for those bolls examined immediately, from the mean obtained from the bolls held three weeks. There was no alternative for this adjustment procedure because the number of exit holes in those bolls held three weeks was not determined when they were first brought in from the field.

In general, the means for the bolls held three weeks were greater than for the immediately-examined bolls during July and early August; this trend was reversed in mid-August. The only apparent explanation is that the held bolls began to open in the holding trays in August and September. Larvae were then able to leave the bolls through the exposed lint without cut-

Table 8. Mean number of bolls per plant. Mesa, Arizona. 1968.

	Top-half of plant		Bottom-half of plant		Total plant	
Date	$\overline{X}$	$S\bar{x}$	$\overline{X}$	$S\bar{x}$	$\overline{X}$	$S\bar{x}$
June						
17	0.000	0.000	0.089	0.025	0.089	0.025
24	.134	.033	1.741	.116	1.875	.120
July						
1	.598	.105	3.384	.224	3.982	.271
8	1.205	.111	5.625	.340	6.830	.391
15	3.098	.203	9.500	.346	12.598	.566
22	5.178	.332	11.580	.446	16.759	.657
29	4.188	.258	10.241	.387	14.428	.535
August						
9	8.294	.524	9.312	.491	17.608	.842
15	6.786	.347	5.857	.319	12.643	.577
23	5.303	.466	3.312	.318	8.616	.674
28	3.598	.286	1.107	.143	4.705	.377
Sept.						
3	2.339	.357	.500	.094	2.839	.441
11	1.740	.186	.208	.054	1.948	.191
17	1.073	.174	.271	.080	1.344	.195
26	1.225	.173	.362	.086	1.588	.264

Table 9. Percent of pink bollworm infested bolls in samples held three weeks before examination. Mesa, Arizona. 1968.

	Top-half of plant		Bottom-half of plant		Total plant	
Date	$\overline{X}$	$S\bar{x}$	$\overline{X}$	$S\bar{x}$	$\overline{X}$	$S\bar{x}$
June						
24	-	-	0.24	0.24	0.24	0.24
July						
1	-	-	.00	.00	.00	.00
8	-	-	2.62	.71	2.62	.71
15	14.76	1.62	16.90	2.36	15.83	1.68
22	14.52	2.06	23.33	2.48	18.92	1.51
29	17.14	2.15	20.48	1.97	18.80	1.49
August						
9	62.14	3.31	21.90	2.08	42.02	1.79
15	77.38	3.62	19.05	2.13	48.21	2.15
23	97.38	1.10	80.47	1.75	88.93	1.10
28	99.52	0.45	80.24	2.48	89.64	1.23
Sept.						
3	98.33	.88	98.26	-[a]	98.33	-[a]
11	99.44	.38	-	-	99.44	.38
17	99.44	.38	-	-	99.44	.38
26	98.67	.61	-	-	98.67	.61

[a] $S\bar{x}$ not calculated because bottom-half samples were accidentally mixed.

Table 10. Percent of pink bollworm infested bolls in samples examined immediately after collection. Mesa, Arizona. 1968.

Date	Top-half of plant		Bottom-half of plant		Total plant	
	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$
July						
15	3.57	1.68	7.14	3.11	5.36	1.87
22	8.03	2.59	14.28	3.26	11.16	2.43
29	4.46	1.84	21.43	3.80	12.95	2.18
August						
9	38.39	5.22	34.82	4.51	36.61	3.63
15	47.32	4.52	37.50	5.22	42.41	3.54
23	98.21	1.24	60.71	4.15	79.46	2.25
28	97.32	1.49	66.96	3.42	82.86	1.74
Sept.						
3	98.21	1.24	96.43	-[a]	97.32	-[a]
11	100.00	0.00	-	-	100.00	0.00
17	100.00	.00	-	-	100.00	.00
26	98.75	1.25	-	-	98.75	1.25

[a] $S\bar{x}$ not calculated because bottom-half samples were accidentally mixed.

ting holes in the carpel wall. Exit holes through the lint were very difficult to discern. Apparently, a large number of larvae, and hence exit holes, went undetected because of this. This undoubtedly makes the holding method less accurate late in the season. However, this problem could be eliminated by capturing the larvae emerging from each sample.

The number of pink bollworm larvae per acre as determined by both methods of boll evaluation is presented in Table 13. The population of the total plant, as calculated from the holding data, was higher than that calculated from the immediate examination data through August 15 because the percent infestation and mean number larvae per infested boll were higher for the holding method in July and early August. Beginning August 23, the estimated population on the total plant was greater for those bolls examined immediately because the percent infestation data for each method became nearly equal after mid-August and because the number of larvae found in bolls examined immediately was greater. Even though the holding data appear to be more precise, this method probably does not present as accurate a picture of population development as the immediate examination method.

The estimates by both methods show that the larval population was initially greater in the bottom-half bolls. In early August the population became greater in the top-half bolls. This relationship is shown in Figure 1 for those bolls examined immediately. The shift in the population was undoubtedly stimulated by the hardening and maturing

Table 11. Mean number of pink bollworm larvae per sampling station in bolls examined immediately after collection. Mesa, Arizona. 1968.

Date	Top-half of plant			Bottom-half of plant			Total plant		
	$\bar{X}_1$[a]	$S\bar{x}$[a]	$\bar{X}_2$[b]	$\bar{X}_1$	$S\bar{x}$	$\bar{X}_2$	$\bar{X}_1$	$S\bar{x}$	$\bar{X}_2$
July									
15	0.143	0.067	0.036	0.286	0.124	0.071	0.429	0.149	0.054
22	.429	.158	.107	.679	.171	.170	1.107	.279	.138
29	.286	.125	.071	.964	.202	.241	1.250	.239	.156
August									
9	2.214	.438	.554	.357	.092	.089	2.571	.419	.321
15	1.536	.429	.384	.786	.238	.196	2.321	.357	.290
23	13.857	.899	3.464	3.000	.337	.750	16.857	.959	2.107
28	11.286	.891	2.822	4.393	.467	1.098	15.679	.891	1.960
Sept.									
3	18.429	1.198	4.607	-[c]	-[c]	2.473	-[c]	-[c]	3.540
11	21.125	1.194	5.281	-	-	-	21.125	1.194	5.281
17	23.875	1.326	5.969	-	-	-	23.875	1.326	5.969
26	27.050	1.376	6.763	-	-	-	27.050	1.376	6.763

[a] $\bar{X}_1$ and $S\bar{x}$ calculated on a sampling station basis since records were not kept on an individual boll basis.

[b] $\bar{X}_2$ = mean number larvae per boll and obtained by dividing $\bar{X}_1$ by station sample size. $S\bar{x}$ of $\bar{X}_2$ not available for reason cited in footnote a above.

[c] $\bar{X}_1$ and $S\bar{x}$ not calculated for this date because bottom-half samples were mixed.

FIGURE 1

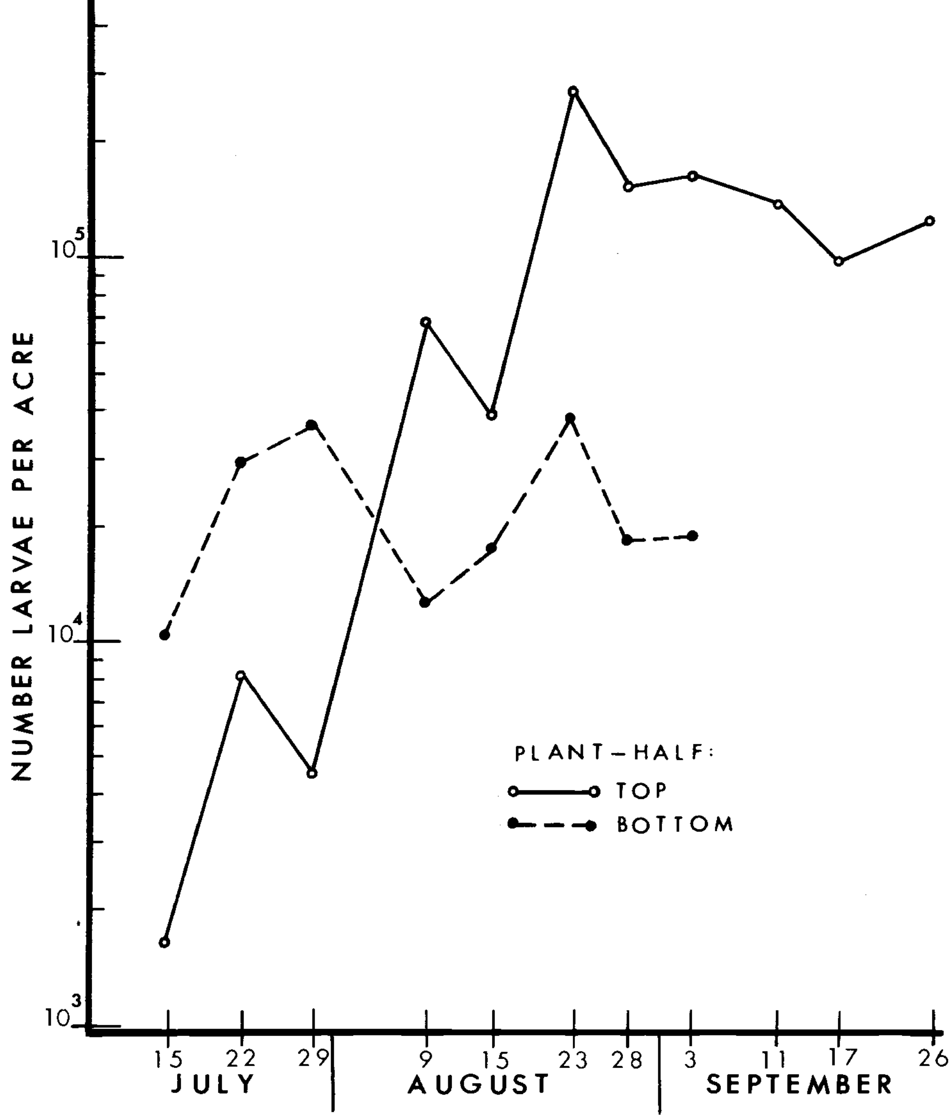

Figure 1. Population Growth of the Pink Bollworm in Top- and Bottom-Half Bolls. Mesa, Arizona. 1968.

of the bottom bolls. The first open bolls were found on the bottom half of the plant on August 9.

Both sampling methods indicate that there were two population peaks in the bottom-half bolls. The peak in late July probably represents the population peak for the first generation in bolls and the one in August for the second generation in bolls. There were no well-defined peaks in the top-half bolls until August 23, a point which corresponds with the second peak in the bottom bolls. The population appears to have literally exploded after the first generation in bolls. At the end of July, approximately 20% of the bolls were infested. Between 80 and 90% were infested by August 23. This was a 60-70% increase in 23 days compared to a 20% increase (0 to 20%) during the entire month of July.

The larval population declined after August 23, but the data indicate a third generation was initiated in bolls during September. The population increase on September 26 probably indicates the peak of this third generation.

1968 Summary

A summary of the larval population development in squares, blooms, and bolls on a total plant basis is shown in Figure 2. A population was not detected on dates between unconnected points in the curves for each fruiting structure. No square samples were taken in August or on September 3, and that portion of the square curve is therefore unavailable. Only the population in bolls examined immediately is shown.

During July and August, the populations in squares and blooms comprised a relatively small fraction of the total population. Bolls were readily available during these two months. Apparently, squares play a significant role in the population dynamics of the pink bollworm at the beginning and end of the season only. Squares maintain a population in June until bolls become available and begin to support the larval population when bolls become scarce. Approximately 25% of the larval population was in squares and blooms during September.

1969 Population Growth Studies

No volunteer cotton plants were available in 1969, and the plants in the sampling field were not examined for oviposition as in 1968.

Population Growth in Squares

The first squares were found on May 28, 1969, and sampling was initiated on June 9. The mean number of squares per plant and per plant-half are presented by sampling date in Table 14. Square density in the top half and on the total plant reached a maximum in mid-July and then decreased through the first half of August. Bottom squares reached a maximum in early July. A second cycle of increased square production began in mid-August. The standard errors were generally within 10% of the mean only during June and early July, the first period of increasing square density.

The percent square infestation is shown by sampling date in Table 15. The highest infestation during June and July was 5% on June 12. The square infestation never exceeded 1.5% during the same period in 1968. The square infestation began to increase in late July; and, as in 1968, more than 50% of the squares became infested in September. This trend in square infestation was quite similar to that reported by Rude and Smith (1932).

FIGURE 2

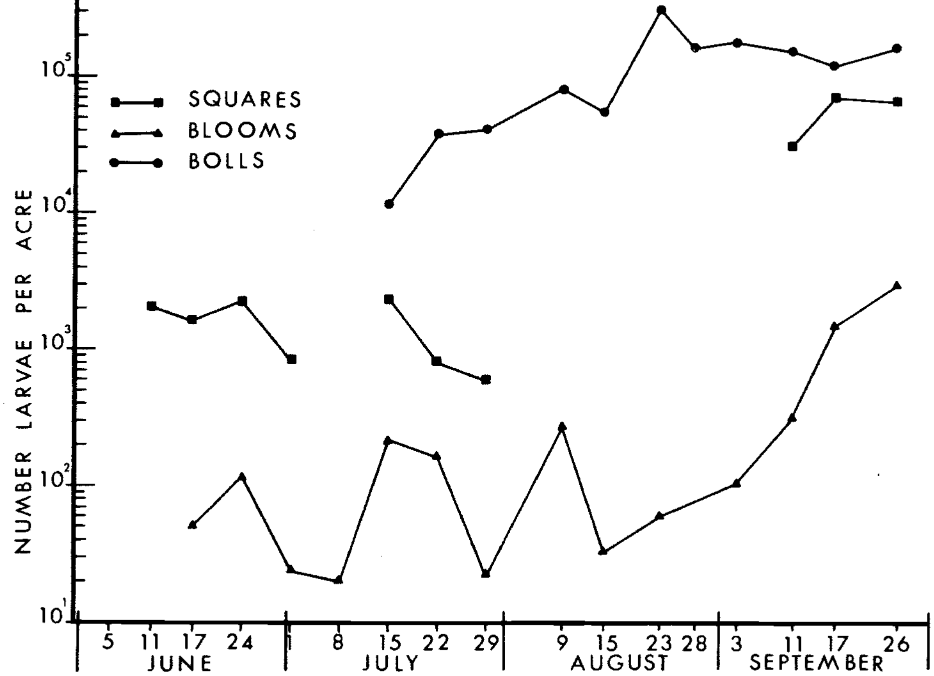

Figure 2. Population Growth of the Pink Bollworm in Squares, in Blooms, and in Bolls on the Total Cotton Plant. Mesa, Arizona. 1968.

Table 12. Mean number of pink bollworm larvae per damaged boll. Mesa, Arizona. 1968.

	Bolls Examined Immediately[a]			Bolls Held Three Weeks[b]		
Date	Top-half of plant	Bottom-half of plant	Total plant	Top-half of plant	Bottom-half of plant	Total plant
June						
24	-	-	-	-	1.000	1.000
July						
1	-	-	-	-	0.000	0.000
8	-	-	-	-	1.000	1.000
15	1.000	1.000	1.000	1.403	1.324	1.361
22	1.333	1.188	1.240	1.180	1.510	1.384
29	1.600	1.125	1.207	1.556	1.302	1.418
August						
9	1.442	0.256	0.878	1.205	.527	1.181
15	0.811	.524	.684	0.977	.710	.883
23	3.464	1.235	2.652	2.689	1.712	2.275
28	2.824	1.640	2.389	2.828	.820	1.973
Sept.						
3	4.691	2.565	3.637	2.246	.200	1.375
11	5.281	-	5.281	2.710	-	2.710
17	5.968	-	5.968	2.105	-	2.105
26	6.848	-	6.848	2.964	-	2.964

[a] Counts based on live larvae and exit holes.

[b] Counts based on exit holes only.

Bottom-half squares were not sampled after July 21 because they had become extremely difficult to locate and because no infested bottom squares had been detected since June 26. The disappearance of an infestation on the lower-half of the plant may be a result of the fruiting characteristics of the cotton plant. New squares are formed at the terminals of the branches; and after the initial growth period, most terminals were located on what was considered the top half of the plant. Therefore, by the end of June there were few young squares available for infestation on the bottom half of the plant.

The percent infestation on the total plant is not the average of the plant-halves as in 1968. This is due to the ratio sampling technique employed. The standard errors were within 10% of the mean only on September 2, when almost 57% of the squares were infested.

The number of pink bollworm larvae per square and number of larvae per infested square are presented in Tables 16 and 17, respectively. The data in Table 16 are very similar to those in Table 5 for 1968. In both years, the number of larvae per square did not exceed 0.5 until September. The standard error is within 10% of the mean on September 2 only. The data in Table 17 were used in calculating population density. In this table there was variation about the mean on June 12, August 21 and 25, and September 2 only. This general lack of variation resulted because each infested square contained only one larva. On the four dates when variation did occur the standard error was within 10% of the mean. In late August and September, up to three larvae were found in some squares.

The number of pink bollworm larvae per acre, in squares, is shown in Table 18. Independent estimates of the variables used in calculating population density were made in each of the four blocks. It was therefore possible to make four independent estimates of population density. The standard errors shown in Table 18 were calculated from the four estimates for each date. The standard error is also presented as a percentage of the average population per acre.

The population in top-half squares reached peaks on June 12 and July 3. The erratic behavior of the July population is probably a result of the sample size. Only one infested square containing one larva was found on July 7, 14, 21, and 28. On July 10, 17, and 25, no infestation was found. Calculations based on one infested square per date produced an estimate of sev-

Table 13. Number of pink bollworm larvae, in bolls, per acre. Mesa, Arizona. 1968.

	Bolls Examined Immediately			Bolls Held Three Weeks		
Date	Top-half of plant	Bottom-half of plant	Total plant	Top-half of plant	Bottom-half of plant	Total plant
June						
24	-	-	-	-	64	68
July						
1	-	-	-	-	0	0
8	-	-	-	-	2,239	2,717
15	1,683	10,314	11,997	9,740	32,224	41,964
22	8,411	29,920	38,331	13,494	62,028	75,522
29	4,546	37,370	41,916	17,035	41,453	58,488
August						
9	69,682	12,815	82,497	93,992	16,120	110,112
15	39,572	17,375	56,947	78,291	12,051	90,342
23	273,838	37,887	311,725	211,098	69,253	280,351
28	150,224	18,535	168,759	154,164	11,105	165,269
Sept.						
3	163,883	18,767	182,650	78,718	1,494	80,212
11	139,693	-	156,552	71,297	-	79,902
17	97,126	-	121,639	34,136	-	42,751
26	125,478	-	162,509	54,177	-	70,164

Table 14. Mean number of squares per plant.[a] Mesa, Arizona. 1969.

	Top-half of plant		Bottom-half of plant		Total plant	
Date	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$
June						
9	4.479	0.457	2.281	0.193	6.760	0.599
12	5.083	.376	2.385	.303	7.469	.640
16	7.229	.430	3.969	.321	11.198	.676
19	9.208	.575	4.490	.374	13.698	.872
23	12.094	.750	6.156	.427	18.250	1.204
26	14.333	.975	6.458	.459	20.792	1.554
30	17.115	1.382	6.615	.633	23.729	1.897
July						
3	21.875	1.134	7.917	.791	29.792	1.435
7	17.813	1.188	4.417	.476	22.229	1.633
10	25.781	2.131	6.281	.656	32.062	2.118
14	25.948	1.752	2.938	.444	28.885	2.843
17	22.281	1.079	1.510	.300	23.792	1.176
21	16.177	1.571	0.792	.195	16.969	1.636
25	10.427	1.648	.198	.050	10.625	1.726
28	6.531	1.547	.135	.071	6.667	1.636
31	3.385	.523	.010	.010	3.396	.516
August						
5	2.469	.588	.010	.010	2.479	.588
7	1.531	.294	.010	.010	1.542	.294
11	1.667	.308	.000	.000	1.667	.308
14	1.344	.486	.000	.000	1.344	.154
18	2.333	.797	.052	.037	2.385	.288
21	2.094	.830	.031	.032	2.125	.832
25	4.156	1.626	.302	.108	4.458	1.675
Sept.						
2	8.031	1.468	.635	.212	8.667	1.555

[a] The cotton, of the variety Delta Pine 16, was planted on April 4.

eral thousand larvae per acre. Apparently, the sample size was too small to detect an infestation on all dates during July. The estimated population steadily increased after July.

The bottom-half population in squares peaked on June 12 and again on June 26 and then completely disappeared. The population on the total plant peaked in accordance with the peaks on each plant-half. The population in squares during 1969 was similar to that during 1968. Each year, the population apparently fluctuated about some average density in June and July and then increased rapidly in August and September.

The standard errors in Table 18 indicate that the population estimates were highly variable. Part of the variation is due to the fact that a population was not detected in all sampling blocks in June and July. The only time a population was found in all blocks occurred on June 12 and all dates after August 11. Another part of the variation can be ascribed to that present in each of the variables used to calculate the population. As previously pointed out, the standard error of these estimates was not always within 10% of the mean. It appears that a reasonable estimate of population density was not attained until there was at least a 50% infestation in squares (on September 2).

Variations in the 1968 population in squares could not be determined because only one random sample (sampling was systematic with a random starting point) was taken each date. The data for both years were quite similar. This indicates that the 1968 population estimates were highly variable also.

The mean number of each larval instar per square is presented in Table 19. The data are for the total square sample only. A few mature squares were apparently sampled in August since some fourth instar (pink) larvae were found. These data are presented in order to give an indication of the age structure of the population in squares.

The trends in the number of first and second instar larvae generally parallel each other. Taken together these young larvae probably give a good indication of the generation cycles in June and early July. The sum of the means for each instar in Table 19 is equal to the mean in the total plant column of Table 16.

Population Growth in Blooms

The first blooms were found on June 16, 1969, and the first infested blooms on June 19. The mean number of blooms per plant and the percent infestation on each sampling date are shown in Table 20. The number of blooms increased until July 17 and then declined. The highest infestation in June or July, 3.8%, occurred on June 23.

The pink bollworm population in blooms, on a per acre basis, is shown in Table 21. The population estimates in each block were used to calculate the standard error. As in 1968, the population in blooms exhibited a cyclic trend. Definite peaks were reached on June 26, July 28, and August 21. The standard errors indicate that the population estimates were highly variable.

As in 1968, the peaks in percent infestation were not exactly correlated with the population peaks. This again indicates that percent infestation counts are not a reliable index of the actual population trend. This was also observed by Noble and Robertson (1964) who indicated that the number of infested blooms per acre was a more reliable index of population trend than the percent infestation in blooms.

Population Growth in Bolls

The first bolls were found on June 19, 1969. The boll counts on each sample date are shown in Table 22. The counts reached and maintained a plateau from late July through mid-August. The top and total boll counts did not show a definite decreasing trend until August 18. This pattern of boll increase was different from that of 1968, when the bolls reached a peak on August 9 and then decreased. There was no leveling-off of the 1968 counts, but this may have been a result of the interval between sampling. In general, the standard errors were within 10% of the mean during late July and early August, in agreement with the trend of 1968.

The percent boll infestation data are presented in Table 23. The first samples were taken on July 3, when the bolls were 14 days old. The total plant data are weighted due to the ratio sampling. The 20% level of infestation was reached between July 25 and 28. A greater percentage of the bolls was infested in the top half of the plant after August 5. As in 1968, the infestation increased from the 20% level at the end of July to nearly 100% by the first of September. The standard errors were within 10% of the mean only after a 35% infestation level had been reached.

The number of larvae per boll is shown in Table 24. An average of one larva per boll was not reached until after August 14, when from 60 to 80% of the bolls were infested. The data in Tables 24 and 11 are similar to those of Ohlendorf (1926).

The average number of pink bollworm larvae per infested boll is shown in Table 25. These data were used to calculate population density. The means for the bottom half decreased below 1.00 during August because several bolls had exit holes but no larvae. The greatest number of larvae found in any one boll was 18. After July the standard errors in both Tables 24 and 25 were generally less than 10% of the mean except for the bottom-half counts, where the standard error was rarely within 10% of the mean. Again, the total plant estimates are weighted.

The estimated number of larvae, in bolls, per acre is presented in Table 26. The standard errors were calculated from the population estimates in each sampling block. Except for the observation on July 25, the population was greater in the bottom-half bolls through July 28. The relationship between top- and bottom-half populations is shown in Figure 3. This is the same relationship found in 1968 (see Figure 1). The first open bolls were found on July 31, 1969.

There were two major population peaks in the bottom bolls. The peak on August 21 was nearly twice as great as that on July 28. In 1968 the corresponding peaks were nearly equal. The population in the top half of the plant

Table 15. Percent of squares infested by pink bollworm larvae. Mesa, Arizona. 1969.

	Top-half of plant		Bottom-half of plant		Total plant	
Date	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$
June						
9	2.78	1.23	4.76	2.24	3.27	0.89
12	4.36	1.33	5.95	2.45	4.75	1.08
16	1.98	1.00	2.38	1.65	2.08	1.01
19	0.40	0.40	0.19	0.19	0.59	.41
23	.00	.00	2.38	1.65	.59	.41
26	.40	.40	3.57	1.98	1.18	.56
30	.19	.66	.00	.00	.89	.49
July						
3	.19	.66	.00	.00	.89	.49
7	.40	.40	.00	.00	.30	.29
10	.00	.00	.00	.00	.00	.00
14	.92	.92	.00	.00	.69	.69
17	.00	.00	.00	.00	.00	.00
21	.92	.92	.00	.00	.69	.69
25	.00	.00	-	-	.00	.00
28	1.39	1.39	-	-	1.39	1.39
31	2.08	1.08	-	-	2.08	1.08
August						
5	.69	.69	-	-	.69	.69
7	2.08	1.08	-	-	2.08	1.08
11	4.17	1.92	-	-	4.17	1.92
14	9.72	2.87	-	-	9.72	2.87
18	11.80	3.38	-	-	11.80	3.38
21	34.72	5.22	-	-	34.72	5.22
25	38.19	4.28	-	-	38.19	4.28
Sept.						
2	56.94	3.53	-	-	56.94	3.53

reached a peak on July 31, 1969, fluctuated until August 11, and then increased to a second peak on August 21. This second peak corresponded with that on the bottom half of the plant. The population in bolls declined after August 21.

The first larval generation in bolls reached a peak at the end of July. As in 1968, this population peak appeared at the same time and again corresponded with the 20% level of boll infestation. Larval density did not reach high levels until the initiation of the second generation in bolls during August. The only major difference between 1968 and 1969 was in the number of larvae per acre. At the height of the 1968 infestation there were 312,000 larvae per acre compared to twice that number in 1969.

The standard errors indicate that the early season estimates for the population in bolls were highly variable. In general, the estimates for the population in bolls were less variable than for those in squares and blooms. This reduction in variation is probably due in part to the more widespread boll infestation.

The average number of each larval instar per boll is shown in Table 27. Also shown is the average number of exit holes per boll. These data are for the total boll sample only. The samples were taken from bolls within restricted age limits, and the accuracy of the data for third and fourth instar larvae and for exit holes may be reduced. Because the older bolls were not generally picked until late in the season when boll density became low, those bolls containing the older larvae were probably not adequately represented in the samples; however, the data do give a general picture of the age structure of the population in bolls.

As in squares the trend in numbers of first and second instar larvae in bolls generally parallel each other, and major peaks were reached on the same dates. The peaks of fourth instar larvae and exit holes generally lagged behind those of the younger larvae. Collectively, the younger larvae probably give a good indication of the generation cycles in bolls. The sum of the means for each instar in Table 27 is equal to the mean in the total plant column of Table 24.

FIGURE 3

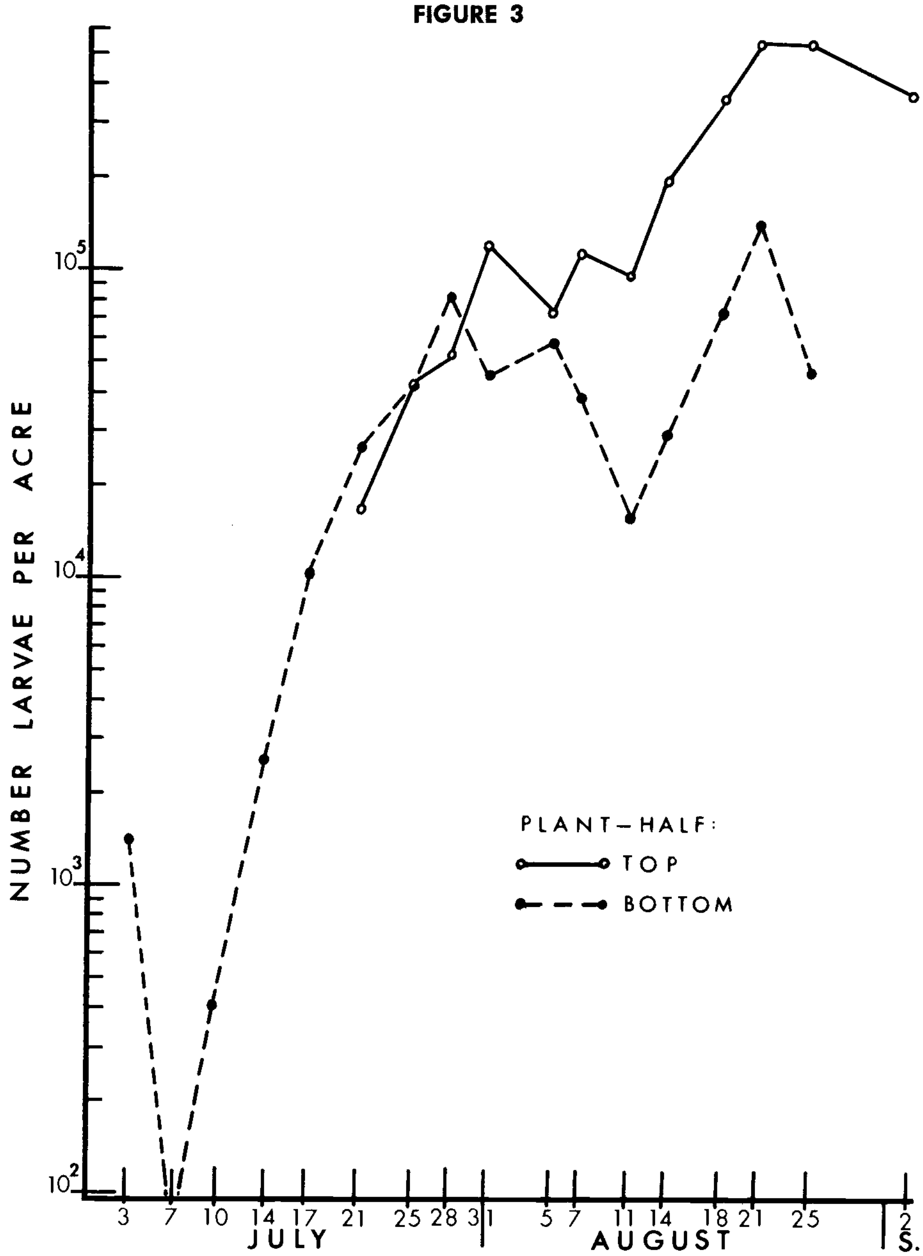

Figure 3. Population Growth of the Pink Bollworm in Top- and Bottom-Half Bolls. Mesa, Arizona. 1969.

1969 Summary

Population development on the total plant in squares, blooms, and bolls is summarized in Figure 4. The population was zero on sampling dates between unconnected points.

As in 1968, the population did not begin to increase until bolls became available. The population in squares varied erratically during July and did not show a definite trend of increase until early August. This period of population increase in squares corresponded with a decrease in the boll supply. On September 2, 1969, approximately 25% of the larval population was in squares. These curves support the contention that squares are important in the maintenance of the pink bollworm only during the early and late part of the season.

In both 1968 and 1969, the curves for the population in blooms were very cyclic. It would at first seem that this trend might be of value in predicting when the first generation in bolls would reach a peak since the data of both years indicate that the economic threshold coincides with this peak. Unfortunately, the larval population in blooms

FIGURE 4

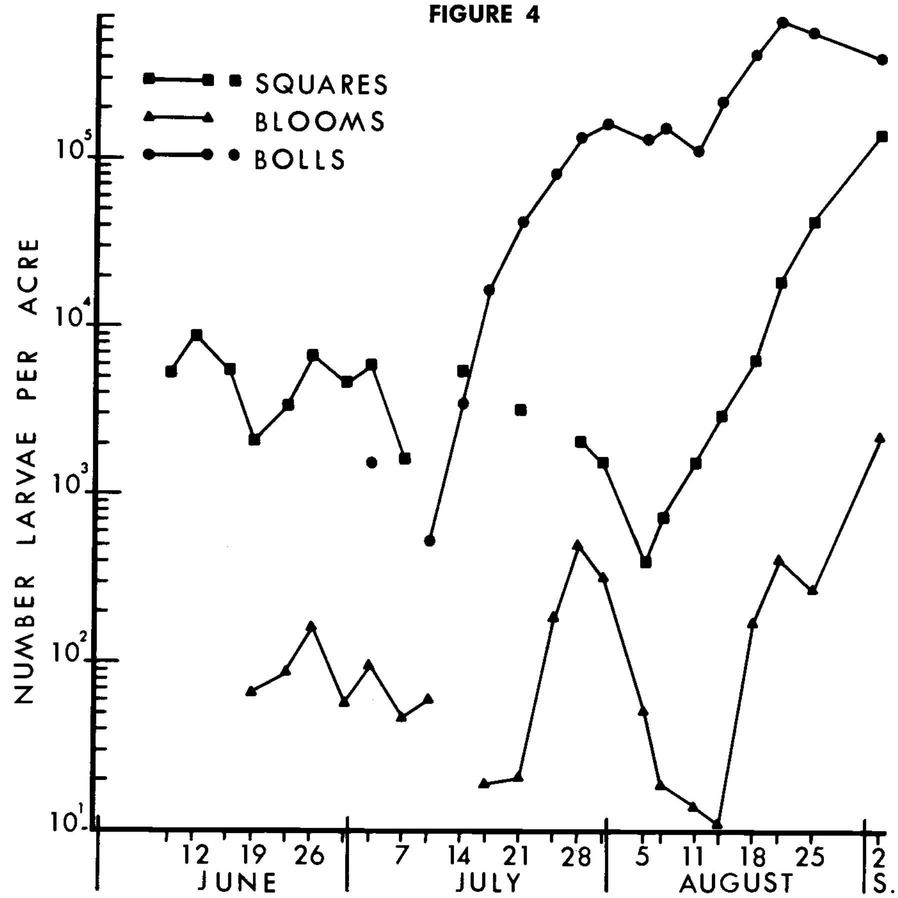

Figure 4. Population Growth of the Pink Bollworm in Squares, in Blooms, and in Bolls on the Total Cotton Plant. Mesa, Arizona. 1969.

FIGURE 5

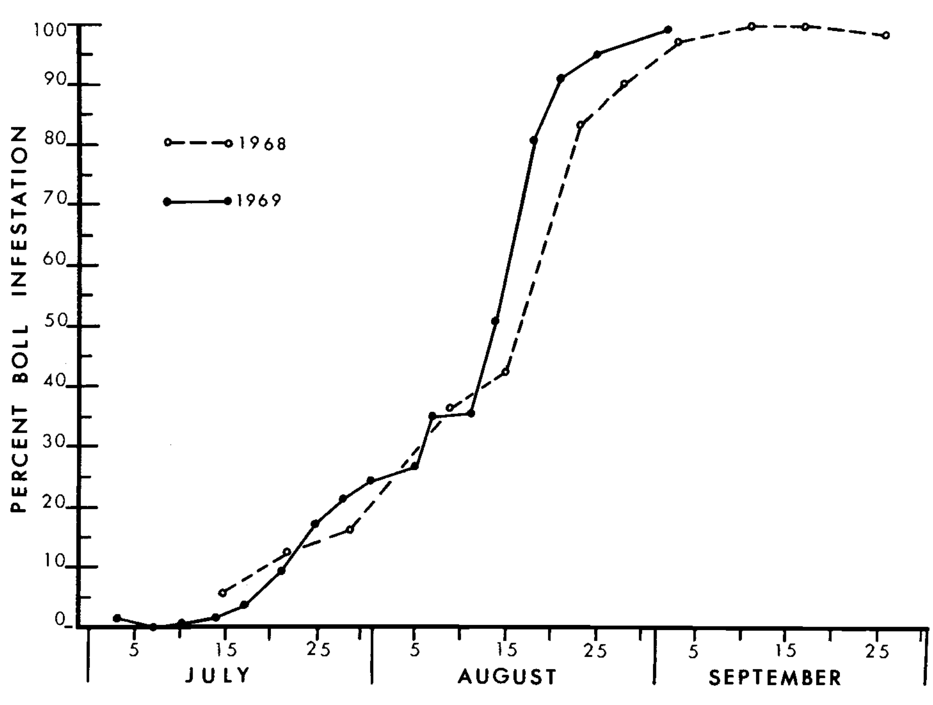

Figure 5. Population Development of the Pink Bollworm as Determined by the Adjusted Percent Boll Infestation. Mesa, Arizona. 1968, 1969.

was at a low in late July, 1968, and at a high in late July, 1969. Therefore, the monitoring of the population in blooms only seems unwise.

DISCUSSION

1968 And 1969 Compared

The percent boll infestation on the total plant in both years is compared in Figure 5. These percentages are weighted values and are not the same as those presented in Tables 10 and 23. The data for bolls examined immediately were utilized for the 1968 curve. Some of the percentages shown in Table 23 are lower than those shown for a preceding date. This problem was eliminated with the weighted percentages which always increased throughout the season. Another effect of weighting values was that the two curves were drawn closer together.

As the curves indicate, the growth rate each year on a percent boll infestation basis was nearly identical. By interpolation, the 20% level of infestation was reached on July 31 in 1968 and on July 27 in 1969. The 20% infestation level reported by Watson and Fullerton (1969) was reached during the first week in August in both years of their experiments in fields located approximately ten miles west of this population study site. In essence, data from three years and from three locations in the Phoenix, Arizona, area indicate that a 20% boll infestation in both long- and short-staple cotton is not reached until the end of July.

A 20% boll infestation was recorded by Rude and Smith (1932) during the first week in August in Mexico. Ohlendorf (1926), also working in Mexico, reported a 20% boll infestation near the end of July. Darling (1951) found a 15% boll infestation in Sudan on August 30. This level corresponded with the first population peak (larvae per acre) in bolls. Loftin et al. (1921) recorded a 20% infestation on August 2, 1918, in Mexico, but this level was not reached until August 30 in their 1919 studies. Apparently, the 1919 infestation was delayed a month because the

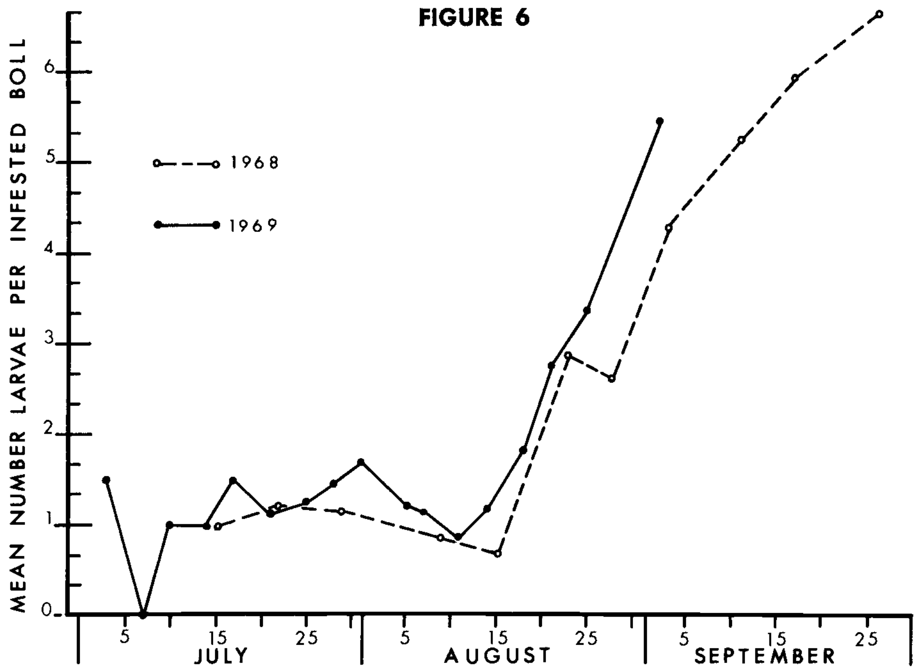

Figure 6. Population Development of the Pink Bollworm as Determined by the Adjusted Mean Number of Larvae per Infested Boll. Mesa, Arizona. 1968, 1969.

Table 16. Mean number of pink bollworm larvae per square. Mesa, Arizona. 1969.

Date	Top-half of plant		Bottom-half of plant		Total plant	
	X̄	Sx̄	X̄	Sx̄	X̄	Sx̄
June						
9	0.028	0.010	0.048	0.023	0.033	0.010
12	.048	.015	.060	.026	.051	.011
16	.020	.009	.024	.017	.021	.008
19	.004	.004	.012	.012	.006	.004
23	.000	.000	.024	.017	.006	.004
26	.004	.004	.036	.020	.012	.006
30	.012	.003	.000	.000	.009	.005
July						
3	.012	.003	.000	.000	.009	.005
7	.004	.004	.000	.000	.003	.003
10	.000	.000	.000	.000	.000	.000
14	.009	.009	.000	.000	.007	.007
17	.000	.000	.000	.000	.000	.000
21	.009	.009	.000	.000	.007	.007
25	.000	.000	-	-	.000	.000
28	.014	.010	-	-	.014	.010
31	.021	.012	-	-	.021	.012
August						
5	.007	.007	-	-	.007	.007
7	.021	.012	-	-	.021	.012
11	.042	.017	-	-	.042	.017
14	.097	.025	-	-	.097	.025
18	.118	.027	-	-	.118	.027
21	.382	.047	-	-	.382	.047
25	.424	.047	-	-	.424	.047
Sept.						
2	.694	.059	-	-	.694	.059

first boll infestation was not found until August 9. It still took a month, however, to reach the 20% level after the initial infestation. The infestations reported in Texas by Fenton and Owen (1953) took at least a month to reach the 20% level.

These data all indicate a definite time-infestation increase relationship. The relationship appears to be a 20% increase (from 0 to 20%) in the first 25 days, approximately, of boll infestation. The data reported in this paper and by Darling (1951) indicate that this level corresponds with the first population peak in bolls. Based on these data the development of a prediction equation for rate of increase of infestation would seem justified. However, the role of interaction between populations in adjacent fields is not known. A migrating population of gravid females could significantly affect the pattern of population growth exhibited by a resident population, and the only sure way to avoid a disastrous infestation is by weekly, or even more frequent, inspection. The present data do indicate that under "normal" circumstances there are about 25 days between the initial boll infestation and the economic threshold. The economic threshold may be reached at lower levels, and therefore in a shorter period, in areas where boll rot is a problem.

The 1969 curve indicates that the boll infestation begins to level-off at the end of July. This leveling trend is vaguely indicated in the 1968 curve between July 22 and 29. This characteristic suggests one clue to the approach of the first population peak in bolls. However, the infestation increases rapidly after this short stable period. A second clue to the approach of the population peak is the number of days bolls have been available. Bolls had been present for 44 days in 1968 and for 38 days in 1969. The initial appearance of exit holes or fourth instar larvae provide a third indication of the approaching end of the first generation in bolls. In 1969 the first exit holes were found on July 25 and the first fourth instar larvae on July 28. Comparable data are not available from 1968.

Table 17. Mean number of pink bollworm larvae per infested square. Mesa, Arizona. 1969.

Date	Top-half of plant		Bottom-half of plant		Total plant	
	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$
June						
9	1.000	0.000	1.000	0.000	1.000	0.000
12	1.091	.091	1.000	.000	1.063	.063
16	1.000	.000	1.000	.000	1.000	.000
19	1.000	.000	1.000	.000	1.000	.000
23	0.000	.000	1.000	.000	1.000	.000
26	1.000	.000	1.000	.000	1.000	.000
30	1.000	.000	0.000	.000	1.000	.000
July						
3	1.000	.000	.000	.000	1.000	.000
7	1.000	.000	.000	.000	1.000	.000
10	.000	.000	.000	.000	0.000	.000
14	1.000	.000	.000	.000	1.000	.000
17	.000	.000	.000	.000	.000	.000
21	1.000	.000	.000	.000	1.000	.000
25	.000	.000	-	-	.000	.000
28	1.000	.000	-	-	1.000	.000
31	1.000	.000	-	-	1.000	.000
August						
5	1.000	.000	-	-	1.000	.000
7	1.000	.000	-	-	1.000	.000
11	1.000	.000	-	-	1.000	.000
14	1.000	.000	-	-	1.000	.000
18	1.000	.000	-	-	1.000	.000
21	1.100	.052	-	-	1.100	.052
25	1.109	.050	-	-	1.109	.050
Sept.						
2	1.220	.052	-	-	1.220	.052

An infestation should be evaluated critically when any one of the above factors occurs. In 1968, the infestation level was not at the economic threshold when the slope decrease occurred or when bolls had been present for 40 days, but the population quickly surpassed the 20% level shortly thereafter. The curves for both years indicate that the infestation builds rapidly after the first population peak in bolls. Therefore, any infestation should be monitored carefully, especially one that has been present for 20 to 25 days and the possibility of a migrating population should always be kept in mind.

After a 100% infestation was reached, the percent infestation curves in Figure 5 indicate a stable population in bolls. However, the number of larvae, in bolls, per acre was actually declining after the peak in August. This was illustrated in Figures 2 and 4.

The average number of larvae per infested boll on the total plant is shown for both years in Figure 6. These are weighted values and are not the same as those presented in the total columns of Tables 12 and 24. The data for the bolls examined immediately are the ones presented for the 1968 curve. These curves further support the contention that population growth rate was the same in both years.

These curves for mean number of larvae per infested boll indicate that the population in bolls was continually increasing throughout August and September. The curves in Figures 2 and 4 show that the population was actually declining after mid-August. Therefore, percent boll infestation and mean number of larvae per infested boll ceased to be reliable indicators of population trends in bolls after mid-August.

Regression equations were developed for several segments of the population growth curves in bolls. The relationship studied was that between population density and time. Population density and corresponding Julian calendar date were transformed to logarithms. These regression equations of population density, Y, on time, X, form exponential curves of the general form (Steel and Torrie 1960):

$$Y = aX^{b} \text{ or } \log Y = a_o + b \log X$$

The Y-intercept, a_o, and slope, b, of the various growth curves in bolls are presented in Table 28. The column labelled "generations included" is for those generations occurring in bolls only and not for the season as a whole. These equations were developed to describe population change only. They are not intended to use for predictive purposes because they are suitable only for the data and year from which they were developed.

The first six equations are for population growth on the total plant. The first generation is that portion of the curve from initial boll infestation to the peak in late July, and the second generation is that portion from early August to the peak in late August. The first and second generations combined are for the total increasing population. The third generation represents the decreasing population after the peak in August. Equations 7-13 are for the population in the top half of the plant only. Generations are the same as those on the total plant.

The main importance of these equations rests in the values obtained for the slopes, or b-values. Various pairs of b's were compared by a t-test for homogeneity of regression. Comparisons made were equations 1 vs. 2, 5 vs. 6, 3 vs. 4, 7 vs. 8, 7 vs. 11, 8 vs. 11, 12 vs. 13, and 9 vs. 10. None of the slopes compared were significantly different at the .05 probability level. Hence, each pair of lines can be regarded as having a common slope. This does not necessarily imply that the two lines are the same (Steel and Torrie 1960).

The following conclusions are indicated from the results of the analyses. The population growth rate was the same for each method of boll evaluation in 1968. This applies to both the increasing and decreasing segments of the curves. Secondly, the first and second generations in bolls on the total plant in 1969 have a common slope, and these two generations increased at the same rate in the top-half bolls also.

Table 18. Number of pink bollworm larvae, in squares, per acre. Mesa, Arizona. 1969.

Date	Top-half of plant			Bottom-half of plant			Total plant		
	Popn.[a,c]	$S_{\bar{x}}$[a]	% of $\bar{X}$[b]	Popn.	$S_{\bar{x}}$	% of $\bar{X}$	Popn.	$S_{\bar{x}}$	% of $\bar{X}$
June									
9	2,913	1,969	67.58	2,539	847	33.36	5,452	2,514	46.11
12	5,647	1,106	19.59	3,326	1,832	55.08	8,973	2,759	30.74
16	3,349	1,979	59.10	2,210	2,210	100.00	5,559	4,127	74.23
19	862	862	100.00	1,250	1,250	100.00	2,112	2,112	100.00
23	0	0	0.00	3,429	2,148	62.65	3,429	2,148	62.65
26	1,341	1,341	100.00	5,395	3,091	57.30	6,736	2,637	39.14
30	4,763	2,744	57.62	0	0	0.00	4,763	2,744	57.62
July									
3	6,091	4,027	66.11	0	0	.00	6,091	3,487	57.25
7	1,666	1,666	100.00	0	0	.00	1,666	1,666	100.00
10	0	0	.00	0	0	.00	0	0	.00
14	5,585	5,585	100.00	0	0	.00	5,585	5,585	100.00
17	0	0	.00	0	0	.00	0	0	.00
21	3,482	3,482	100.00	0	0	.00	3,482	3,482	100.00
25	0	0	.00	-	-	-	0	0	.00
28	2,123	2,123	100.00	-	-	-	2,165	2,165	100.00
31	1,644	954	58.01	-	-	-	1,649	954	57.84
August									
5	399	399	100.00	-	-	-	400	400	100.00
7	749	541	72.23	-	-	-	754	552	73.23
11	1,619	831	51.35	-	-	-	1,619	831	51.35
14	3,047	1,243	40.79	-	-	-	3,047	1,243	40.78
18	6,431	1,938	30.14	-	-	-	6,569	2,069	31.50
21	18,671	5,241	28.07	-	-	-	18,940	5,474	28.90
25	41,251	9,073	22.00	-	-	-	44,226	9,683	21.89
Sept.									
2	130,647	16,685	12.77	-	-	-	141,047	15,511	11.00

[a] Mean number larvae per acre and standard error rounded to nearest whole number.

[b] Standard error expressed as a percentage of the mean population.

[c] Popn. = population.

Because sampling from the top half of the plant was initiated at about the same time each year, slope comparisons were made between years for the increasing portions of the larval population growth curves. Also, population density in the top half was low when the first samples were taken each year. The third tentative conclusion is that the populations increased on the top half of the plant at the same rate each year. No other comparisons were made between years because of insufficient data in one year or the other.

The results should be interpreted with caution, however. In some cases the coefficients of determination, R^2, shown in Table 28, are not particularly high (i.e., near 1.0). This indicates a straight line may not adequately describe the population change. Also, logarithms modify the slopes of lines and tend to diminish irregularities between a series of points; and when the logarithmic transformation is used, very large populations are required to change the slope late in the season. Thus, the use of logarithms may have masked true differences.

Larval population growth on the total plant in all fruiting structures combined is shown in Figure 7. During August and on September 3, the 1968 curve represents the population in blooms and bolls only because square samples were not taken. Except for the points on June 24 and July 8, the data for bolls examined immediately were used in the 1968 curve.

In both years, the curves indicate that the population actually declined during June. At best, the population can be said only to have fluctuated about an average density. After July 1 and July 10 in 1968 and 1969, respectively, the populations showed a definite increase, but this increase did not occur until bolls had been available for at least two weeks. The larval populations reached a peak near the end of July and then maintained this level for a short time. A second major increase occurred during the second week of August and culminated on August 23 and August 21 in 1968 and 1969, respectively.

The decrease after these August dates probably indicates that the carrying capacity of the environment — the food supply — had been exceeded. It should be recalled that the number of green bolls was declining by mid-August each year; also, the number of squares was at a minimum during mid-August. After this initial decline, the 1968 population became very stable, showing only a slight tendency to increase. The few points for 1969 indicate that a steady state was also being approached at this time.

An equilibrium density was not reached until September, three months after the initial infestation. In 1968, this equilibrium level was reached only after 100% of the bolls and 35% of the squares became infested. At this time, there were at least three squares for each available green boll.

The population growth curves appear to be of the type described by Nicholson (1954) as prompt density conditioned and where the governing requisite is accumulative. According to Nicholson, this type of curve occurs when some requisite accumulates before and during the initial phases of population growth. The growing population first exceeds the equilibrium level by utilizing the accumulation. The population then decreases to an equilibrium density because of a depletion in the requisite. Equilibrium is finally attained when the amount of the requisite used equals that generated. In the case of the pink bollworm, the governing mechanism appears to be the food supply, i.e., bolls and squares.

The data presented in Table 29 indicate the rates of increase of the larval populations and the number of days between generation peaks in 1968 and 1969. The dates, and hence population density values, chosen for 1969 were based on the peaks of the first and second larval instar counts (see Tables 19 and 27). In 1969 the sum of both instars in squares and bolls reached peaks on June 12, July 3 and 28, and August 21. These dates do not necessarily correspond with the total population peaks in Figure 7. However, population peaks in top-half squares occurred on June 12

FIGURE 7

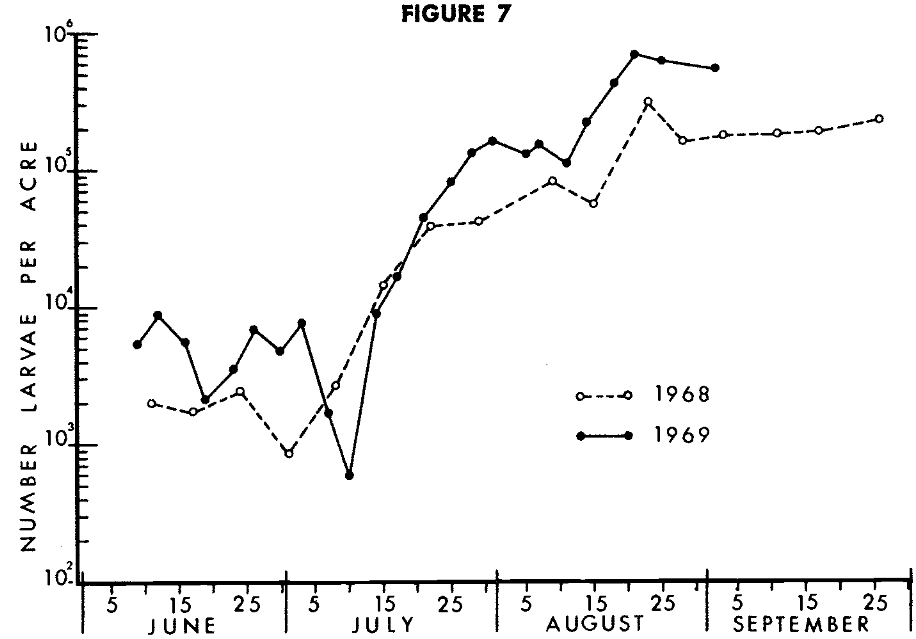

Figure 7. Population Growth of the Pink Bollworm on the Total Cotton Plant in All Fruiting Structures Combined. Mesa, Arizona. 1968, 1969.

Table 19. Mean number of each pink bollworm larval instar per square in samples representing the total cotton plant. Mesa, Arizona. 1969.

	Larval Instar							
	First		Second		Third		Fourth	
Date	$\bar{X}$	$S_{\bar{x}}$	$\bar{X}$	$S_{\bar{x}}$	$\bar{X}$	$S_{\bar{x}}$	$\bar{X}$	$S_{\bar{x}}$
June								
9	0.024	0.008	0.009	0.005	0.000	0.000	0.000	0.000
12	.036	.011	.015	.007	.000	.000	.000	.000
16	.012	.005	.009	.005	.000	.000	.000	.000
19	.003	.003	.000	.000	.003	.003	.000	.000
23	.003	.003	.000	.000	.003	.003	.000	.000
26	.006	.004	.000	.000	.006	.004	.000	.000
30	.009	.005	.000	.000	.000	.000	.000	.000
July								
3	.006	.004	.003	.003	.000	.000	.000	.000
7	.000	.000	.003	.003	.000	.000	.000	.000
10	.000	.000	.000	.000	.000	.000	.000	.000
14	.007	.007	.000	.000	.000	.000	.000	.000
17	.000	.000	.000	.000	.000	.000	.000	.000
21	.007	.007	.000	.000	.000	.000	.000	.000
25	.000	.000	.000	.000	.000	.000	.000	.000
28	.000	.000	.000	.000	.014	.010	.000	.000
31	.014	.010	.000	.000	.007	.007	.000	.000
August								
5	.007	.007	.000	.000	.000	.000	.000	.000
7	.007	.007	.000	.000	.014	.010	.000	.000
11	.021	.012	.014	.010	.007	.007	.000	.000
14	.000	.000	.076	.022	.021	.012	.000	.000
18	.035	.015	.042	.017	.035	.015	.007	.007
21	.021	.012	.299	.045	.035	.015	.028	.028
25	.118	.030	.188	.033	.118	.027	.000	.000
Sept.								
2	.472	.052	.188	.034	.035	.015	.000	.000

and July 3, and peaks in bottom-half bolls occurred on July 28 and August 21. The 1968 dates were based on population peaks in the plant-halves. Because records were not kept on the abundance of each larval instar in 1968, the dates chosen in July and August were based on population peaks in the bottom bolls. The September date was based on the peak in the top-half population in bolls. The record of June 24, 1968, is probably not an accurate indicator of the second generation peak, but it was the only choice since the population reached an obvious low by July 1. The correct population peak probably occurred between June 24 and July 1 but was undetected because of the long interval between samples. If this is the case, the generation time would be shorter with a different rate of increase than that presented in the table.

In Table 29, the generation peaks for 1968 were labelled to correspond with those of 1969, which were chosen as being more correct because larval instar counts were made. The third seasonal generation peak occurred on July 28 in 1969 and corresponded to the first generation peak in bolls. Because the population peaks in the bottom-half bolls occurred on almost the same dates each year, the peak on July 29 was chosen as the third population peak for 1968. Thus, the peak on June 24, 1968, became the second population peak. The first peak in 1968 was not detected, probably because of an extended time interval between sampling. However, the percent infestation data presented in Table 4 indicate that the initial infestation occurred sometime between June 5 and 11. Thus, the first generation peak of 1968 is presumed to have occurred sometime between June 5 and 11 and the second generation between June 24 and July 1. Therefore, the population peak on June 24 was chosen as the second generation peak and the first generation peak is considered as being missing.

The data in Table 29 for rate of increase per generation are in general agreement with those presented by Graham et al. (1965) for the Waco and Brownsville, Texas, areas, although these workers apparently labelled their generations differently. The rate of increase in their first generation corresponds to the rate between the second and third generations in Table 29. These workers also noted that the rate of increase slowed as the season progressed. In the present study, the rate of increase between the second and third generations is two to three times greater than that between the third and fourth generations. This sheds some doubt on the validity of the results obtained by the t-tests (see Table 28, especially equations 3 vs. 4 and 9 vs. 10) which indicated that the first and second larval generations in bolls shared a common slope. Tsao and Lowry (1963) reported a 15.6 fold increase in moth populations between June 25 and July 25 at Brownsville, Texas. The data of these workers were obtained from field populations confined within cages, and this is similar to the rate of increase for the corresponding dates shown in Table 29.

The generation times reported here are generally shorter than those recorded by Fenton and Owen (1953) for square and boll reared larvae. The generation times reported by Philipp and Watson (1971) were also greater than those presented in Table 29. Apparently, generation peaks on a natural population basis are shorter than those indicated by laboratory observations. This is probably due to many interacting factors which affect the daily age-specific fecundity rates in the adult population.

One of these factors is the prolonged emergence during spring and early summer of the adults from overwintering larvae. The data presented by Wene, Sheets, and Woodruff (1961) and by Watson et al. (1970) indicate that these moths emerge as late as July and August in the Phoenix, Arizona, area. Lukefahr and Griffin (1962) reported that developmental rates are different in squares and bolls and also vary with the age of the fruiting structure at the time of infestation. There are differences in the developmental rates of larvae in the same type of fruiting structure. The data recorded

Table 20. Pink bollworm population development in blooms on the total cotton plant. Mesa, Arizona. 1969.

	Blooms per plant		Percent blooms infested	
Date	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$
June				
16	0.021	0.014	-	-
19	.115	.037	2.65	1.38
23	.104	.028	3.77	1.36
26	.396	.081	1.75	0.39
30	.427	.079	0.58	.27
July				
3	.531	.069	.80	.19
7	.906	.110	.22	.06
10	1.042	.114	.25	.10
14	1.583	.205	.00	.00
17	1.635	.234	.05	.21
21	1.521	.132	.06	.21
25	1.031	.258	.78	.32
28	1.188	.288	1.81	.34
31	.708	.173	1.98	.49
August				
5	.542	.197	.42	.22
7	.125	.038	.67	.26
11	.104	.036	.62	1.25
14	.073	.032	.70	1.56
18	.083	.055	9.23	2.63
21	.156	.042	11.43	2.43
25	.094	.045	13.21	6.60
Sept.				
2	.260	.119	37.34	5.55

here indicate that population cycles in the top- and bottom-half fruiting structures are not necessarily synchronized. Phillipp and Watson (1971) reported that various population parameters of the pink bollworm vary with temperature. These workers also indicated that a greater number of eggs are laid by young pink bollworm adults. Undoubtedly, all of these factors taken together continuously modify the age structure of the adult population because they produce overlapping generations. Hence, it seems reasonable to assume that periodic but synchronized emergence of adults from several sources, and from different generations, could act to decrease the generation time at the population level. The actual proof of this probably awaits a systems analysis of population development.

The Environment

One of the interesting features of the growth curves was that the spring and early summer moth emergence from overwintering larvae in 1968 was several times greater than that in 1969 (Watson et al., unpubl. data), but the population density was generally greater throughout the season in 1969. A second point of interest was the apparent decrease in population density during June. A third point was that the population peak in August of 1969 was approximately twice that in 1968. An explanation of these features of the growth curves may rest in the various biotic and abiotic environmental factors which affect populations. Some of these factors are reviewed in the following discussion.

The Physical Environment

Only the larval population was measured during these population studies. Because of the cryptic feeding habits of the larvae, it seems likely that the physical environment has a greater impact on the egg stage, on newly hatched larvae, and on the pupal and adult stages. Since none of these other stages were measured, the following discussion is purely speculative. However, the conditions under which these studies were conducted are described.

Temperature. Brazzel and Martin (1957) reported that over 90% of the pink bollworm eggs are laid on the vegetative parts of the cotton plant before bolls are readily available. However, after bolls become available, they found that more than 20% of the eggs are laid under the calyx of the boll. They suggested that mortality may be higher in June because the young larvae must migrate in search of the fruit. Fye and Surber (1971) reported that egg survival varied with temperature and duration of exposure. They also found that high humidity partially alleviated the effects of long exposure periods to high temperatures.

Because of the ovipositional characteristics of the pink bollworm during June, many of the eggs and newly hatched larvae would be exposed to direct solar radiation, and thus to the high temperature extremes. It is therefore suggested that June temperature differences between 1968 and 1969 may partially explain the larval population differences.

The 1968 temperature records are presented in Table 30. The temperatures recorded at standard height are most likely the ones influencing eggs on exposed vegetative parts. The temperatures obtained at one-half plant height are thought to more nearly describe the microclimate below the vegetative canopy and are probably the ones influencing adult activity, especially at night.

Similar temperature data for 1969 are presented in Table 31. Average temperatures in the top- and bottom-half fruiting structures are also shown. Square temperatures are shown only for June; and only boll temperatures are presented for July, August, and September.

The June temperatures were higher in 1968 than in 1969, as indicated by the data from the instruments at standard height. In June, 1968, there were 23, 13, and 6 days that had tempera-

Table 21. Number of pink bollworm larvae, in blooms, per acre. Mesa, Arizona. 1969.

Date	Total Plant		
	Population[a]	$S_{\bar{x}}$[a]	% of $\bar{X}$[b]
June			
12	0	0	0.00
16	0	0	.00
19	68	34	49.84
23	88	30	33.94
26	164	69	41.82
30	58	56	96.55
July			
3	97	85	87.43
7	47	17	37.00
10	61	29	48.18
14	0	0	.00
17	19	19	100.00
21	21	18	83.33
25	188	62	33.13
28	504	90	17.85
31	324	61	18.72
August			
5	53	28	53.25
7	19	10	54.74
11	14	14	100.00
14	11	11	100.00
18	173	108	62.14
21	428	194	45.22
25	278	63	22.67
Sept.			
2	2,271	884	38.91

[a] Mean number larvae per acre and standard error rounded to nearest whole number.

[b] Standard error expressed as a percentage of the mean population.

tures $\geq$100°F, $\geq$ 105°F, and $\geq$ 110°F, respectively. The corresponding numbers of days in 1969 were 16, 7, and 1, respectively. In 1968 there were 21, 20, 13 and 5 days on which temperatures remained $\geq$ 100°F for two, four, six, and eight hours, respectively; in 1969, the corresponding numbers were 16, 12, 8 and 2 days, respectively. There were 10, 8 and 5 days in 1968 that had temperatures $\geq$ 105°F for two, four, and six consecutive hours. There were five, two, and one days, respectively, in 1969. Lastly, a temperature $\geq$ 110°F was maintained for at least two hours on the five consecutive days from June 18 to 22 in 1968, but this occurred on only one day, June 30, in 1969.

Loftin et al. (1921) reported that greater numbers of infested blooms are shed from the cotton plant than non-infested blooms. Hence, larvae within fallen squares and blooms would be exposed to high soil surface temperatures during June. Fye and Bonham (1970) reported that soil surface temperatures in Arizona become hot enough to cause mortality of immature boll weevils in fallen squares. Fye (1971a) has also indicated that soil surface and immediate subsurface temperatures in the early season are sufficient to cause mortality of mature pink bollworm larvae which are seeking a pupation site. The soil temperatures during June, 1968, were undoubtedly higher than those in June, 1969.

In 1969, the larval population decreased to a seasonal low on July 10. This decline may have been representative of a generation trend; however, the data represented in Table 31 show that early July was also the period of maximum temperature extremes. The population increased rapidly after July 10, indicating that the high temperatures may not have coincided with a period of maximum oviposition. Also, bolls were available at this time as ovipositional sites, and the cotton foliage was denser. These factors may have compensated for the high temperatures, thereby reducing mortality.

Philipp and Watson (1971) found that a night temperature of 90°F caused a decline in their laboratory populations. Lukefahr and Griffin (1957) reported that ovipositional activity takes place between 2:00 and 5:00 A.M. The data obtained at one-half plant height in the present study show that temperatures as high as 90°F do not generally occur between 10:00 P.M. and 8:00 A.M. Hence, night temperatures do not

Table 22. Mean number of bolls per plant. Mesa, Arizona. 1969.

	Top-half of plant		Bottom-half of plant		Total plant	
Date	$\bar{X}$	$S_{\bar{x}}$	$\bar{X}$	$S_{\bar{x}}$	$\bar{X}$	$S_{\bar{x}}$
June						
19	0.000	0.000	0.031	0.017	0.031	0.017
23	.000	.000	.115	.065	.115	.065
26	.000	.000	.396	.067	.396	.067
30	.083	.044	1.365	.279	1.448	.317
July						
3	.198	.105	2.927	.613	3.125	.707
7	.500	.113	3.917	.293	4.417	.340
10	1.732	.763	5.742	1.397	7.475	2.272
14	2.415	.950	6.087	1.081	8.502	1.939
17	5.387	.844	8.072	.424	13.460	1.026
21	6.732	.816	9.625	.479	16.357	1.051
25	8.333	.710	7.729	.442	16.062	1.146
28	9.708	1.099	8.240	.429	17.948	.706
31	10.719	.496	6.604	.330	17.323	.717
August						
5	9.844	.586	7.479	.455	17.323	.852
7	9.156	.394	7.125	.612	16.281	1.031
11	9.167	.481	6.313	.393	15.479	1.064
14	9.844	.507	6.260	.284	16.104	.620
18	8.323	.745	4.219	.759	12.542	1.495
21	7.719	.703	3.781	.514	11.500	1.218
25	6.521	.455	1.385	.433	7.906	1.058
Sept.						
2	3.021	.444	.188	.066	3.208	.443

Table 23. Percent of bolls infested by pink bollworm larvae. Mesa, Arizona. 1969.

	Top-half of plant		Bottom-half of plant		Total plant	
Date	$\bar{X}$	$S_{\bar{x}}$	$\bar{X}$	$S_{\bar{x}}$	$\bar{X}$	$S_{\bar{x}}$
July						
3	-	-	1.39	0.93	1.39	0.93
7	-	-	0.00	.00	0.00	.00
10	-	-	.30	.29	.30	.29
14	-	-	1.78	.65	1.78	.65
17	-	-	3.57	.90	3.57	.90
21	8.93	4.72	10.42	1.95	10.20	1.75
25	17.86	5.87	16.67	2.41	16.84	2.30
28	17.86	5.28	26.49	3.35	25.26	2.90
31	25.00	6.30	22.92	2.22	23.21	2.55
August						
5	24.40	2.89	30.36	6.48	25.26	2.61
7	37.20	3.82	32.14	6.91	36.48	3.59
11	35.12	3.22	37.50	7.21	35.46	3.00
14	61.61	3.16	37.50	6.62	58.16	2.96
18	88.10	2.44	67.86	6.91	85.20	3.77
21	97.32	0.74	80.36	5.36	94.90	1.03
25	98.44	.83	81.25	4.72	95.98	1.13
Sept.						
2	99.48	.52	-	-	98.48	.52

appear to be the factor responsible for the decrease in population density during June. Philipp and Watson (1971) reported that reproduction was reduced when night temperatures were below 70°F. The temperature data for one-half plant height in both Tables 30 and 31 show that the night temperatures were below 70°F until mid-July.

Apparently, the high daytime temperatures greatly increase egg and larval mortality, while low night temperatures reduce adult fecundity. These factors interact to prevent population increase during June. The June temperatures in 1968, therefore explain why a greater emerging adult population actually produced a smaller larval population than that in 1969. The June temperatures also elucidate the decline in the larval populations before bolls were readily available.

Fye and Poole (1971) attribute the rapid pink bollworm population increase later in the season to temperature modification brought about by shading in the plant canopy. According to these workers, this results in improved fecundity and egg hatch and thus allows the population to increase. The population curves in Figure 7 and the temperature data presented in Tables 30 and 31 support their conclusions.

The average temperatures within squares and bolls (Table 31) were nearly equal to the average ambient temperature at one-half plant height. This is in general agreement with that reported by Fye (1971b). He found that during the day there was little modification of square and boll temperatures by the cotton plant but that there was some modification during the night.

Humidity. The average range of relative humidity at the two hygrothermograph locations is presented in Table 32. In both locations, the humidity was lowest during the period of maximum temperature. The low point was generally reached between 2:00 and 6:00 P.M.; and a high point was reached between midnight and 6:00 A.M. The higher humidities were recorded at the one-half plant height level.

During June before the foliage becomes dense, the pink bollworm eggs are probably most affected by the humidities at standard height. The data in the table indicate that the relative humidity was lowest during June. As mentioned earlier, Fye and Surber (1971) noted that high relative humidities partially compensated for the effects of long exposure to high temperatures. These workers found that only 31% of the eggs survived when exposed to 104°F for four hours on four consecutive days at a 20% relative humidity. These humidity and even

Table 24. Mean number of pink bollworm larvae per boll. Mesa, Arizona. 1969.

Date	Top-half of plant		Bottom-half of plant		Total plant	
	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$
July						
3	-	-	0.021	0.015	0.021	0.015
7	-	-	.000	.000	.000	.000
10	-	-	.003	.003	.003	.003
14	-	-	.018	.015	.018	.015
17	-	-	.054	.017	.054	.017
21	0.107	0.049	.116	.020	.115	.018
25	.214	.066	.229	.032	.227	.029
28	.232	.076	.432	.053	.403	.047
31	.482	.135	.295	.040	.321	.039
August						
5	.321	.035	.339	.112	.324	.034
7	.551	.048	.232	.081	.505	.043
11	.461	.042	.107	.042	.411	.037
14	.848	.053	.214	.066	.760	.048
18	1.848	.080	.732	.145	1.689	.074
21	3.030	.118	1.607	.318	2.826	.113
25	3.583	.184	1.469	.320	3.281	.171
Sept.						
2	5.432	.215	-	-	5.432	.215

Table 25. Mean number of pink bollworm larvae per infested boll. Mesa, Arizona. 1969.

Date	Top-half of plant		Bottom-half of plant		Total plant	
	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$
July						
3	-	-	1.500	0.500	1.500	0.500
7	-	-	0.000	.000	0.000	.000
10	-	-	1.000	.000	1.000	.000
14	-	-	1.000	.000	1.000	.000
17	-	-	1.500	.195	1.500	.195
21	1.200	0.200	1.114	.068	1.125	.064
25	1.200	.133	1.375	.091	1.348	.082
28	1.300	.213	1.629	.136	1.596	.124
31	1.930	.305	1.285	.115	1.385	.110
August						
5	1.320	.071	1.118	.296	1.283	.077
7	1.480	.076	.722	.211	1.384	.074
11	1.314	.067	.286	.101	1.158	.066
14	1.377	.062	.571	.148	1.303	.060
18	2.098	.080	1.079	.190	1.982	.073
21	3.113	.118	2.000	.373	2.978	.114
25	3.640	.184	1.808	.364	3.419	.172
Sept.						
2	5.461	.214	-	-	5.461	.214

Table 26. Number of pink bollworm larvae, in bolls, per acre. Mesa, Arizona. 1969.

Date	Top-half of plant			Bottom-half of plant			Total plant		
	Popn.[a]	$S\bar{x}$[a]	% of $\bar{X}$[b]	Popn.	$S\bar{x}$	% of $\bar{X}$	Popn.	$S\bar{x}$	% of $\bar{X}$
July									
3	-	-	-	1,430	912	63.80	1,527	950	62.21
7	-	-	-	0	0	0.00	0	0	0.00
10	-	-	-	403	311	77.10	524	397	75.76
14	-	-	-	2,536	873	34.42	3,543	1,208	34.11
17	-	-	-	10,108	5,699	56.38	16,860	7,473	44.33
21	16,870	6,693	39.68	26,027	9,472	36.39	42,897	14,917	34.77
25	41,761	15,657	37.49	41,597	13,436	32.30	83,358	27,885	33.45
28	52,736	21,498	40.76	83,226	15,137	18.19	135,962	22,474	16.53
31	120,992	54,544	45.08	45,294	10,253	22.64	166,286	51,600	31.27
August									
5	74,135	22,132	29.85	59,496	16,867	28.35	133,631	28,635	21.43
7	117,969	30,312	25.70	38,541	6,539	16.97	156,510	23,957	15.31
11	98,580	6,669	6.76	15,523	9,109	58.68	114,103	12,849	11.26
14	195,700	15,285	7.81	28,796	4,470	15.52	224,496	16,704	7.44
18	360,068	48,765	13.54	72,346	25,024	34.59	432,414	65,710	15.20
21	546,570	23,938	4.38	142,112	65,286	45.94	688,682	89,071	12.93
25	546,499	94,707	17.33	47,473	5,371	11.31	593,972	95,708	16.11
Sept.									
2	383,712	61,851	16.12	-	-	-	407,851	59,675	14.63

[a] Mean number larvae per acre and standard error rounded to nearest whole number.

[b] Standard error expressed as a percentage of the mean population.

more extreme temperature conditions occurred during June of 1968. When the high temperatures occurred during early July of 1969, the relative humidities at one-half plant height indicate that conditions were more favorable for egg survival. The relative humidity data further support the hypothesis that the June climatic conditions had a greater suppressive effect on the population in 1968 than those in 1969.

In both years, the humidity became greater in both hygrothermograph locations in July, the period when the populations began to increase. These higher humidity conditions were maintained throughout the rest of the season. Adkisson (1959) has also reported that egg survival is greater at higher humidity levels.

Rainfall. Rainfall and wind data for the Experiment Station at Mesa, Arizona, were obtained from records published by the U.S. Department of Commerce, Environmental Data Service (1968, 1969). No precipitation occurred during June in either year or during September in 1968. In July and August of 1968 there were 1.57″ and 0.86″ of rainfall, respectively. The corresponding amounts in 1969 were 0.31″ and 1.29″, respectively. In 1969, 1.53″ of rain was recorded during September; but none occurred before September 2, the last sample date.

In both years all rainfall during July and August occurred before the populations peaked in late August. During these two months, measurable amounts of rain fell on 13 days in 1968 but on only five days in 1969.

Again, these data indicate that during the month of June there is a severe climatic stress placed upon the populations. Population growth in both years coincided with the summer rainy season.

Wind. There was more wind movement in 1969 than in 1968. The total wind movement, in miles, during June, July, August, and September of 1968 was 401, 610, 502, and 272 miles, respectively. In 1969, the corresponding totals were 1160, 1466, 1600, and 1149 miles, respectively. A zero wind movement was recorded on some days each month in 1968, but wind was recorded on all days during the 1969 study.

The 1969 population curve in Figure 7 indicates that the population decreased from August 7 to 11. High winds occurred on the evening of August 7 and 0.49″ of rain fell on August 8. As a result the cotton became badly lodged and the plants in the study field were flattened toward the west. The severity of this storm in the vicinity of the field was also indicated by a palm tree within 200 yards of the study field which was decrowned by a lightning strike. The meteorological events appear to have caused the reduced population on August 11. Whether the reduction was caused by mortality of the exposed stages or dispersal of the adults is unknown. Other than the event just described, the higher winds in 1969 did not appear to have any other adverse effects on the populations. However, the rate of increase between the third and fourth population peaks in 1969 was less than that in 1968 (see Table 29). Perhaps the

Table 27. Mean number of each pink bollworm larval instar per boll in samples representing the total cotton plant. Mesa, Arizona. 1969.

	Larval Instar									
	First		Second		Third		Fourth		Exit Holes	
Date	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$	$\bar{X}$	$S\bar{x}$
July										
3	0.000	0.000	0.021	0.015	0.000	0.000	0.000	0.000	0.000	0.000
7	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
10	.000	.000	.003	.000	.000	.000	.000	.000	.000	.000
14	.009	.004	.009	.004	.000	.000	.000	.000	.000	.000
17	.024	.009	.024	.010	.006	.005	.000	.000	.000	.000
21	.051	.013	.061	.013	.003	.000	.000	.000	.000	.000
25	.082	.015	.110	.019	.036	.009	.000	.000	.003	.000
28	.110	.018	.186	.038	.089	.016	.020	.007	.010	.004
31	.077	.017	.128	.023	.064	.014	.054	.013	.054	.015
August										
5	.087	.015	.128	.020	.061	.015	.046	.016	.041	.014
7	.087	.017	.171	.023	.120	.018	.128	.024	.102	.024
11	.153	.022	.130	.020	.092	.016	.036	.010	.115	.022
14	.265	.032	.270	.028	.107	.017	.115	.017	.247	.034
18	.564	.044	.633	.052	.293	.030	.191	.026	.309	.041
21	.768	.062	1.179	.070	.566	.046	.311	.034	.319	.044
25	.701	.079	1.045	.077	.701	.048	.835	.060	.804	.063
Sept.										
2	.412	.043	2.104	.163	1.771	.117	1.099	.092	.974	.108

greater wind movement in August, 1969, caused, or aided, a greater percentage of the moths to disperse from the field, thus acting to retard the rate of increase.

The Biotic Environment

Very little information was obtained on any of the biotic agents which may have affected the pink bollworm populations. Only the food supply was measured in detail, as required to estimate population density.

Predators. Sweep net samples were not taken at any time in 1968, and they were taken only between June 23 and July 28 in 1969. Sampling was discontinued after July 28 because the cotton became lodged, making sweeping very difficult.

The most abundant predators were **Geocoris** spp. and **Orius** spp.; an average of 11.5 and 15.1 individuals, respectively, were found per 100 sweeps during the period that samples were taken. Other predators found were coccinellids (mostly **Hippodamia convergens** Guerlin-Meneville), reduviids, **Collops** spp., **Chrysopa** spp., and **Nabis** spp.; the average numbers of these predators per 100 sweeps were 1.8, 2.1, 0.8, 4.0, and 2.1, respectively.

Orphanides, Gonzalez, and Bartlett (1971) indicate that several of the predator groups mentioned above may be important natural enemies of the pink bollworm. Lindsey (1970) conducted a predation study in the field used for this population study in 1969. He observed an **Orius** nymph and a lacewing larva feeding on pink bollworm eggs located under the calyses of bolls.

Food. The equilibrium density for the 1968 population was 2 x 10^5 larvae per acre (see Figure 7). The 1969 population apparently was approaching the 5 x 10^5 level. One explanation for this difference in density is that the population during June was greater in 1969 and would therefore produce a larger subsequent population, assuming all other factors were equal. The data in Table 29 indicate that the rates of increase were nearly the same each year.

A second factor that may have influenced the final population equilibrium level was the difference in the fruiting patterns. The number of bolls per plant in 1969 reached and maintained a plateau from late July through mid-August. The total boll supply did not show a definite decreasing trend until August 18, 1969; whereas in 1968, the number of available green bolls steadily declined after August 9. This prolonged availability of bolls in 1969, possibly a varietal characteristic, may have permitted a higher equilibrium density. Gause (1931) found that the population size of **Tribolium confusum** duVal varied exponentially with the amount of food supplied. He also found that the length of the growth period increased with an increased food supply. The latter was not the case in the data reported here; the 1968 and 1969 populations reached their maximum values on almost the same date in August.

An attempt to correlate population density with food supply did not seem justified in this study. Because the food supply was used in the calculation of

Table 28. Regression equations[a] for various segments of the pink bollworm population growth curves in bolls. Mesa, Arizona. 1968, 1969.

Equation[b] Number	Intercept[a] a_o	Slope[a] b	Generations[c] Included	R^2	Sample Dates[d] Included
1	-28.03141	14.04088	1st & 2nd	.824	1968[A]: 7/15 - 8/23
2	-30.94916	15.33941	1st & 2nd	.706	1968[B]: 7/8 - 8/23
3	-114.25125	51.45614	1st	.889	1969 : 7/10 - 7/31
4	-79.80568	36.16666	2nd	.903	1969 : 8/11 - 8/21
5	15.68360	-4.34854	3rd	.496	1968[A]: 8/23 - 9/26
6	31.70433	-11.12863	3rd	.700	1968[B]: 8/23 - 9/26
7	-56.00933	25.82850	1st & 2nd	.886	1968[A]: 7/15 - 8/23
8	-36.55304	17.62853	1st & 2nd	.942	1968[B]: 7/15 - 8/23
9	-71.05974	32.68965	1st	.834	1969 : 7/21 - 7/31
10	-53.07649	24.80769	2nd	.803	1969 : 8/7 - 8/21
11	-42.38307	20.27906	1st & 2nd	.893	1969 : 7/21 - 8/21
12	18.12462	-5.39419	3rd	.623	1968[A]: 8/23 - 9/26
13	32.96877	-11.68464	3rd	.774	1968[B]: 8/23 - 9/26

[a] Equations are of the form: $\log Y = a_o + b \log X$, where Y = population density and X = Julian calendar date.

[b] Equations 1-6 are for the total plant; Equations 7-13 are for the top-half of the plant.

[c] The populations were increasing in the 1st and 2nd generations, decreasing in the 3rd generation.

[d] 1968[A] = bolls examined immediately; 1968[B] = bolls held three weeks.

Table 29. Comparative parameters of pink bollworm populations at various times during the growing season. Mesa, Arizona. 1968, 1969.

Date	Peak of Generation	Population Primarily in	Larvae per Acre	Rate of Increase	Time Between Generations
1968					
6/24	2	Squares	2,465		
				17.25X	35 days
7/29	3	Bolls	42,530		
				7.33X	25 days
8/23	4	Bolls	311,786		
				0.75X	34 days
9/26	5	Bolls	232,464		
1969					
6/12	1	Squares	8,973		
				0.86X	21 days
7/3	2	Squares	7,714		
				17.97X	25 days
7/28	3	Bolls	138,631		
				5.11X	24 days
8/21	4	Bolls	708,050		

population density, the two would appear to be correlated. This difficulty could be overcome by altering the sampling procedure to secure separate and independent estimates of density and food supply. This could be accomplished by making the population estimates on a plant basis rather than on a fruiting structure basis.

Table 30. Temperature (^{o}F) records. Mesa, Arizona. 1968.

Sample Date	Dates Included for $\bar{X}$ Temps.	Standard Height[a]			One-Half Plant Height[b]		
		$\bar{X}$	$\bar{X}$ High	$\bar{X}$ Low	$\bar{X}$	$\bar{X}$ High	$\bar{X}$ Low
June							
5	6/1 - 6/4	85.0	104.4	66.0			
11	6/5 - 6/10	72.8	87.4	59.8			
17	6/12 - 6/16	82.2	103.6	60.9	80.7	101.8	58.2
24	6/17 - 6/23	88.9	110.7	66.3	84.7	103.8	63.7
July							
1	6/24 - 6/30	85.0	103.4	68.3	82.0	99.0	64.0
8	7/1 - 7/7	83.2	98.0	70.8	80.4	93.3	69.4
15	7/8 - 7/14	88.6	104.0	72.1	81.6	96.0	68.0
22	7/15 - 7/21	87.6	102.4	74.3	83.2	94.8	71.8
29	7/22 - 7/28	83.2	97.0	73.6	80.5	91.6	72.1
August							
9	7/29 - 8/8	82.9	95.9	72.2	82.5	94.4	72.4
15	8/9 - 8/14	80.9	94.2	71.3	80.4	93.7	70.7
23	8/15 - 8/22	79.3	92.9	64.4	78.7	94.5	63.0
28	8/23 - 8/27	80.9	95.8	64.8	80.9	96.8	66.0
September							
3	8/28 - 9/2	84.2	97.3	72.2	83.8	99.2	70.8
11	9/3 - 9/10	84.6	99.6	70.0	82.2	101.4	67.0
17	9/11 - 9/16	81.7	95.8	68.0	80.8	96.2	66.5
26	9/17 - 9/25	75.0	93.1	56.8	73.5	95.6	54.6

[a] Hygrothermograph maintained at standard height, 5' above ground.

[b] Hygrothermograph maintained at one-half plant height, which varied with plant growth.

SUMMARY

Population growth studies of the pink bollworm, **Pectinophora gossypiella** (Saunders), were conducted at Mesa, Arizona, during the 1968 and 1969 cotton growing seasons. Populations developed in the same manner each year apparently as follows. Moths produced from overwintering larvae established a larval population in squares by the second week of June. Some of these larvae completed their development, and a second larval generation was initiated in squares before bolls were readily available. A peak in this second generation apparently occurred between the last week in June and the first week of July. Therefore, by the end of June, oviposition was occurring from moths produced from both overwintering and current-season larvae. During June when squares were the only food source for the larvae, the populations showed a slight tendency to decrease. Larval populations began to increase rapidly only after bolls had been available for at least two weeks. This increasing phase began about the first week in July and continued until late August. A third generation peak occurred, principally in bolls, near the end of July. The economic threshold, 20% boll infestation, was not reached until this third population peak. Indications are that it requires 20 to 25 days after the initial infestation in bolls to attain this threshold level. A fourth population peak occurred after the third week of August. After this peak, the population declined to an equilibrium density in September, which occurred only after 100% of the available green bolls became infested. A fifth population peak occurred in late September. The population in squares contributed significantly to the total picture only during June and September.

Five generations were produced between the first of June and the end of September. Cotton in the Phoenix, Arizona, area (where this work was done) is not generally harvested until the end of the year. Based on these observations it is likely that up to seven or eight generations can be completed during the growing season in this area. However, because of the onset of diapause in the fall months, each succeeding generation peak after August would probably be smaller than the preceding one.

The only major difference between the 1968 and 1969 populations was in the actual number of larvae per acre. The 1968 population was smaller throughout the season, even though it had a greater initial potential due to a

Table 31. Temperature (^{o}F) records. Mesa, Arizona. 1969.

Sample Date	Dates included for $\bar{X}$ temps.	Standard height[a]			One-half plant height[b]			Fruiting structure[c]	
		$\bar{X}$	$\bar{X}$ high	$\bar{X}$ low	$\bar{X}$	$\bar{X}$ high	$\bar{X}$ low	top-½	bottom-½
June									
9	6/1 - 6/8	85.6	102.3	66.1					
12	6/10 - 6/11	78.0	90.0	61.5	72.0	85.0	56.0		
16	6/12 - 6/15	81.2	95.5	65.0	74.4	88.0	59.5		
19	6/16 - 6/18	81.7	97.7	65.3	74.2	89.3	58.0	71.7[d]	71.4[d]
23	6/19 - 6/22	85.1	103.5	66.3	74.2	91.0	57.0	74.3	73.0
26	6/23 - 6/25	84.4	100.7	68.0	74.6	89.3	59.7	76.2[d]	74.2[d]
30	6/26 - 6/29	85.8	103.5	66.5	73.4	89.2	59.0		
July									
3	6/30 - 7/2	94.5	112.7	73.7	77.9	93.3	63.3		
7	7/3 - 7/6	94.6	110.5	76.8	76.9	90.2	66.0		
10	7/7 - 7/9	87.5	104.0	70.0	73.5	86.0	60.3		
14	7/10 - 7/13	93.0	105.3	80.3	80.0[e]	91.0	71.0		79.3
17	7/14 - 7/16	92.6	106.0	79.7	79.1[e]	90.7	70.3	80.7	78.6
21	7/17 - 7/20	88.4	99.8	78.3	80.8[e]	96.2	71.8	80.6	78.8
25	7/21 - 7/24	92.3	105.0	78.5	82.9[e]	100.0	70.8	82.4	80.7
28	7/25 - 7/27	89.6	101.0	79,3	79.7[e]	94.7	71.0	80.8	78.6
31	7/28 - 7/30	95.0	108.3	83.7	83.0	98.3	72.0	83.3	79.8
August									
5	7/31 - 8/4	97.4	113.0	85.8	86.5	97.8	77.6	86.1	82.4
7	8/5 - 8/6	99.2	110.5	85.0	86.4	98.5	75.0	84.4	81.6
11	8/7 - 8/10	90.8	104.8	77.3	84.1[d]	97.0	73.0	84.8[d]	80.9[d]
14	8/11 - 8/13	91.0	104.7	79.7	83.7	95.3	74.3	80.1	79.3
18	8/14 - 8/17	89.3	102.5	76.8	81.6	93.0	71.5	80.1	79.1
21	8/18 - 8/20	92.0	106.0	78.3	82.6	96.0	70.7	79.6	77.8
25	8/21 - 8/24	92.8	106.8	81.8	84.6	95.8	75.0	81.2	82.1
Sept.									
2	8/25 - 9/1	91.1	103.9	80.1	83.2	96.2	73.2	82.7	81.5

[a] Hygrothermograph maintained at standard height.

[b] Hygrothermograph maintained at one-half plant height.

[c] Square temperatures in June, boll temperatures in July, August, and September.

[d] Means based on one 24-hour period.

[e] Temperatures obtained from thermocouple, hygrothermograph inoperative.

higher level of spring moth emergence. Temperature conditions during June, 1968, were shown to be more severe than those during June, 1969; and it is therefore hypothesized that the 1968 conditions had a greater detrimental impact on population density. Also, the greater boll supply in 1969 may have allowed the maintenance of a higher population density.

Increases in population density were inhibited twice during each growing season. Stagnant populations in June are thought to be the result of adverse temperature and humidity conditions, aspects of the physical environment. The initial decline in population density in August, followed by the attainment of stability in September, is thought to be conditioned by an insufficient food supply, a biotic factor. Apparently the population overran the supply of available bolls in late August, mainly because the bolls were maturing and the actual number of green bolls was declining. This initially caused a decline in population density. Population pressure at this time resulted in the more complete utilization of the available squares, and the population began to increase in this food source. The decline in population density in bolls was therefore offset by the increased population in squares. The net effect was an equilibrium density.

The limiting environmental factors apparently do not last long enough in the early season or occur early enough later in the season to prevent economic losses. Some bolls escaped infestation because they matured at about the time the economic threshold was reached, and total crop destruction did not occur. However, unchecked populations, as observed in this study, cause severe economic losses.

Table 32. Average range of percent relative humidity. Mesa, Arizona. 1968, 1969.

	Standard Height[a]				One-Half Plant Height[b]			
	1968		1969		1968		1969	
Month	$\bar{X}$ High	$\bar{X}$ Low	$\bar{X}$ High	$\bar{X}$ Low	$\bar{X}$ High	$\bar{X}$ Low	$\bar{X}$ High	$\bar{X}$ Low
June	63	22	75	27	93	24	97	35
July	79	26	82	32	99	46	99	48
August	80	27	85	31	99	41	94	39
September	66	24	90	29	97	32	96	36

[a] Hygrothermograph maintained at standard height, 5' above ground.

[b] Hygrothermograph maintained at one-half plant height, which varied with plant growth.

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