INTRAPLANT DISTRIBUTION OF THE BOLLWORM, *HELIOTHIS ZEA* (BODDIE), EGGS, LARVAE, AND PREDATORS ON COTTON

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CHAPTER I

INTRODUCTION

The bollworm, Heliothis zea (Boddie), and tobacco budworm, Heliothis virescens (F.), are major pests of several crops grown in the United States. The bollworm has several common names, depending upon its host. On cotton, Gossypium hirsutum L., it is the "bollworm"; on corn, Zea mays L., it is generally known as "corn earworm"; on tomato, Lycoperscion esculentum L., the tomato "fruitworm"; and on tobacco, Nicotiana tabaccum L., the "false budworm." The bollworm has been recognized as a serious pest of cotton since at least 1820 (Parencia, 1978). These two species of insects are considered serious pests of cotton in Oklahoma (Robinson et al., 1982; Young and Price, 1975). While frequently found together, the bollworm is the more common species, especially in the early season. The bollworm is found in southwestern Oklahoma primarily on cotton, on sorghum, Sorghum bicolor (L) Moench, and on alfalfa, Medicago sativa L. (Young and Price, 1975).

The life history of the bollworm on cotton has been studied by Quaintance and Brues (1905), Bishopp (1929), Isely (1935), Lincoln et al. (1967), and Parencia (1978). The bollworm is holometabolous, and only the larval stage is destructive. This insect produces four to six generations each year between the spring and early fall. The last generation progresses to the pupal stage and overwinters in the soil.

According to Boyer et al. (1962), Lincoln et al. (1967), and Phillips et al. (1979), a common belief was that bollworm moths oviposited mainly on cotton terminals and this "fact" influenced the scouting practices. However, a review of the literature showed that no uniform pattern of egg distribution on the plant existed. Parsons (1940) and Beeden (1974) showed that the leaves were the most preferred oviposition site by the related species, *Heliothis armigera* Hubner. Similar results were found by Wilson et al. (1980) with the bollworm. However, Matthews and Tunstall (1968) and Tunstall et al. (1966) reported that the largest percentage of eggs of *H. armigera* were located on the stems of the cotton plant. Mistric (1964) and Quaintance and Brues (1905) found that more eggs were laid on fruiting structures. Studies on the vertical distribution of eggs within plants show that most are laid on the upper plant parts (Boyer et al., 1962; Gonzalez et al., 1967; Beeden, 1974; Wilson et al., 1980; Ramalho et al., 1984; Farrar and Bradley, 1985b).

Farrar and Bradley (1985a) concluded that *Heliothis* spp. eggs are often laid on cotton plant parts (such as leaves) which have traditionally not been checked by cotton insect scouts. This practice has often resulted in a large percentage of the eggs being overlooked. Mistric (1964) pointed out that there it is unrealistic to expect to detect the minute larvae of *Heliothis* spp. on plant terminals. He noted that larvae which develop on terminals may migrate to other plant parts. Eggs and larvae occur on parts of the plant other than terminals.

Ramalho et al. (1984) found 56% of the first instars of the tobacco budworm in the upper third of the plant canopy and 32% in the middle third. Second and third instars were found on squares during early season and on bolls later in the season. They concluded that the distribution of tobacco budworm larvae within the cotton plant is a function of instar and stage of development of the plant.

Farrar and Bradley (1985a) found no significant differences in survival of bollworm larvae that hatched on small fruits, terminals, or leaves of the cotton plant. They concluded that the site where eggs are laid on the plant is not important because, after hatching, all larvae move to suitable feeding sites. They found that the number of budworms on flowers was significantly lower than the numbers on other plant parts. They concluded that budworms do not prefer flowers to the same extent as do bollworms.

The objectives of this study were to:

1. Study the relationships among bollworm eggs, larvae, and predators within the cotton plant.
2. Study the vertical distribution of bollworm eggs and larvae within the cotton plant.
3. Determine the oviposition and feeding preferences of the bollworm on cotton leaves, squares, flowers, bolls, and main stem terminals.
4. Determine the effect of cotton plant leaves, squares, flowers, bolls, and main stem terminals on larval development and survival.

CHAPTER II

LITERATURE REVIEW

Little basic information is available on the distribution of *Heliothis* spp. eggs and larvae within the cotton, *Gossypium hirsutum* L., plant. According to Farrar and Bradley (1985b), only one such study had been conducted on the bollworm, *Heliothis zea* (Boddie), in the cotton growing areas of the southeastern United States prior to their study, and important changes had occurred since that time in cotton pest management systems.

"Bollworm eggs are shining waxy white, faintly tinged with yellow. Width is around 0.48 mm, height 0.50 mm. The form is almost dome shaped. The base is flat and apex obtusely rounded. The sculpture is rough and consists of 14 primary ribs which converge toward the apex. The shell is rather tough, and although the eggs are quite delicate, they are not easily crushed" (Quaintance and Brues, 1905). When first hatched, the larva is about 1 mm in length. In general, newly hatched larvae do not immediately search for food, but consume the chorion of the egg. They then begin searching for other food, particularly tender tissues of the cotton plant. Small larvae are quite mobile on the cotton plant, but when a square is located, feeding begins (Quaintance and Brues, 1905; Bishopp, 1929).

Overwintering studies on the bollworm conducted by Young and Price (1975) in southwestern Oklahoma, showed that adult emergence starts around May 15, while trap capture of adults begins on approximately May 10. They reported that alfalfa (Medicago sativa L.) fields were the most likely sites for overwintering. According to Vargas (1984), bollworm adults captured by pheromone traps in Perkins and Stillwater, Oklahoma, started no earlier than mid-March and no later than mid-April. High captures were made from mid-July to mid-August with a peak in mid-August. Spring emergence of the bollworm started the third week of May. The latest emergence, in an alfalfa field, occurred in the third week of June. Vargas (1984) showed that migration of adults occurred at least 30 days before the emergence of the overwintered populations. Lopez et al. (1984) found synchrony between spring emergence of male budworms, Heliothis virescens (F.), and their capture in pheromone traps, and demonstrated the feasibility of using pheromone traps to monitor overwintering emergence.

The bollworm requires approximately 815 to 910 degree-days above a developmental threshold of 54°F to complete a life cycle. The important generations economically are those which occur in July and August. Relative to cotton, the most susceptible period is during peak squaring, and the major period of susceptibility in terms of degree-days is between 1200 and 1800 (Young et al., 1983).

Greenhouse and field cage studies by Johnson et al. (1975) showed that the bloom period is the most favorable stage for oviposition by bollworms on cotton plants. They detected a positive correlation between plant maturity and ovipositional preference. Essentially the same results were found by Wilson et al. (1980).

Ramalho et al. (1984) reported that most tobacco budworm eggs were deposited on the upper one-half of the cotton plant canopy. Oviposition on leaves was greater than on squares, bolls, meristems, and flowers throughout the season. Presence of eggs on cotton leaves was negatively correlated with plant height, diameter of canopy, number of nodes, and number of flowers and bolls. Eggs on squares were correlated with number of squares and flowers. Eggs laid on bolls were correlated with plant height, diameter of canopy, number of nodes, squares, flowers and bolls, and eggs laid on squares. Similar results were reported by Bernhardt and Phillips (1982).

According to Farrar and Bradley (1984), small cotton bolls with drying corollas adhering to them suffered more damage from *Heliothis* spp. than did those without corollas. They called the drying corollas "bloomtags." The structures apparently provide a highly favorable microhabitat for the development of small larvae. Boyer et al. (1962), Lincoln et al. (1967), and Phillips et al. (1979) emphasized the importance of drying corollas on small cotton bolls, which in common scouting practice are generally not considered. They stated that between 25 and 50% of small bolls had bloomtags and that this usually occurred more frequently during very dry weather when the corolla desiccated before abscission, or during very wet weather, when it rotted. They concluded that the presence of bloomtags on small bolls increased the probability that bolls would be damaged by *Heliothis* spp. larvae.

Smaller larvae usually are found on squares and terminals, while larger ones are on bolls (Quaintance and Brues, 1905; Wilson et al., 1980; Ramalho et al., 1984; Farrar and Bradley, 1985b). Studies by

Reese et al. (1981) showed that more than 50% of the bollworm damage occurred on squares less than 6 mm in diameter. Burkett et al. (1983), studying the behavior of H. zea on tomato, Lycopersicon esculentum L., found that first instar larvae on flowers fed for at least four days. As feeding declined on flowers, it increased on leaves and on fruits. They concluded that larvae tend to feed initially on the plant part where they were placed. Lincoln et al. (1967) showed that each bollworm larva can damage an average of 3.8 squares and 2.2 bolls.

Nadgauda and Pitre (1983) found that larvae and pupae of tobacco budworm on soybean, Glycine max (L.) Merr., usually weighed less when reared at 20°C than at 25 or 30°C. Temperature had more effect than diet on the longevity of female and male larvae.

Lincoln et al. (1967) stated that all stages of the bollworm are attacked by many species of predators from several insect orders as well as spiders. Predators of bollworm eggs can be divided into those that pierce vs. those that bite into them. Important egg-piercing predators are the insidous flower bug, Orious spp.; the big-eyed bug, Geogoris spp.; and the damsel bug, Nabis spp. Among the egg-chewing predators, the most important are the larvae of the green lacewing, Chrysopa spp., and several species of ants, including native fire ants, Solenopsis spp. The majority of spiders observed feeding on bollworm eggs were jumping spiders, usually belonging to one of two species, Metaphidippus galathea Walchenaer or Habronathus coronatus Hentz. Bell and Whitcomb (1962) concluded that lady beetle larvae were the most important predator of bollworm eggs, consuming over two-thirds of them, followed by ants, the convergent lady beetle, spotted lady beetle adults, and the jumping spider. However, Whitcomb (1967) found that ants removed 48% of the bollworm eggs in the field and green lacewing larvae ranked a distant second with 4%. McDaniel and Sterling (1982) found the sack spider, Chiracanthium inclusum Hentz, and three species of lady beetles consumed 14.2 and 7.3%, respectively, during 24 hours.

Lincoln et al. (1967) found ants to be highly efficient predators of small larvae. Species mentioned were Pheidole., the little black ant, Menomorium minimum Buckley, and native fire ants. The convergent lady beetle, Hippodamia convergens Guerin-Meneville, appeared to feed only on first instars. However, the spotted lady beetle, Coleomegilla maculata DeGeer, destroyed first and second instars, but tended to ignore the third instar. The nine-spotted lady beetle, Coccinella novemnotata Herbst, and the soft-winged flower beetles, Collops balteatus LeConte and Collops quadrimaculatus (F.), fed freely on small bollworm larvae. Four species of damsel bugs were found to be good predators of first and second instar larvae. Assassin bugs, Zelus spp. and Sinea spp., destroyed many young bollworm larvae. Big-eyed bugs and insidious flower bugs fed on newly-hatched bollworm larvae. More than a dozen species of spiders were highly efficient predators of young bollworm larvae.

Quaintance and Brues (1905) reported that more than 98% of bollworm eggs hatched when they were protected from weather, predators, and parasites. However, results in field experiments by Fletcher and Thomas (1943), Bell and Whitcomb (1962), Whitcomb and Bell (1964), and Lingren et al. (1968) indicated that only a small percentage of the eggs developed into late instars. They deduced that several arthropod predators were responsible for reducing the populations of bollworm eggs and larvae. Lingren et al. (1968) estimated, from artificial release of Geocoris punctipes adults and Chrysopa larvae, a reduction of 88 and 99% of budworm eggs and larvae, respectively.

Cosper et al. (1983) found that during early season G. punctipes, H. convergens, and C. maculata were primarily located on cotton plant terminals. However, when fruiting structures were present, these species were found between the bud and the bracts. As the season progressed, many predators were detected lower within the plant canopy.

Young and Wilson (1984), using models to predict the relationship between predators and the damage caused by the bollworm and budworm on cotton, found a high correlation (r^2 = 0.99) between percent of occupancy by two predators, the convergent lady beetle and soft-flower beetle, and damage reduction from the two pests. They concluded that, if one or more of the two predators were present in an area of 0198 m2, damage by Heliothis spp. did not occur in southwestern Oklahoma. The above predators were assumed to be distributed independently of the bollworm-budworm infestation. Thus, if a plant were infested with Heliothis spp. eggs or larvae, it had no greater probability of having a predator than any other plant.

CHAPTER III

RELATIONSHIPS AMONG EGGS, LARVAE AND PREDATORS OF THE BOLLWORM, HELIOTHIS ZEA (BODDIE) (LEPIDOPTERA: NOCTUIDAE), WITHIN THE COTTON PLANT

Introduction

The bollworm, *Heliothis zea* (Boddie), is a pest widely distributed throughout the world. It has been recognized as a serious cotton (*Gossypium hirsutum* L.) pest in the United States since at least 1820 (Parencia, 1978). The bollworm and tobacco budworm, *Heliothis virescens* (F.), are considered serious pests of cotton in Oklahoma (Robinson et al., 1982; Young and Price, 1975). While the two insects are frequently found together, the bollworm is the more common species, especially in the early season. In southwestern Oklahoma, the bollworm is found primarily on cotton, on sorghum, *Sorghum bicolor* (L) Moench, and on alfalfa, *Medicago Sativa* L. (Young and Price, 1975).

The life history of the bollworm on cotton has been studied by Quaintance and Brues (1905), Bishopp (1929), Isely (1935), Lincoln et al. (1967), and Parencia (1978). It usually produces four to six generations each year between spring and early fall. The last generation progresses to the pupal stage and overwinters in the soil. Young and Price (1975) showed that the first adult bollworm emerges from overwintering in southwestern Oklahoma around May 15, and the first adult captured in a light trap occurs approximately on May 10. They reported alfalfa fields to be the most lively sites for overwintering. According to Vargas (1984), first adult captures by pheromone traps in Perkins and Stillwater, Oklahoma, occur no earlier than mid-March and no later than mid-April. High capture rates were obtained from mid-July to mid-August with a peak in mid-August. Spring emergence of the bollworm started in the third week of May.

Distribution of Heliothis spp. eggs within the cotton plant showed great variation from year to year (Farrar and Bradley, 1985b). Leaves were the most common oviposition site observed in 1980 and 1981. In 1982, eggs were laid equally on leaves and terminals; and in 1983, plant terminals were the most common oviposition site. Other authors reported that cotton plant terminals were the preferred oviposition site by bollworm moths (Boyer et al., 1962; Fye, 1972; Hillhouse and Pitre, 1976; Wilson et al., 1980).

The phenological stage and morphological characteristics of the cotton plant have a great effect on oviposition stimulus for the bollworm. Johnson et al. (1975) found that the blooming period had more eggs than any other growth stage of cotton. Lukefahr and Martin (1974) emphasized the importance of glabrous cotton strains in the reduction of oviposition by the bollworm.

Quaintance and Brues (1905) reported that usually the neonate bollworm larvae do not search for food immediately after egg hatching but it consumes the egg-chorion. Identical behavior was reported by Reed (1965) with Heliothis armigera Hubner. Wilson et al. (1980) showed that the first and second instars preferred flowers. Farrar and Bradley (1985b) found that small larvae were most commonly found on squares and terminals during a three-year study, but in another year they were more commonly found on bolls.

Quaintance and Brues (1905) reported that more than 98% of bollworm eggs laid hatched when protected from weather, predators, and parasites. However, results in field experiments by Fletcher and Thomas (1943), Bell and Whitcomb (1962), Whitcomb and Bell (1964), and Lingren et al. (1968) indicated that only a small percentage of the population developed into eggs to late-instar larvae. They deduced that several arthropod predators were responsible for reducing the population of bollworm eggs and larvae. Lingren et al. (1968) estimated a reduction of 88 and 99% of bollworm eggs and larvae, respectively, from artificial release of Geocoris punctipes (Say) adults and Chrysopa larvae. Bell and Whitcomb (1962) concluded that lady beetle larvae were the most important predators on bollworm eggs, consuming over two-thirds of them, followed by ants, the convergent lady beetle, spotted lady beetle adults, and jumping spiders. However, Whitcomb (1967) found that ants removed 48% of the bollworm eggs in the field and green lacewing larvae ranked a distant second with 4%. MacDaniel and Sterling (1982) found the sack spider, Chiracanthium inclusum Hentz, and three species of lady beetles consumed 14.2 and 7.3%, respectively, during 24 hours.

Cosper et al. (1983) found that during the early season Geocoris punctipes, Hippodamia convergens Guerin-Meneville, and Coleomegilla maculata DeGeer were primarily located on cotton plant terminals. However, when fruiting structures were present, those species were found between the buds and the bracts. As the season progressed, many predators were detected lower in the plant.

Young and Willson (1984), using models to predict the relationship between predators and the amount of damage caused by the bollworm and budworm on cotton, found a high correlation ($r^2 = 0.99$) between percent of occupancy of two predators, the convergent lady beetle and soft-flower beetle, and damage reduction from the two cotton pests. They concluded that if one of the two predators was present in an area of 0.98 m2, damage by *Heliothis* spp. did not occur. The two above predators were assumed to be distributed independently of the bollworm-budworm infestation. Thus, if a plant were infested with *Heliothis* spp. eggs or larvae, it had no greater probability of having a predator than any other plant.

The objective of this research was to study the relationships among bollworm eggs, larvae, and predators within the cotton plant.

Materials and Methods

These experiments were conducted at the Agronomy Research Station near Perkins, Oklahoma, from 1986 through 1988 on a Teller Loam soil with medium granular structure. In 1986, the commercial cotton cultivar, "Stoneville 112," was planted in an area approximately 5,500 m^2 on May 23. In 1987 and 1988, the cotton cultivar was changed to an earlier cultivar, "Tamcot CAMD-E." In 1987, the general area was divided into three smaller areas of about 1,833 m^2 each. Each small area was planted with the cultivar, "Tamcot CAMD-E," on three different dates, i.e., May 7, May 15, and June 2. In 1988, "Tamcot CAMD-E" was planted on May 11. The cotton was planted on 0.92 m row apart with approximately 15 cm between single plants. During the three-year period, the study area was not sprayed with insecticides, nor was supplemental irrigation used. To assure the presence of a population of bollworm eggs and larvae in the plots, 50 female and 50 male adult moths were randomly released every week in the field in 1987 and 1988. These moths were fed on a sugar solution for 24 hours in cages where they were allowed to mate. Bollworm eggs, larvae, and moths had been primarily collected from sweet corn, Zea mays L., near Stillwater, Oklahoma. The insects were reared in the laboratory and fed on the special diet described by Burton (1969, 1970). The rearing container was a 30 mL plastic cup. In each cup was put the diet and larva. It was then covered with a paper lid. Trays containing cups were placed in a growth chamber with a temperature of 26 ± 2°C, a relative humidity of 65 ± 5%, and photoperiod of 14 day:10 night hours.

In 1986, sampling was initiated on July 7 when the plants had squares approximately 0.5 cm in diameter. The area was sampled on alternate days. Each sample consisted of 10 consecutive plants counted in a row, and 10 samples were randomly selected in the area in each sampling day. Bollworm eggs, bollworm larvae, and seven predators were recorded on plant parts such as leaves, squares, and open flowers, bolls with and without "bloomtags" and main stem terminals.

In 1987 and 1988, the cotton plant was divided into four sections: terminal, upper, middle, and lower. In the last three plant divisions, bollworm eggs, larvae, and predators were counted on leaves, squares, flowers, and bolls. In these two years, the main stem terminal was considered as a plant division, not as a plant part as in 1986. Flowers included those with white flowers or red petals.

Each plant was checked for bollworm eggs, bollworm larvae, and seven predators (lady beetle larvae and adults, minute pirate bugs, soft-winged flower beetles, lacewing larvae, big-eyed bugs, assassin bugs, and various species of spiders).

In 1987, sampling was initiated for the first plant date on July 12 when the plants had squares. Sampling on planting dates two and three were started on July 22 and July 28, respectively. Each sample was a randomly selected plant. Every day, 20 plants were randomly checked from each of the three planting dates. In 1988, sampling was initiated on July 6. Plants were checked three times per week. Each time, 20 plants were randomly checked for bollworm eggs, bollworm larvae, and predators.

Chi-square tests were performed to determine if there were statistically significant relationships among numbers of eggs, larvae, and predators on different plant parts. The chi-square values were calculated according to the SAS User's Guide (1985). Significant values suggest rejection of the null hypothesis of independent occurrence. Graphs and tables were constructed to show the distribution and frequencies of observed vs. expected values of bollworm eggs, larvae, and predators on cotton throughout the season.

Results and Discussion

The numbers of bollworm eggs, larvae, and predators found within the cotton plant "Stoneville 112" in 1986 are shown in Table I. The population of bollworm eggs and larvae was low and variable during the season of 1986. The predator population was not high, but remained almost constant throughout the season, except for two peaks (35 and

TABLE I

NUMBERS OF BOLLWORM EGGS, LARVAE, AND PREDATORS ON "STONEVILLE 112" COTTON IN 1986

Sampling Date	No. Egg	No. Larva	No. Predator
07/07	6	0	21
07/09	2	1	22
07/11	1	5	22
07/14	2	1	27
07/16	0	0	19
07/18	3	1	29
07/21	1	2	28
07/23	2	1	35
07/25	6	0	20
07/29	1	1	29
08/06	1	1	28
08/13	1	1	47
08/18	0	0	24

47) on July 23 and August 13, respectively. All samples resulted in 26 eggs, 14 larvae, and 351 predators. The proportions of predators found in 1986 in different plant parts, compared to the total number on the whole plant, were 15% on leaves, 18% on bolls, 26% on terminals, and 40% on squares, white flowers, and red flowers. This high percent on squares was mainly found during the blooming period, after July 18. Predators on bolls were recorded when there were bolls available, i.e., on July 23 (Table II). This high percent of predators on the main stem terminals agreed with the findings of Farrar and Bradley (1985b).

Lady beetle larvae and adults, various species of spiders, Collops spp., and minute pirate bugs were the most abundant predators throughout the season of 1986. These four groups represented 94% of the total arthropod predators recorded in the field. About 50% of lady beetles were located on squares and leaves, while minute pirate bugs were located primarily on squares and terminals. Big-eyed bugs, lacewings, and assassin bugs were much less abundant than those groups previously mentioned. Spiders occurred predominantly on terminals and almost equally on squares, bolls, and leaves (Figure 1).

In 1987, bollworm eggs, larvae, and predators were recorded within "Tamcot CAMD-E," planted in three different dates. The first planting date (05/07/87) had data from July 12 to August 14 (Table III). The numbers of eggs and larvae per 20 plants were variable throughout the season with a peak of 30 eggs and 14 larvae on July 24-25. The concentration of eggs and larvae coincided with the blooming period from July 20 to August 2. The numbers of predators were also quite variable during the season. The second planting date (05/15/87)

TABLE II

DISTRIBUTION OF PREDATORS ON "STONE-
VILLE 112" COTTON IN 1986

Sampling Date	Leaf	Squares	Boll	Terminal
07/07	1	10	--	10
07/09	5	3	--	14
07/11	5	9	--	8
07/14	10	6	--	11
07/16	4	7	--	8
07/18	3	20	--	6
07/21	3	19	--	6
07/23	4	16	6	9
07/25	5	7	3	5
07/29	4	13	6	6
08/26	5	10	7	6
08/13	9	12	23	3
08/18	4	2	18	0

Figure 1. Population of lady beetles, soft-winged flower beetles, spiders, minute pirate bugs, big-eyed bugs, lacewings, and assassin bugs on cotton plant parts in 1986.

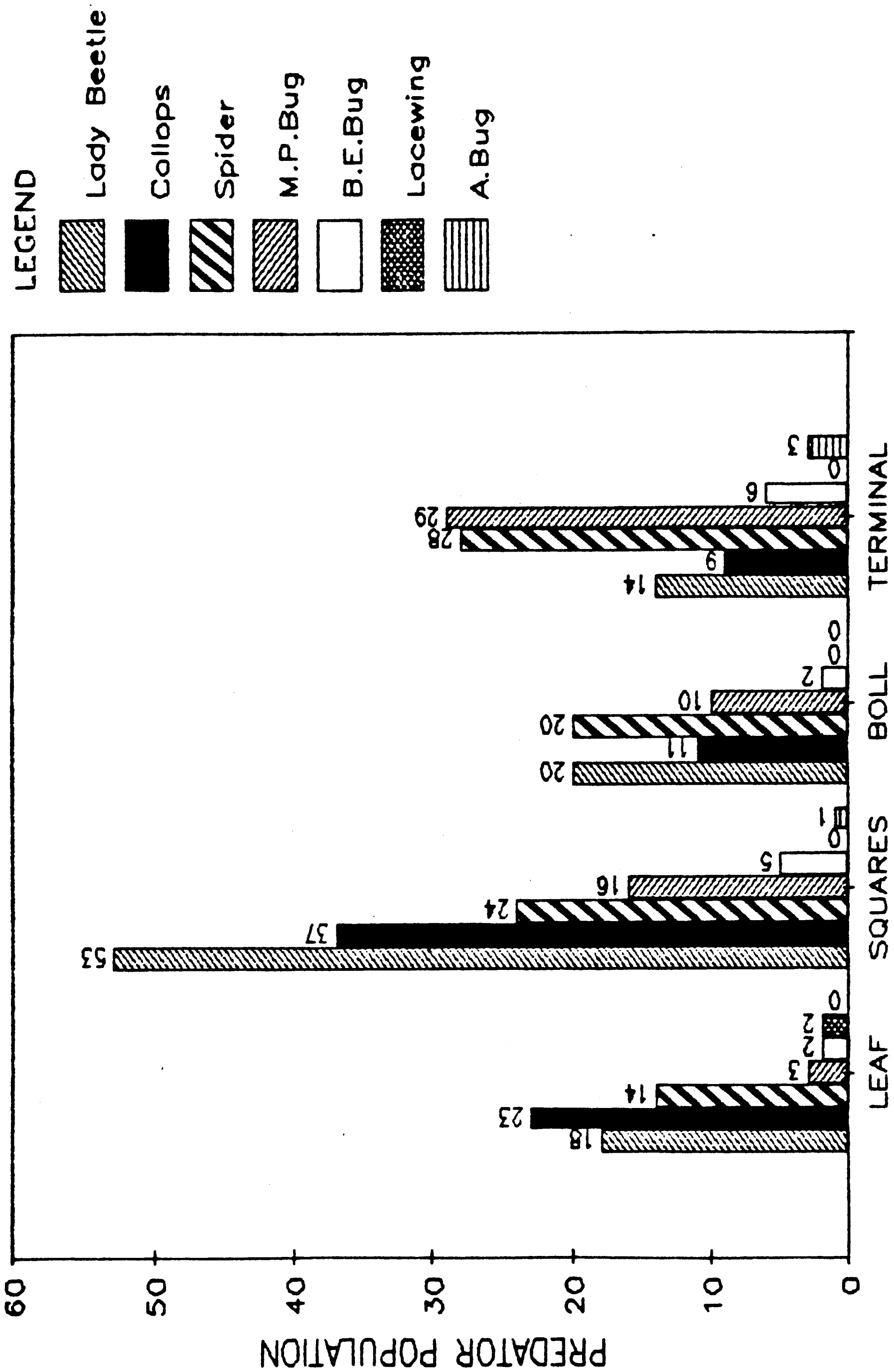

LEGEND
Lady Beetle
Callops
Spider
M.P.Bug
B.E.Bug
Lacewing
A.Bug
PREDATOR POPULATION
0
10
20
30
40
50
60
LEAF
SQUARES
BOLL
TERMINAL
18
23
14
3
2
2
0
53
37
24
16
5
0
1
20
11
20
10
2
0
0
14
9
28
29
6
0
3

TABLE III

NUMBERS OF BOLLWORM EGGS, LARVAE, AND PREDATORS ON COTTON DURING 1987

Sampling Date	Planting Date I 5/7			Planting Date II 5/15			Planting Date III 6/2		
	Egg	Larv.	Pred.	Egg	Larv.	Pred.	Egg	Larv.	Pred.
07/12-13	4	0	9						
07/14-15	3	0	9						
07/16-17	4	0	10						
07/18-19	18	1	20						
07/20-21	8	8	15						
07/22-23	11	11	19	8	5	5			
07/24-25	30	14	11	13	6	7			
07/26-27	18	8	11	7	8	9			
07/28-29	16	9	20	7	3	13	8	6	23
07/30-31	12	7	23	4	3	15	5	2	10
08/01-02	11	5	21	6	5	14	9	3	7
08/03-04	9	6	16	5	4	21	12	3	13
08/05-06	5	1	21	3	2	24	5	2	16
08/07-08	0	2	19	0	3	27	7	5	16
08/09-10	0	1	14	1	0	19	8	4	16
08/11-12	1	3	13	3	3	17	13	2	19
08/13-14	0	1	19	3	4	18	11	4	19
08/15-16				2	3	17	5	1	23
08/17-18				2	4	22	8	4	22
08/19-20				2	6	17	3	2	18
08/21-22				0	2	22	9	5	15
08/23-24				0	3	14	8	4	15
08/27-28							8	3	14
09/01-02							8	4	14
09/04-05							5	6	14

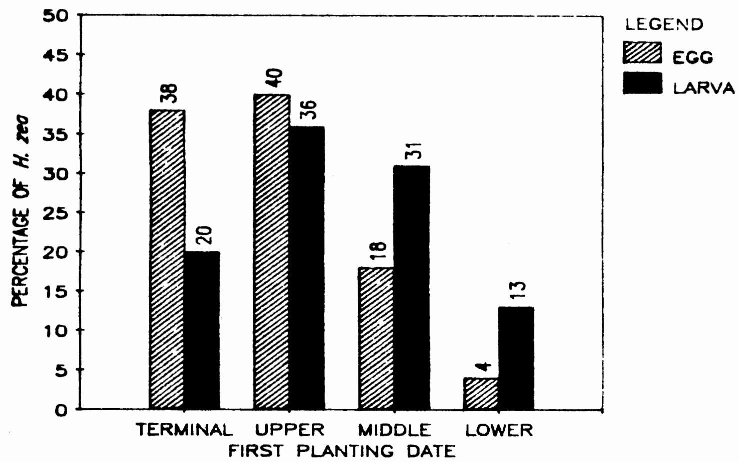
*Each sampling date represents 20 plants.

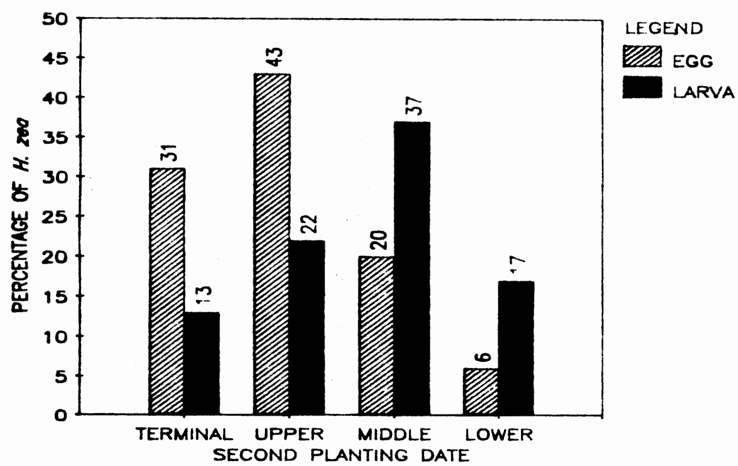
shows data from July 22-23 to August 23-24. This period had a peak of 13 eggs and 8 larvae on July 24-25 and July 26-27, respectively. Similar results were obtained from the third planting date (06/02/87) which was sampled from July 28-29 to September 4-5. Distributions of bollworm eggs, bollworm larvae, and predators were variable during the growing seasons for the three planting dates.

Intraplant distributions of bollworm eggs within the four plant divisions (terminal, upper, middle, and lower) are shown in Figure 2. In three planting dates, the proportions of eggs found on the terminal were 38, 31, and 45%, respectively, while on the upper of the plant were 40, 43, and 43% for the first, second, and third planting dates, respectively. However, these proportions were much lower on the middle than on the lower for the first, second, and third planting dates, respectively. If terminal and upper fourth of the plant were considered as a plant division together, there would be an average concentration of 80% of the total eggs for each planting period. These results agreed with the most recent literature on the distribution of budworm eggs on cotton. However, since the results presented here are focused specifically on the bollworm and its relationship with predators, additional inferences can be drawn from these studies.

The data presented here show high proportions of eggs on the terminal which were comparable to the proportions found on the upper of the plant. Chi-square tests showed significant relationships among eggs on the terminal and eggs on the upper of the plant with eggs on the rest of the plant (Tables IV and V). This suggests that terminals can be used when a plant is sampled for eggs. These results do not disagree with the assumption that sampling for eggs has to be done on

Figure 2. Percentages of *H. zea* eggs and larvae on main stem terminals, upper, middle, and lower parts of cotton during first, second, and third planting dates in 1987.


PERCENTAGE OF H. zea
50
45
40
35
30
25
20
15
10
5
0
38
20
40
36
18
31
4
13
TERMINAL
UPPER
MIDDLE
LOWER
FIRST PLANTING DATE
LEGEND
EGG
LARVA


PERCENTAGE OF H. zea
50
45
40
35
30
25
20
15
10
5
0
31
13
43
22
20
37
6
17
TERMINAL
UPPER
MIDDLE
LOWER
SECOND PLANTING DATE
LEGEND
EGG
LARVA

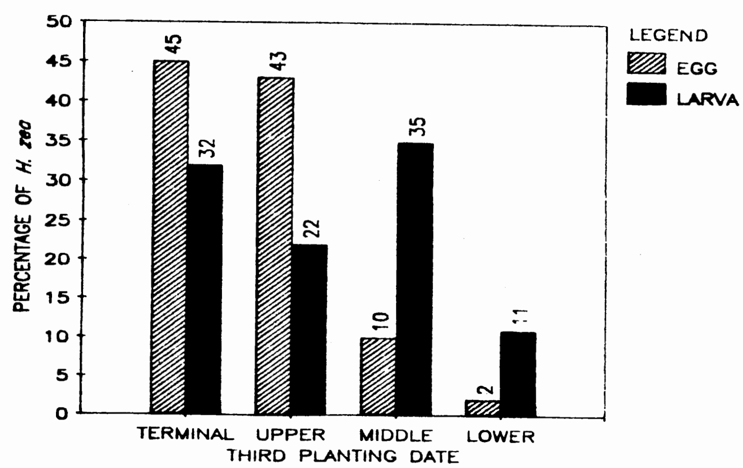

PERCENTAGE OF H. zea
50
45
40
35
30
25
20
15
10
5
0
45
32
43
22
10
35
2
11
TERMINAL
UPPER
MIDDLE
LOWER
THIRD PLANTING DATE
LEGEND
EGG
LARVA

TABLE IV

CHI-SQUARE TESTS OF INDEPENDENCE OF TOTAL BOLLWORM EGGS ON MAIN STEM TERMINAL AND TOTAL NUMBER OF EGGS ON REST OF PLANT IN THREE PLANTING DATES IN 1987

Pair Comparison		Planting Date 05/07/87	05/15/87	06/02/87
(0 0)	OBS.	66.4**	81.5**	66.8**
	EXP.	64.9	80.6	68.7
(0 1)	OBS.	9.6	5.6	15.8
	EXP.	11.1	6.6	13.9
(1 0)	OBS.	15.5	8.9	13.0
	EXP.	13.2	9.8	11.5
(1 1)	OBS.	3.5	1.7	0.8
	EXP.	2.7	0.8	2.3
(2 0)	OBS.	3.6	2.1	3.4
	EXP.	4.4	2.0	3.0
(2 1)	OBS.	1.4	0.2	0.2
	EXP.	0.7	0.2	0.6
Chi Square		6.763	6.577	9.206
$P < 0.05$		0.034	0.037	0.010

*First number represents total number of eggs on the plant; second number represents total number of eggs on terminal.

**Percent of 500 plants.

TABLE V

CHI-SQUARE TESTS OF INDEPENDENCE OF TOTAL BOLLWORM EGGS ON UPPER FOURTH OF PLANT AND TOTAL NUMBER OF EGGS ON REST OF PLANT IN THREE PLANTING DATES IN 1987

Pair Comparison		Planting Date 05/07/87	05/15/87	06/02/87
(0 0)	OBS.	76.0**	87.2**	82.6**
	EXP.	64.0	79.1	71.5
(0 1)	OBS.	9.3	3.6	4.0
	EXP.	20.5	11.6	15.1
(1 0)	OBS.	0.0	0.0	0.0
	EXP.	11.2	8.1	11.1
(1 1)	OBS.	14.7	9.2	13.4
	EXP.	3.5	1.2	2.3
Chi Square		300.800	366.826	367.271
$P < 0.05$		0.0	0.0	0.0

*First number represents total number of eggs on the upper fourth; second number represents total number of eggs on rest of the plant.

**Percent of 500 plants.

the basis of a vertical distribution within the plant. In this case, sampling for eggs on the upper plant, terminal and upper are much safer due to higher concentration of eggs on these parts.

Larval distributions on different plant divisions are also shown in Figure 2. The percentages of larvae on terminals were 20, 13, and 32 in the first, second, and third planting dates, respectively. On the upper, 36, 33, and 22% for the three planting dates. On the middle, 31, 37, and 35%. If terminal and upper part were combined as a whole plant division, the proportions of larvae would be 67, 70, and 56% for the first, second, and third planting dates, respectively. Chi-square tests showed no significant relationships among larvae on the terminals and larvae on the rest of the plant for two planting dates. However, larvae on the upper and larvae on the rest of the plant showed significant relationships (Tables VI and VII). These data support the results found with Heliothis spp. by Mistric (1964), Ramalho et al. (1984), and Farrar and Bradley (1985a, 1985b). The results presented here strongly suggest that sampling for bollworm larvae should be made using the terminal and the upper part of the plant together as a sampling site, or in case of a more accurate sampling procedure, using terminal, upper, and middle of the plant.

In relation to the distribution of eggs and larvae on different plant parts (Figure 3), leaves were the most preferred place for egg deposition in all three planting dates. This was followed by squares, flowers, and bolls. Larvae were more commonly found on squares, 34, 45, and 64% in the three periods. Larvae numbers on bolls ranked second, followed by those on flowers and leaves. These data suggested

TABLE VI

CHI-SQUARE TESTS OF INDEPENDENCE OF TOTAL BOLLWORM LARVAE ON TERMINAL AND TOTAL NUMBER OF LARVAE ON REST OF PLANT IN THREE PLANTING DATES IN 1987

Pair Comparison		Planting Date 05/07/87	05/15/87	06/02/87
(0 0)	OBS.	74.5**	81.1**	83.2**
	EXP.	72.8	81.4	83.2
(0 1)	OBS.	4.5	2.5	3.6
	EXP.	6.3	2.2	3.7
(1 0)	OBS.	17.5	16.2	12.6
	EXP.	19.2	16.0	12.6
(1 1)	OBS.	3.5	0.2	0.6
	EXP.	1.7	0.4	0.5
Chi Square		94.222	0.901	0.023
P < 0.05		0.0	0.342	0.881

*First number represents total number of larvae on upper fourth; second number represents total number of larvae on rest of the plant.

**Percent of 500 plants.

TABLE VII

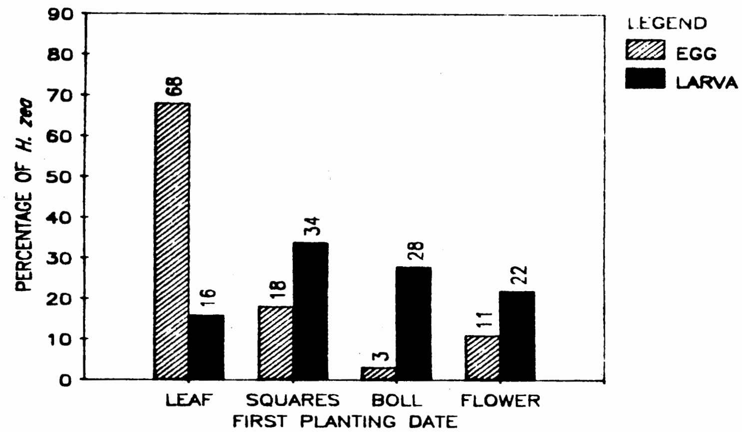
CHI-SQUARE TESTS OF INDEPENDENCE OF TOTAL BOLLWORM LARVAE ON UPPER FOURTH OF PLANT AND TOTAL NUMBER OF LARVAE ON REST OF PLANT IN THREE PLANTING DATES IN 1987

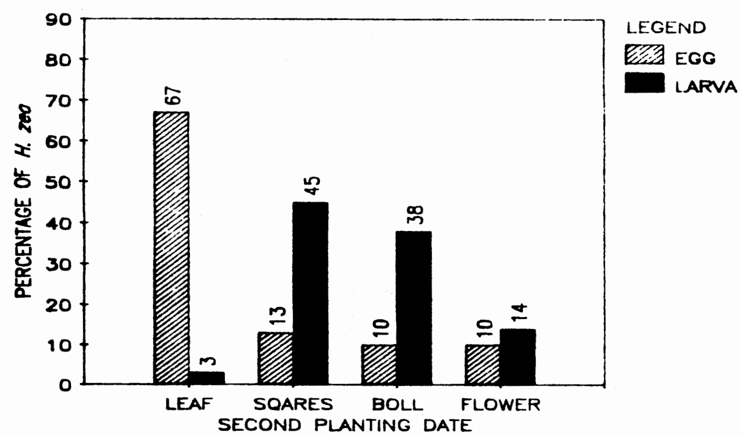
Pair Comparison		Planting Date 05/07/87	05/15/87	06/02/87
(0 0)	OBS.	79.1**	83.6**	86.8**
	EXP.	71.2	78.2	83.5
(0 1)	OBS.	10.91	10.0	9.4
	EXP.	18.8	15.4	12.7
(1 0)	OBS.	0.0	0.0	0
	EXP.	7.9	5.4	3.3
(1 1)	OBS.	10.0	6.4	3.8
	EXP.	2.1	1.0	0.5
Chi Square		231.159	184.994	129.875
P < 0.05		0.0	0.0	0.0

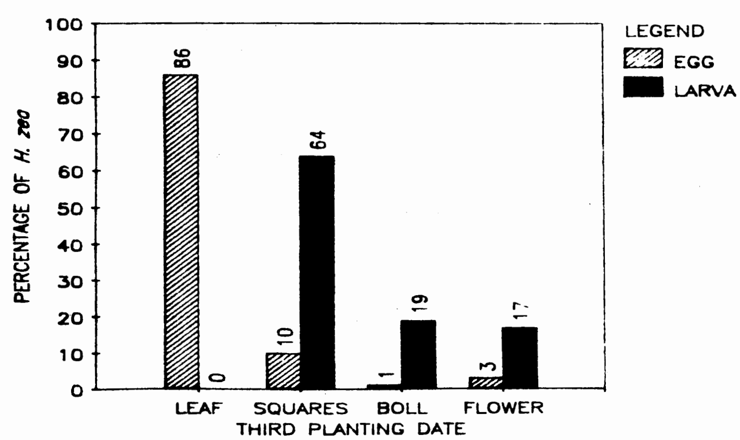
*First number represents total number of larvae on upper fourth; second number represents total number of larvae on rest of the plant.

**Percent of 500 plants.

Figure 3. Percentages of *H. zea* eggs and larvae on leaves, squares, bolls, and flowers of cotton during first, second, and third planting dates in 1987.


90
80
70
60
50
40
30
20
10
0
PERCENTAGE OF H. zea
68
16
18
34
3
28
11
22
LEAF
SQUARES
BOLL
FLOWER
FIRST PLANTING DATE
LEGEND
EGG
LARVA


90
80
70
60
50
40
30
20
10
0
PERCENTAGE OF H. zea
67
3
13
45
10
38
10
14
LEAF
SQARES
BOLL
FLOWER
SECOND PLANTING DATE
LEGEND
EGG
LARVA


100
90
80
70
60
50
40
30
20
10
0
PERCENTAGE OF H. zea
86
0
10
64
1
19
3
17
LEAF
SQUARES
BOLL
FLOWER
THIRD PLANTING DATE
LEGEND
EGG
LARVA

that even though the largest proportions of eggs were laid on terminals and leaves, only small percentages of small larvae stayed on these parts. Intraplant movement probably accounted for the small number of larvae found on places such as leaves and terminals which are not favorable feeding places for long time periods.

The populations of predators in the first, second, and third planting dates were 270, 274, and 281. The numbers of bollworm eggs in the first and third periods were 150 and 132, respectively. The second planting date had only 60 eggs. The number of larvae during three periods showed little variation (Figure 4). The occurrence of predators on all planting dates showed that lady beetles and spiders were the most numerous predators throughout the season in all three planting dates. Minute pirate bugs and Collops occupied the third and fourth places. The total numbers of lady beetles of three planting dates were 76, 77, and 86. Spiders ranked second with 85, 78, and 73. Minute pirate bugs in the first planting date, and Collops in second and third planting dates were 46, 50, and 45, respectively (Figure 5). The population of lady beetles and soft flower beetles in the three-year study may have provided effective protection against bollworm damage. This assumption is based on the findings by Young and Willson (1984).

The numbers of predators within cotton plant parts and terminals in three planting dates throughout the season of 1987 showed that the four plant parts and terminals in all three planting dates had a great variation in number of predators per sampling date. However, leaves and squares had the highest number of predators. The distribution of predators on each plant part showed that spiders were the most

Figure 4. Population of bollworm eggs, larvae, and predators on cotton in three planting dates in 1987.

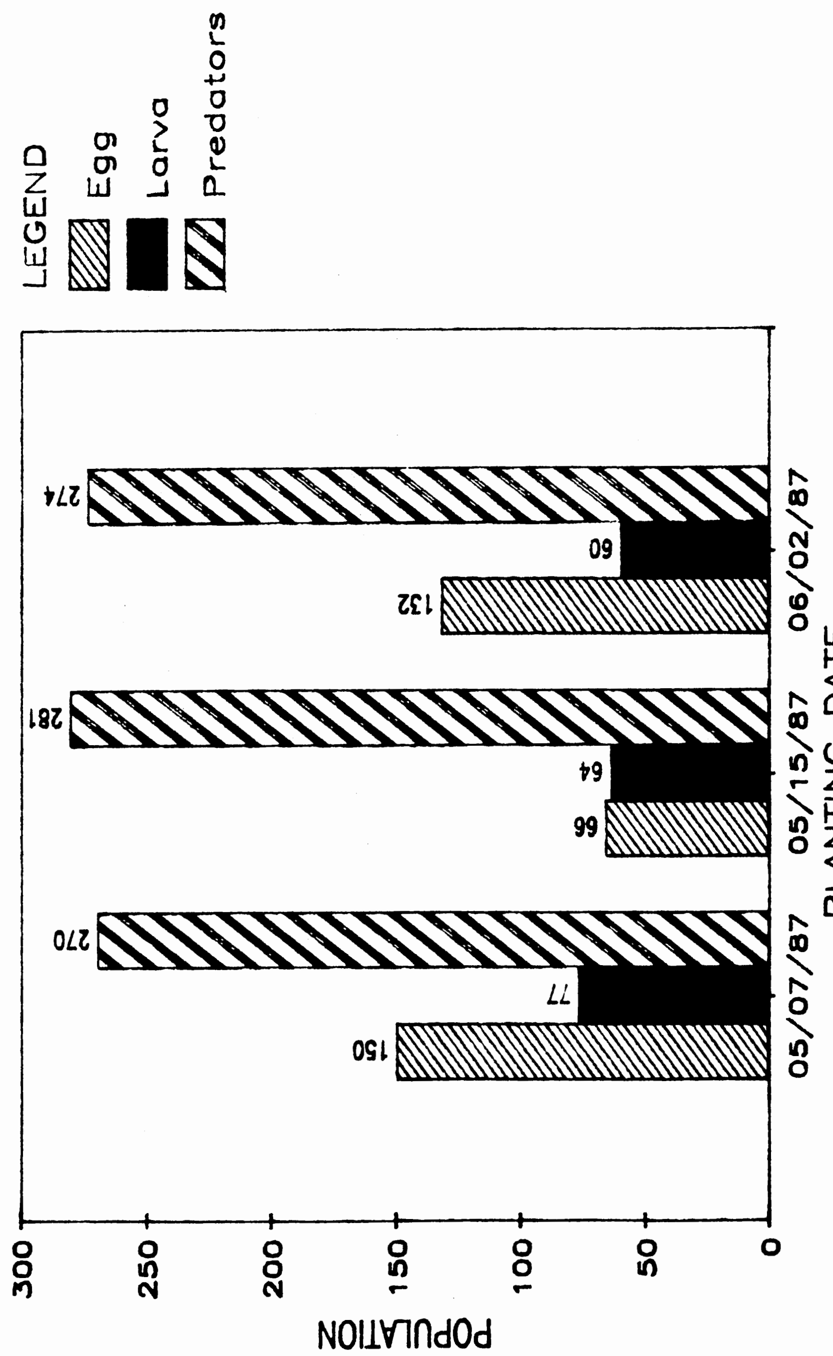
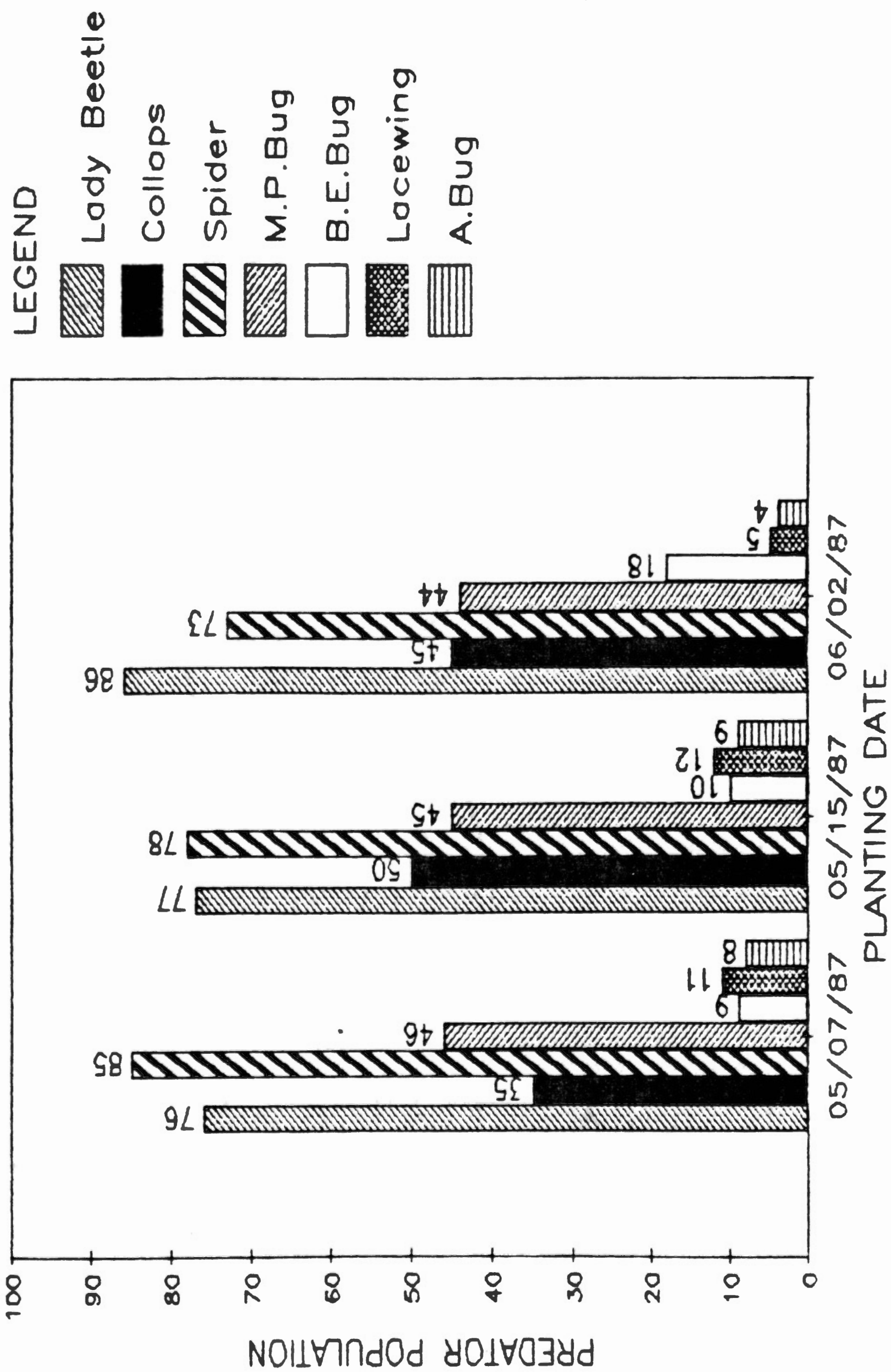

LEGEND
Egg
Larva
Predators
POPULATION
300
250
200
150
100
50
0
PLANTING DATE
05/07/87
05/15/87
06/02/87
150
77
270
66
64
281
132
60
274

Figure 5. Population of predators on cotton in three planting dates in 1987.


LEGEND
Lady Beetle
Collops
Spider
M.P.Bug
B.E.Bug
Lacewing
A.Bug
PREDATOR POPULATION
0
10
20
30
40
50
60
70
80
90
100
PLANTING DATE
05/07/87
05/15/87
06/02/87
76
35
85
46
9
11
8
77
50
78
45
10
12
9
86
45
73
44
18
5
4

numerous on leaves, followed by lady beetles and Collops. Lady beetles, Collops, and spiders were the most common on squares. Minute pirate bugs ranked first on flowers. Spiders and lady beetles were the most abundant on bolls in all planting dates. Minute pirate bugs and lady beetles had the highest numbers on terminals. The total number of predators on plant parts by planting date is shown on Figure 6. Leaves had the largest number of predators with 95, 95, and 96 for first, second, and third periods, respectively. Squares ranked second with 54, 63, and 65. Flowers and bolls had almost no variation in all three planting dates. The highest numbers of predators in the three-year study did not correspond to the highest numbers of bollworm eggs and larvae. These results suggest a degree of independence between the prey and predator complexes as found by Young and Willson (1984).

In 1988, bollworm eggs, larvae, and predators are shown in Table VIII. The numbers of eggs, larvae, and predators per 20 plants were variable throughout the season with 24 eggs on 07/08, 9 larvae on 07/22, and 28 predators on 07/18. The proportions of eggs, larvae, and predators on different plant parts and main stem terminals are shown on Figure 7. The highest proportions of eggs were found on the main stem terminals and leaves, followed by squares, flowers, and bolls. The proportions of larvae on squares, leaves, bolls and terminals were 47, 16, 14, and 13%, respectively. The greatest proportions of eggs were laid on the upper and main stem terminals. If these two plant divisions were combined, there would be a concentration of 80% of the total numbers of eggs. The highest proportions of larvae were found on the upper and middle of the plant. Predators were more commonly found on squares and leaves, followed by bolls,

Figure 6. Population of predators on cotton plant parts and main stem terminals in three planting dates in 1987.

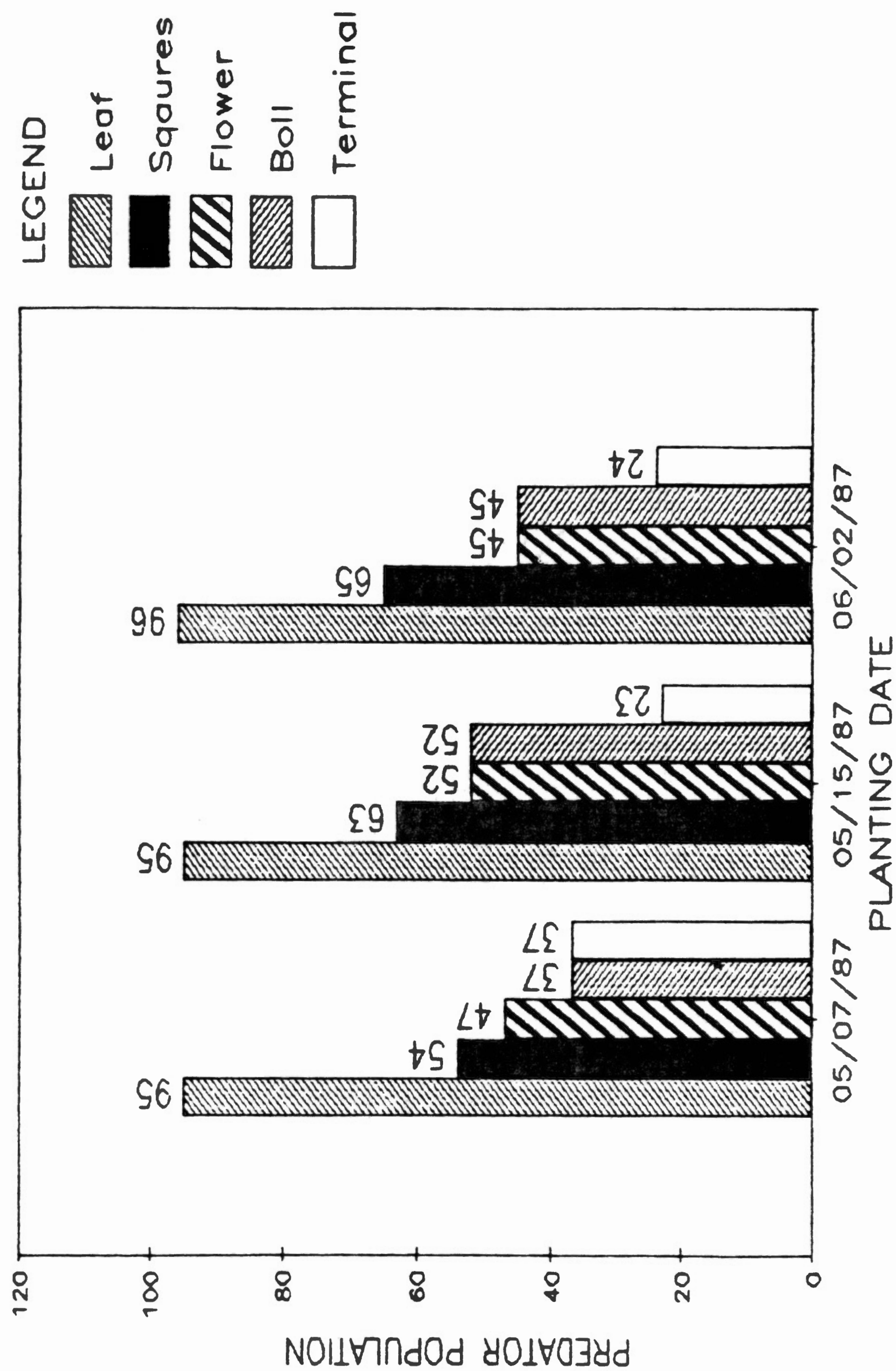
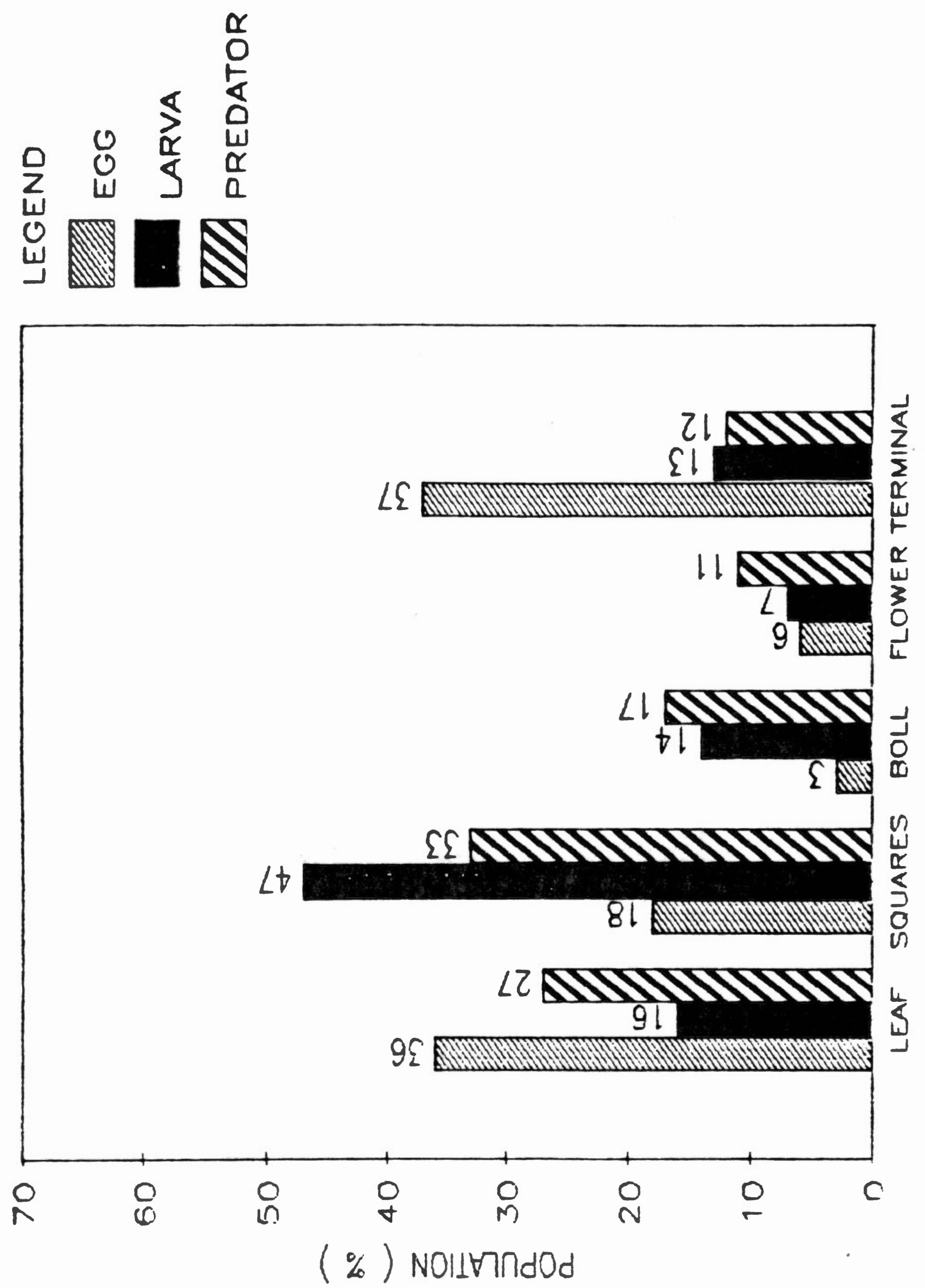

LEGEND
Leaf
Sqaures
Flower
Boll
Terminal
PREDATOR POPULATION
0
20
40
60
80
100
120
PLANTING DATE
05/07/87
05/15/87
06/02/87
95
54
47
37
37
95
63
52
52
23
96
65
45
45
24

TABLE VIII

NUMBERS OF BOLLWORM EGGS, LARVAE, AND PREDATORS ON "TAMCOT CAMD-E" COTTON IN 1988

Sampling Date	No. Egg	No. Larva	No. Predator
07/06	0	0	10
07/08	2	0	10
07/11	1	0	12
07/13	1	2	8
07/15	2	1	15
07/18	24	0	28
07/20	18	8	18
07/22	7	9	20
07/25	19	7	23
07/27	7	8	16
07/29	7	9	24
08/01	20	4	8
08/03	15	4	22
08/05	5	8	19
08/08	19	0	11

Figure 7. Percentages of *H. zea* eggs, larvae, and predators on leaves, squares, bolls, and flowers of cotton during 1988.


LEGEND
EGG
LARVA
PREDATOR
POPULATION (%)
0
10
20
30
40
50
60
70
LEAF
SQUARES
BOLL
FLOWER
TERMINAL
36
16
27
18
47
33
3
14
17
6
7
11
37
13
12

terminals, and flowers. The most abundant predators were lady beetles, spiders, and minute pirate bugs.

Chi-square tests were used to determine the degree of association among bollworm eggs and predators, and larvae and predators within cotton plants on three planting dates. These tests showed no relation between total number of eggs and total number of predators within the plant in the first and third planting dates. However, the second planting date was not independent (Table IX). Total number of larvae and total number of predators presented a high degree of relation in the third planting date, and no relation in the first and second planting times (Table X).

Tests of independence among the total numbers of eggs on the upper of the plant and the total numbers of predators on the whole plant showed no dependence in all planting dates (Table XI). The total numbers of larvae within the upper of the plant and the total numbers of predators within the whole plant showed no relation in all planting dates (Table XII). These results support the findings of Young and Willson (1984) who found the independence of relationships between prey and predator complexes.

Total bollworm eggs on terminal, and total bollworm eggs on the rest of the plant showed significant relationships. These results agreed with Farrar and Bradley (1985b), but did not agree with Wilson et al. (1980). Highly significant relationships were found in all three planting dates for the total eggs on the upper of the plant and the total eggs on the rest of the plant. These results agreed with several authors on Heliothis spp., such as Boyer et al. (1962).

TABLE IX

CHI-SQUARE TESTS OF INDEPENDENCE OF TOTAL BOLLWORM EGGS AND TOTAL PREDATORS ON COTTON IN THREE PLANTING DATES IN 1987

Pair Comparison		Planting Date 05/07/87	05/15/87	06/02/87
(0 0)	OBS.	31.1**	34.7**	34.2**
	EXP.	31.5	36.2	34.5
(0 1)	OBS.	44.9	52.4	48.4
	EXP.	44.5	51.0	48.1
(1 0)	OBS.	8.5	5.1	6.4
	EXP.	7.8	4.4	5.8
(1 1)	OBS.	10.4	5.5	7.4
	EXP.	11.1	6.2	8.0
(2 0)	OBS.	1.8	1.7	1.2
	EXP.	2.1	0.9	1.5
(2 1)	OBS.	3.3	0.6	2.4
	EXP.	3.0	1.3	2.1
Chi Square		1.030	7.119	1.151
$P < 0.05$		0.597	0.028	0.526

*First number represents total number of eggs; second number represents total number of predators.

**Percent of 500 plants.

TABLE X

CHI-SQUARE TESTS OF INDEPENDENCE OF TOTAL BOLLWORM LARVAE AND TOTAL PREDATORS ON COTTON IN THREE PLANTING DATES IN 1987

Pair Comparison		Planting Date 05/07/87	05/15/87	06/02/87
(0 0)	OBS.	31.3**	34.5**	34.0**
	EXP.	32.8	34.7	36.3
(0 1)	OBS.	47.8	49.L	52.8
	EXP.	46.3	48.9	50.5
(1 0)	OBS.	10.2	7.0	7.8
	EXP.	8.7	6.8	5.5
(1 1)	OBS.	10.7	9.4	5.4
	EXP.	12.2	9.6	7.7
Chi Square		3.141	0.045	9.345
P < 0.05		0.076	0.833	0.002

*First number represents total number of larvae; second number represents total number of predators.

**Percent of 500 plants.

TABLE XI

CHI-SQUARE TESTS OF INDEPENDENCE OF TOTAL BOLLWORM EGGS ON UPPER FOURTH OF PLANT AND TOTAL NUMBER OF PREDATORS ON WHOLE PLANT IN THREE PLANTING DATES IN 1987

Pair Comparison		Planting Date 05/07/87	05/15/87	06/02/87
(0 0)	OBS.	34.5**	36.4**	35.2**
	EXP.	34.4	37.4	35.6
(0 1)	OBS.	48.4	53.6	50.0
	EXP.	48.5	52.6	49.6
(1 0)	OBS.	6.0	4.0	6.2
	EXP.	6.0	3.5	5.3
(1 1)	OBS.	8.3	4.5	6.4
	EXP.	8.4	5.0	7.3
(2 0)	OBS.	1.0	1.1	0.4
	EXP.	1.1	0.6	0.9
(2 1)	OBS.	1.8	0.4	1.8
	EXP.	1.6	0.9	1.3
Chi Square		0.419	4.405	3.984
$P < 0.05$		0.811	0.111	0.136

*First number represents total number of eggs; second number represents total number of predators.

**Percent of 500 plants.

TABLE XII

CHI-SQUARE TESTS OF INDEPENDENCE OF TOTAL BOLLWORM LARVAE ON UPPER FOURTH OF PLANT AND TOTAL NUMBER OF PREDATORS ON WHOLE PLANT IN THREE PLANTING DATES IN 1987

Pair Comparison		Planting Date 05/07/87	05/15/87	06/02/87
(0 0)	OBS.	36.7**	38.5**	39.6**
	EXP.	37.3	38.8	40.2
(0 1)	OBS.	53.3	55.1	56.6
	EXP.	52.7	54.7	56.0
(1 0)	OBS.	4.7	3.0	2.2
	EXP.	4.2	2.7	1.6
(1 1)	OBS.	5.3	3.4	1.6
	EXP.	5.8	3.8	2.2
Chi Square		0.852	0.461	2.103
P < 0.05		0.356	0.497	0.147

*First number represents total number of larvae; second number represents total number of predators.

**Percent of 500 plants.

Tests of independence showed relationships among total numbers of larvae on terminal and total larvae on the rest of the plant. However, the second and third planting dates had no relation. Total numbers of larvae on the upper of the plant and total larvae on the rest of the plant showed highly significant relationships. These results agreed with the findings on Heliothis spp., by Mistric (1964) and Ramalho et al. (1984); and on bollworm, by Farrar and Bradley (1985b).

Conclusions

The largest proportions of eggs were found on the main stem terminals and upper parts of the plant. The total bollworm eggs on the terminal and total on the rest of the plant showed significant relationships, which suggest that a plant terminal can be used as a sampling site for bollworm eggs. This does not discard the idea of using two plant divisions, terminal and upper parts of the plant, as a sampling site for eggs. In contrast, the proportions of larvae found on the terminal was very low in comparison to the proportions found on the upper and middle parts of the plant. This suggests a dynamic dependence of small larvae for suitable feeding sites like squares. These data suggest the necessity of using the whole plant, or at least the upper half of the plant, as sampling site for larvae.

Leaves were the most preferred place for egg deposition, followed by squares, flowers, and bolls. Larvae were more commonly found on squares, bolls and flowers. Although large proportions of eggs were laid on terminals and leaves, very small proportions of larvae were found on these parts. This fact might explain the high mobility of larvae within the plant in searching for suitable feeding sites which were usually squares, bolls, or flowers.

This research supports the assumption of independent relationships of *H. zea* eggs, larvae, and their predators found by Young and Willson (1984). The data here showed no relation between total numbers of eggs, larvae, and their predators.

CHAPTER IV

VERTICAL DISTRIBUTION OF EGGS AND LARVAE OF THE BOLLWORM, *HELIOTHIS ZEA* (BODDIE) (LEPIDOPTERA: NOCTUIDAE), WITHIN THE COTTON PLANT

Introduction

Many researchers have investigated the behaviors of the bollworm on different hosts. Among these behavior patterns, the vertical distribution of eggs and larvae has been of interest (Quaintance and Brues, 1905; Hillhouse and Pitre, 1976; Nilakhe and Chalfant, 1981; Pencoe and Linch, 1982; Farrar and Bradley, 1985b; and Terry et al., 1987). The above studies addressed the general description of oviposition and larval feeding site preferences during different phenological stages of the hosts. On cotton, *Gossypium hirsutum* L., Quaintance and Brues (1905), Parsons (1940), Beeden (1974), Hillhouse and Pitre (1976), Ramalho et al. (1984), and Farrar and Bradley (1985b) showed no consistency in *Heliothis* spp. oviposition preference sites and larval feeding sites.

Hillhouse and Pitre (1976) examined spacial oviposition by *H. zea* and *H. virescens* on soybeans, *Glycine max* (L.), and cotton. They reported that both species preferred the pubescent lower leaf surface to the upper leaf surface stems or pods of soybeans. Oviposition by both species on soybeans occurred in the upper two-thirds of the plant, whereas on cotton, occurred in the upper one-third of the plant. Wilson et al. (1980) said that 89.6% of the eggs were found on cotton leaves, with 48.2% on mainstem leaves compared with 23.1% on fruit branch leaves, and 18.3% on vegetative branch leaves.

Mistric (1964) and Lincoln et al. (1967) suggested that terminal counts of eggs and larvae of Heliothis spp. on cotton were unreliable indices of damage by these insects, and that square damage should be used in determination of the economic threshold infestations. Lincoln et al. (1967) found that high counts of eggs and larvae on the terminal were associated with high square damage percentages. They stressed the necessity of a more intensive study of this subject in different times and locations of the cotton growing area.

Studies on the behavioral responses of newly hatched bollworm larvae on cotton were carried out by Quaintance and Bishopp (1929), and Quaintance and Brues (1905). They found that the neonate larvae usually do not immediately search for food on the plant, but consume the egg choria. After that, they start looking for other food sources such as any tender leaf or flower. Before finding a square as a feeding site, the small larvae exhibit a highly mobile behavior. The decreasing order of preference for feeding on cotton structures was flower, squares, bolls, and leaves. Farrar and Bradley (1985b) reported that larval distribution within cotton plants varied among years. Small larvae were most commonly found on flowers, squares, and terminals. Flowers and bolls were the most common feeding sites of larger larvae in all years. They concluded that flowers were the most common feeding site for both large and small larvae.

Reese et al. (1981) found that the patterns of larval distribution varied from one location to another. At each location, more than half of all larvae were found on squares less than 6 mm in diameter. Farrar and Bradley (1985b) reported that within plant distribution of Heliothis spp., eggs and larvae can also vary from one geographic area to another. They stressed that when egg counts were used in making pest management decisions, they should be supplemented with data on larval populations.

The objective of this study was to study the vertical distribution of bollworm eggs and larvae within the cotton plant.

Materials and Methods

The study of the vertical distribution of bollworm eggs and larvae within the plant was conducted at the Agronomy Research Station near Perkins, Oklahoma, in 1987. The cotton cultivar "Tamcot CAMD-E" was planted in three areas of approximately 1,833 m^2 each in three different planting dates, May 7, May 15, and June 2.

Five wood-framed screen cages, measuring 1.2 m x 1.7 m at the base, and 1.7 m in height with 1 mm mesh nylon screen were used to cover 30 cotton plants during match-head squares (5 mm of diameter) and blooming phase for each planting date. Each cage was placed over six plants. The plants and cages were sprayed with Malathion (1g AI/ liter of water) to control predator and parasites. Twenty-four hours after insecticide treatments, five female and five male bollworm moths were released in each cage. Bollworm eggs, larvae, and adults were obtained from corn fields in Stillwater, Oklahoma, and they were reared in the laboratory and fed on a diet according to Burton (1969, 1970).

The moths were held in oviposition cages in the laboratory until they began to lay eggs and then they were released in field cages between 6 pm and 8 pm. The moths remained in the cages for 36 hours, including two periods of darkness. After this oviposition period, the moths were removed by hand from the cages. Counts for eggs were immediately made on the six plants in each of the five cages. The plants remained covered by cages until they were checked for larvae, which occurred three days after egg counting. The same procedure was used in all three planting dates and two growing periods of cotton.

Eggs and larvae in each planting date and each growing phase were recorded from the main stem terminals, upper, middle, and lower parts of the cotton plant. Within upper, middle, and lower plant divisions, eggs and larvae were checked on plant parts such as leaves, squares, bolls, and flowers. The plant part leaf comprised leaves of all sizes; squares comprised flower buds of all sizes; flowers comprised white and red flowers; bolls comprised bolls of all sizes, including those with bloomtags (drying corollas); and terminals comprised the main stem terminal.

The first and second infestations of cages with five pairs of moths on the first planting date were on 07/13/87 and 7/22/87, and sampling for eggs and larvae on (7/15 and 7/17), and (7/24 and 7/27) for first and second infestations, respectively. The second planting date the infestations were on 08/02 and 08/11, counting for eggs and larvae on (08/04 and 08/07) and (8/13 and 8/16) for the first and second infestations, respectively. For the third planting date, the infestations were done on 8/18 and 8/30, and recording for eggs and larvae on (8/20 and 8/23) and (09/01 and 09/04) for first and second infestations, respectively.

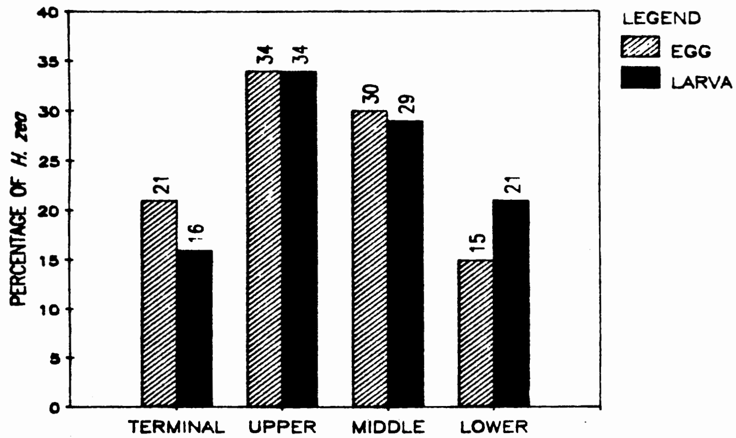
Graphs were prepared to illustrate proportions of eggs/larvae on regions of the plant and on plant parts for each planting date. In addition, a series of stepwise regression procedures was completed to determine the best model to explain variation in each of the dependent variables (egg, larva) on plant divisions and plant parts.

Results and Discussion

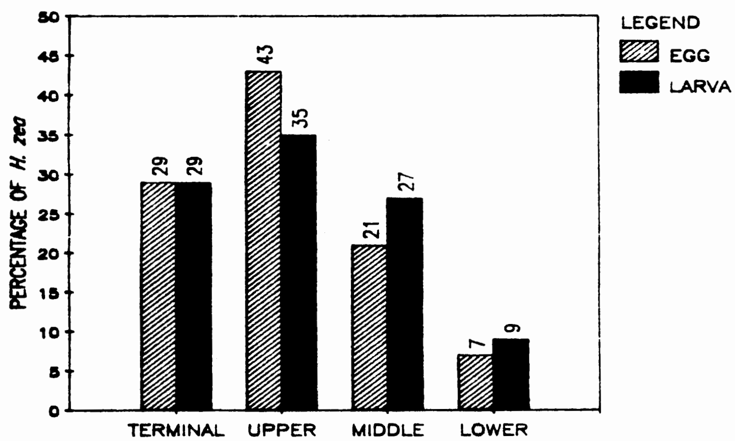
The total numbers of eggs on 60 cotton plants in two infestation periods, in the first planting date, were 1,747. Each plant had an average of 29 eggs. The distribution of eggs on each plant division in three planting dates is shown in Figure 8. In the first planting date, 21% of the eggs were found on the terminal, 34% on the upper, 30% on the middle, and 15% on the lower of the plant. From a total of 1,343 eggs in the second planting date, 29% were laid on the terminal, 43% on the upper, 21% on the middle, and 7% on the lower of the plant. This planting date had an average of 22.3 eggs per plant. Records of the third planting date showed an average of 18.7 eggs per plant from a total of 1,122 eggs. The proportions of eggs on each plant division were 30% on the terminal, 39% on the upper, 26% on the middle, and 5% on the lower of the plant.

The proportions of eggs deposited on leaves were 74, 63, and 73% for the first, second, and third planting dates, respectively. Squares ranked second, with 22, 16, and 17% for the three planting dates. They were followed by bolls and flowers (Figure 9).

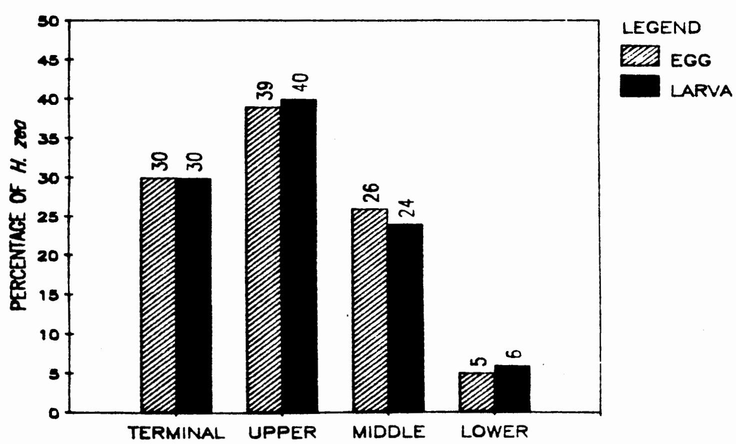
Figure 8. Percentages of *H. zea* eggs and larvae on main stem terminals, upper, middle, and lower parts of cotton in field cages during first, second, and third planting dates in 1987.



FIRST PLANTING DATE

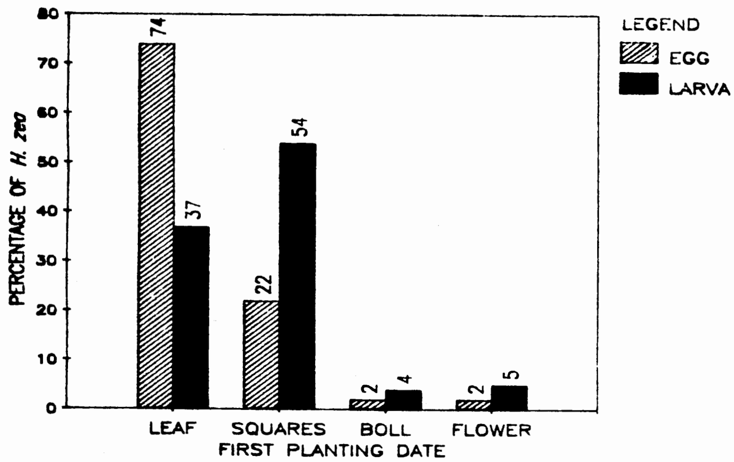


SECOND PLANTING DATE

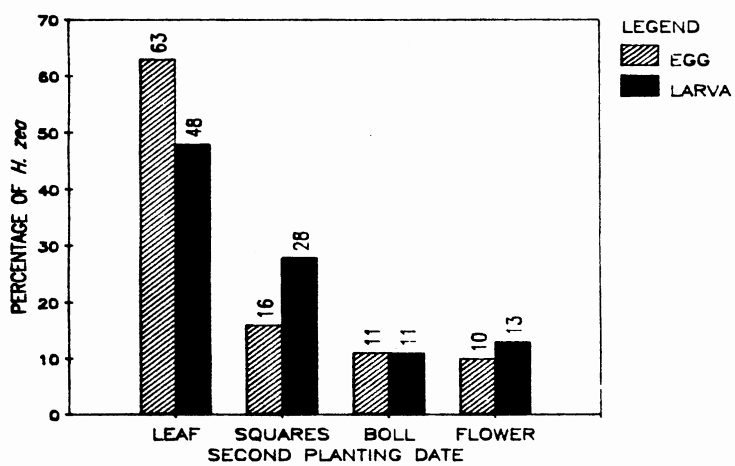


THIRD PLANTING DATE

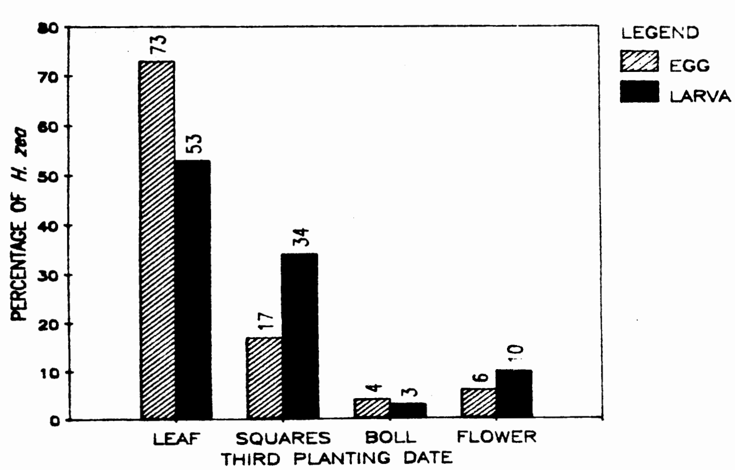
Figure 9. Percentages of *H. zea* eggs and larvae on leaves, squares, bolls, and flowers of cotton in field cages during first, second, and third planting dates in 1987.



80
70
60
50
40
30
20
10
0
PERCENTAGE OF H. zea
74
37
22
54
2
4
2
5
LEAF
SQUARES
BOLL
FLOWER
FIRST PLANTING DATE
LEGEND
EGG
LARVA



70
60
50
40
30
20
10
0
PERCENTAGE OF H. zea
63
48
16
28
11
11
10
13
LEAF
SQUARES
BOLL
FLOWER
SECOND PLANTING DATE
LEGEND
EGG
LARVA



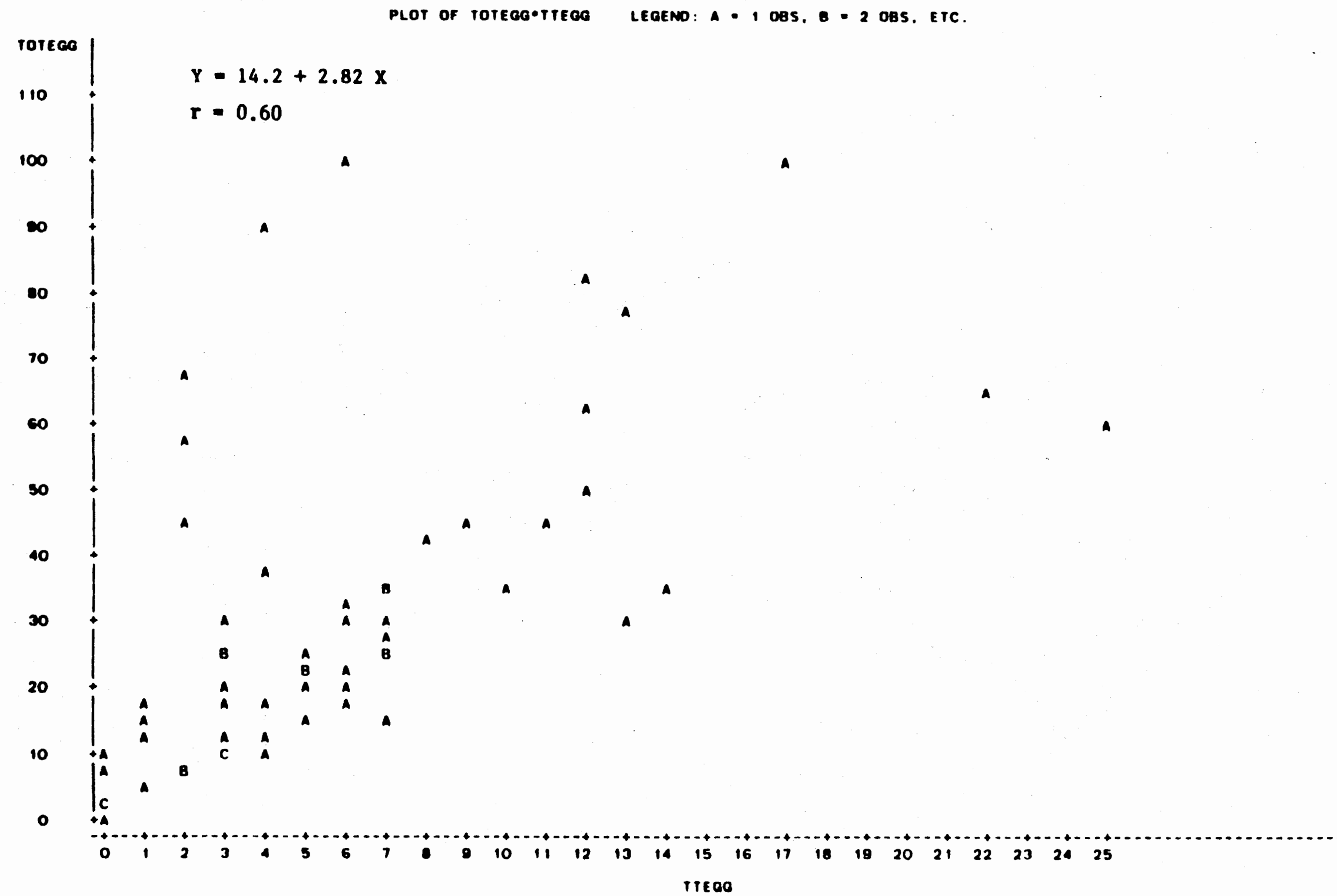
80
70
60
50
40
30
20
10
0
PERCENTAGE OF H. zea
73
53
17
34
4
3
6
10
LEAF
SQUARES
BOLL
FLOWER
THIRD PLANTING DATE
LEGEND
EGG
LARVA

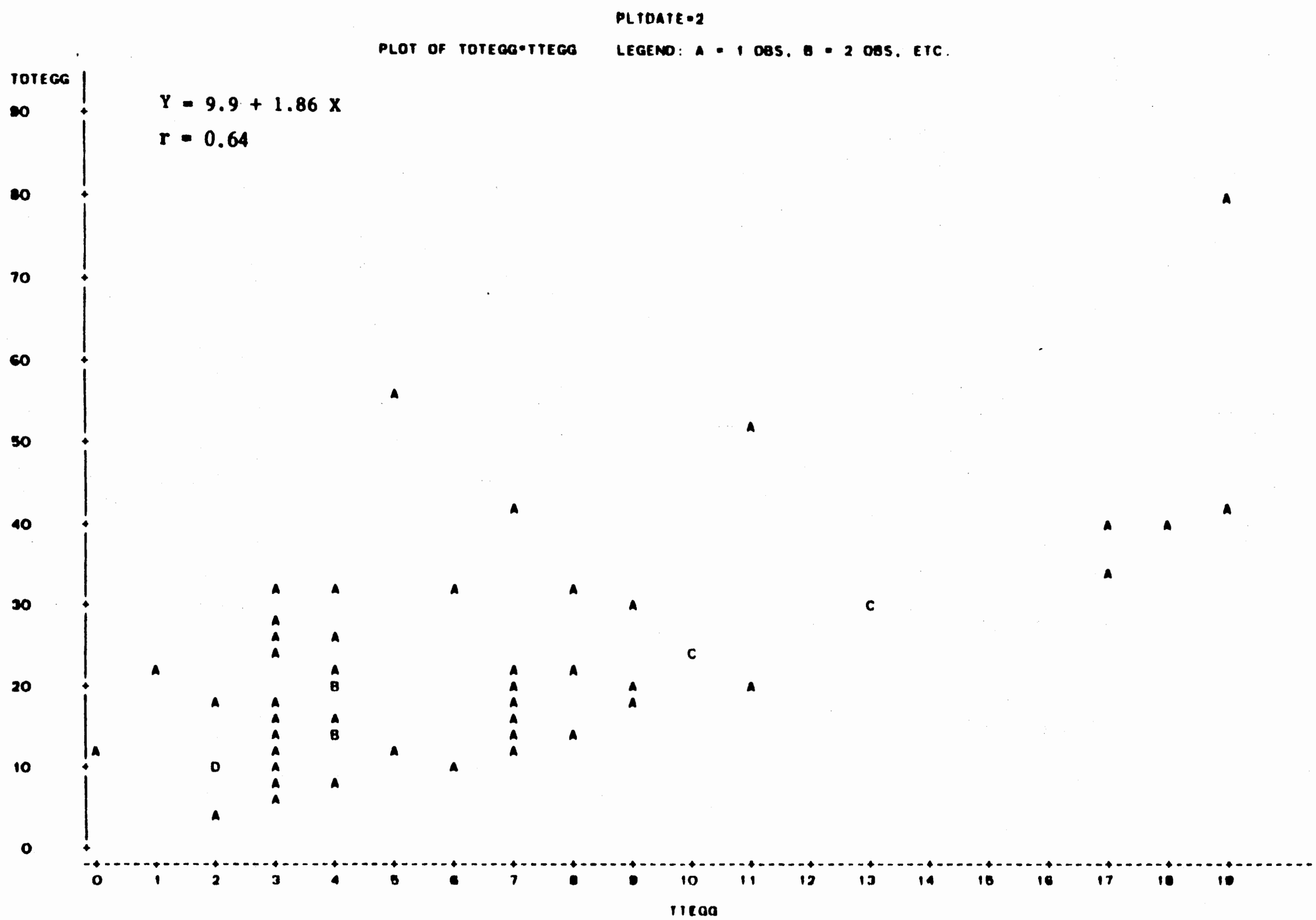
A total of 514 larvae were recorded in five cages, during two infestation periods in the first planting date. Of these, 16% were found on the terminal, 34% on the upper, 30% on the middle, and 15% on the lower part of the plant. The second planting date had a total of 299 larvae in all five cages. The proportions of larvae on each plant division were 29% on terminal, 35% on the upper, 27% on the middle, and 9% on the lower of the plant. The proportions for the third planting date were 30, 40, 24, and 6% on terminal, upper, middle, and lower of the plant, respectively (Figure 8). Leaves and squares were the most preferred place for neonate larvae during all planting dates. This was followed by flowers and bolls (Figure 9).

Regressions of total numbers of eggs and total eggs on the main stem terminal (TOTEGG*TTEGG) yielded positive and significant relationships (slope > 0; $p < 0.001$) in planting dates 1, 2, and 3 (Figure 10). Higher correlations were obtained among total eggs on leaves with total numbers of eggs on the whole plant (TOTEGG*TLEGG) in all planting dates (Figure 11). Correlations among total numbers of larvae on the whole plant with larva on terminal were lower than with the total larva on squares. Correlations among total incidence of larvae on leaves with total larvae on the whole plant (TOTLAR*TLLAR) were positive and significant ($r > 0.70$; $P < 0.001$) (Figure 12). Since larval counts were made in the morning, three days after egg deposition, most of the neonate larvae had not moved yet to suitable feeding sites. These results agree with previous studies which reported that newly hatched larvae did not immediately move from leaves to another place searching for food, but they stayed there for one or two days, rasping the epidermis of the leaf. When the larval population for

Figure 10. Regressions of total bollworm eggs on plant and eggs on main stem terminals during planting dates 1, 2, and 3.

PLTDATE=1


PLOT OF TOTEGG*TTEGG
LEGEND: A = 1 OBS, B = 2 OBS, ETC.
TOTEGG
Y = 14.2 + 2.82 X
r = 0.60
0
10
20
30
40
50
60
70
80
90
100
110
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
TTEGG


PLTDATE=2
PLOT OF TOTEGG*TTEGG
LEGEND: A = 1 OBS, B = 2 OBS, ETC.
Y = 9.9 + 1.86 X
r = 0.64
TOTEGG
0
10
20
30
40
50
60
70
80
90
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
TTEGG

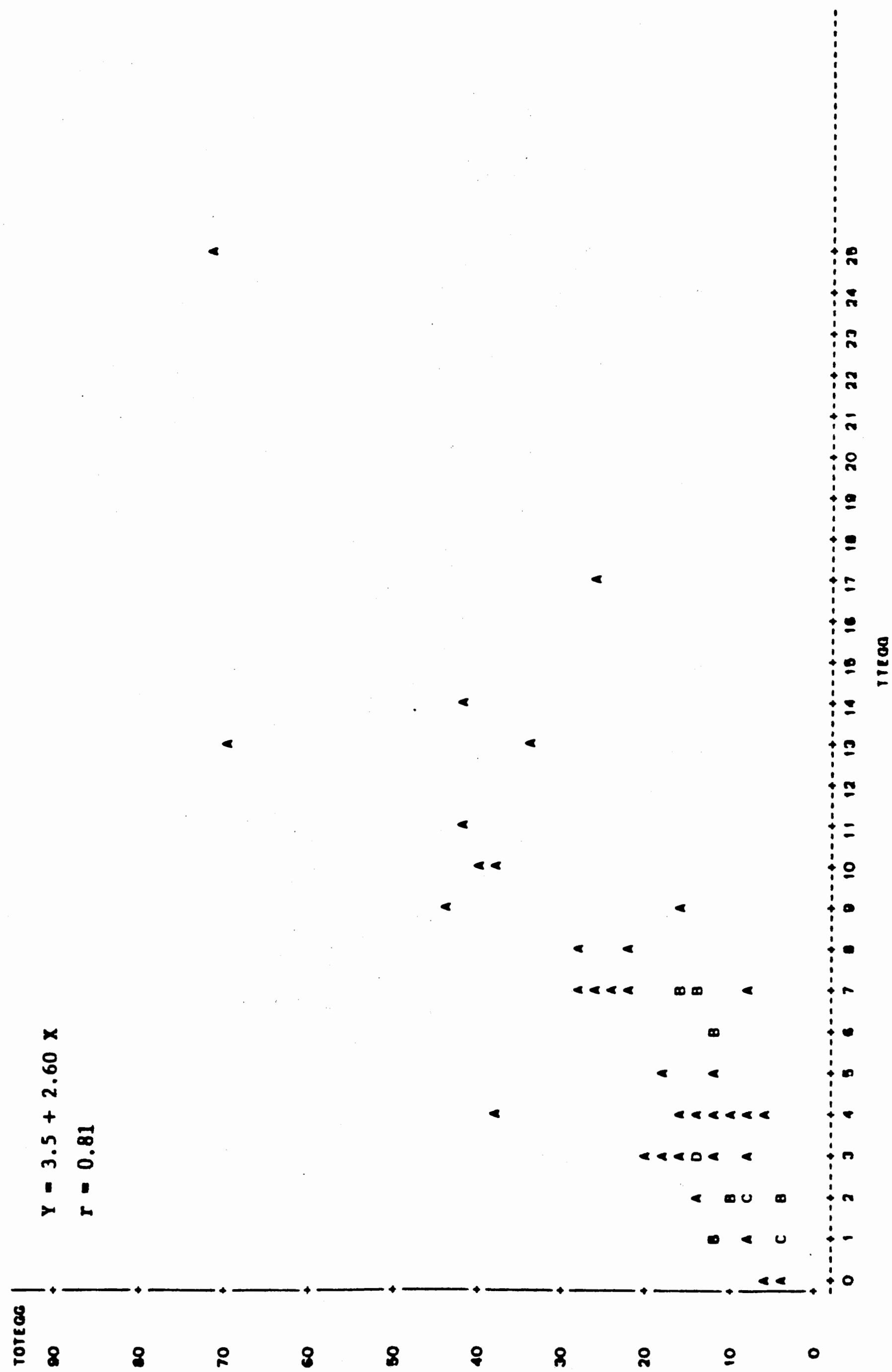
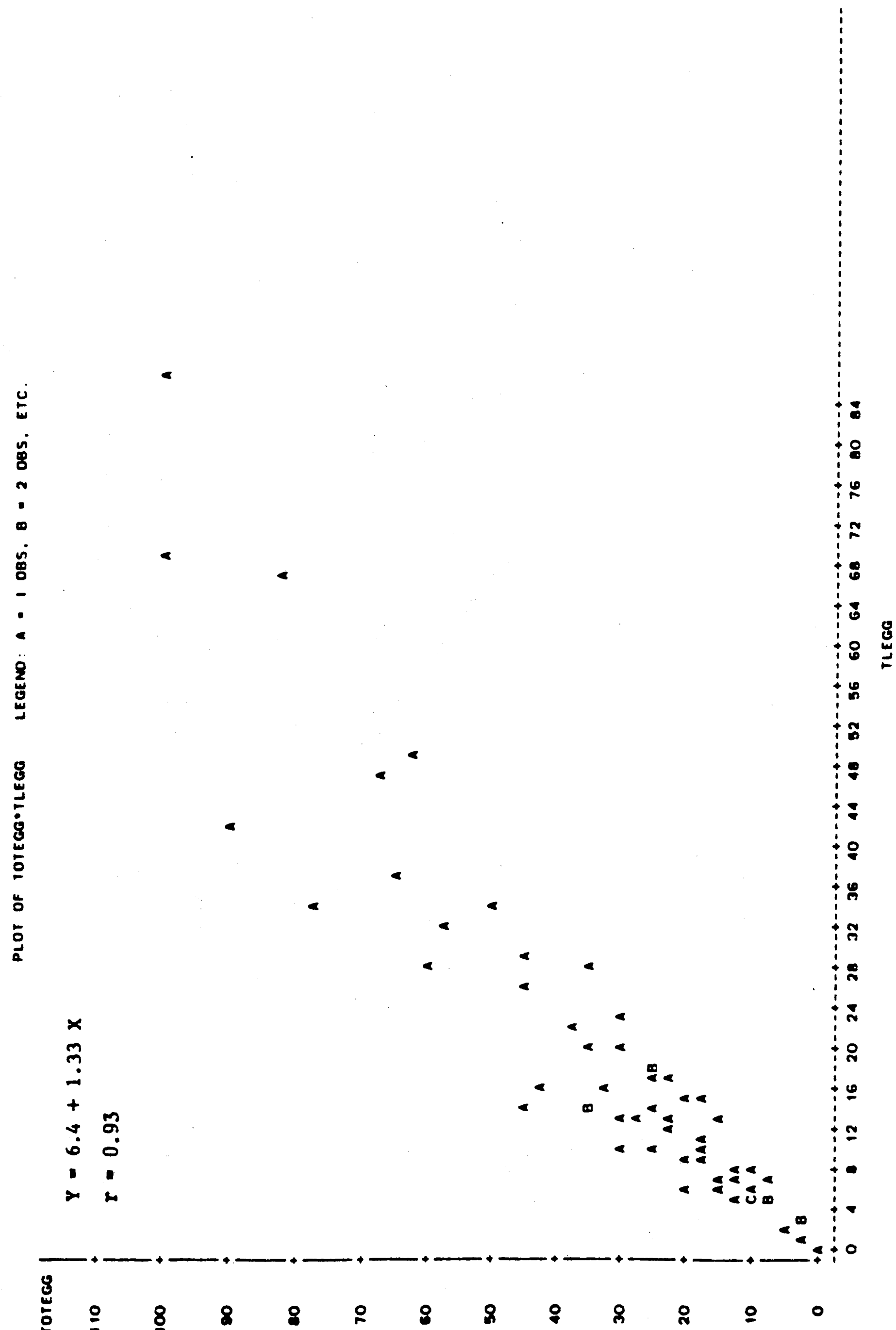
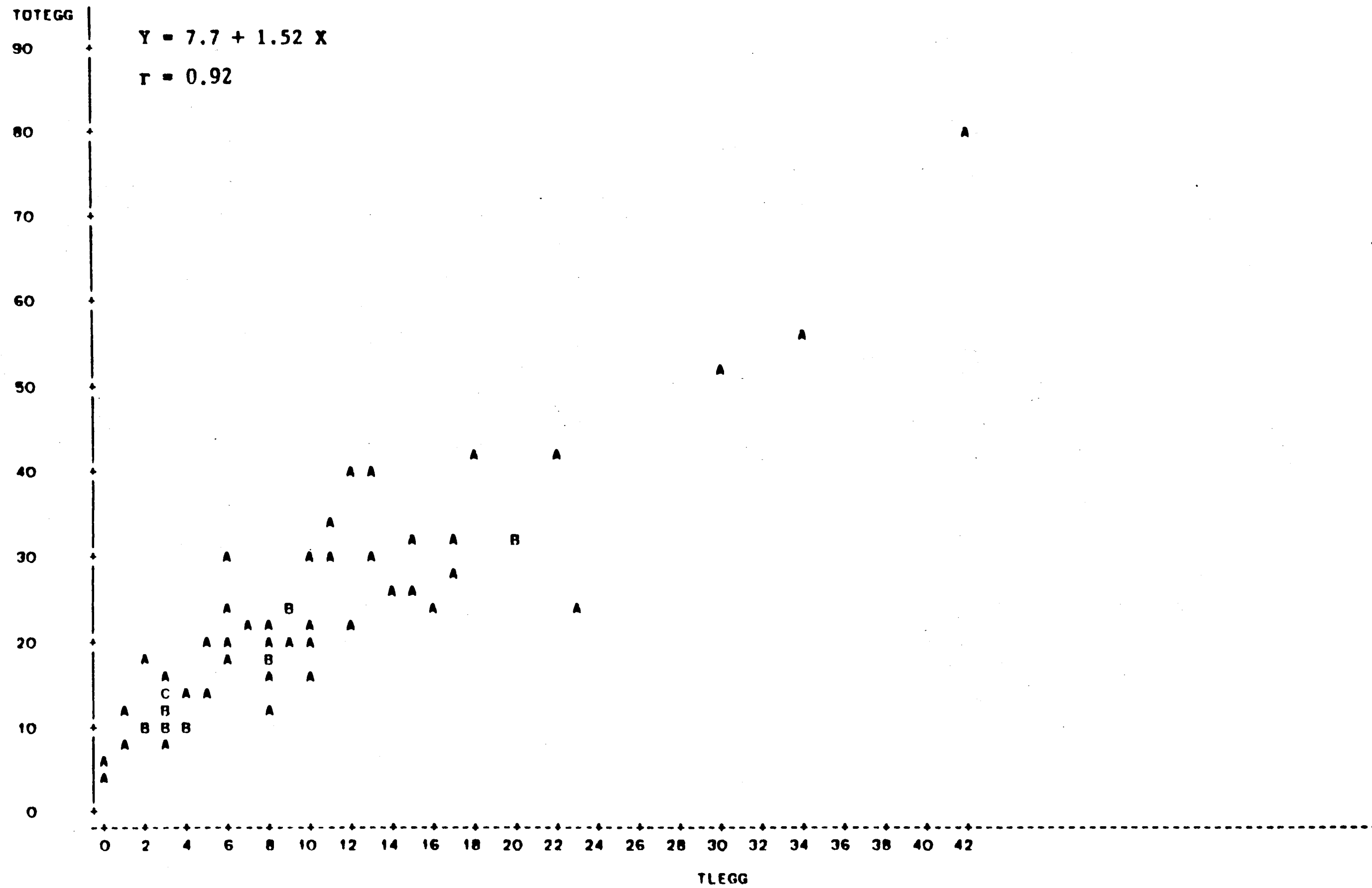

PLOT OF TOTEGG*TTEGG
PLTDATE=3
LEGEND: A = 1 OBS, B = 2 OBS, ETC.
Y = 3.5 + 2.60 X
r = 0.81
TOTEGG
TTEGG

Figure 11. Regressions of total bollworm eggs on plant and eggs on leaves during planting dates 1, 2, and 3.


PLOT OF TOTEGG*TLEGG
PLTDATE=1
LEGEND: A = 1 OBS, B = 2 OBS, ETC.
Y = 6.4 + 1.33 X
r = 0.93
TOTEGG
TLEGG

PLTDATE=2

PLOT OF TOTEGG*TLEGG   LEGEND: A = 1 OBS, B = 2 OBS, ETC.



PLTDATE=3

PLOT OF TOTEGG*TLEGG LEGEND: A = 1 OBS, B = 2 OBS, ETC.

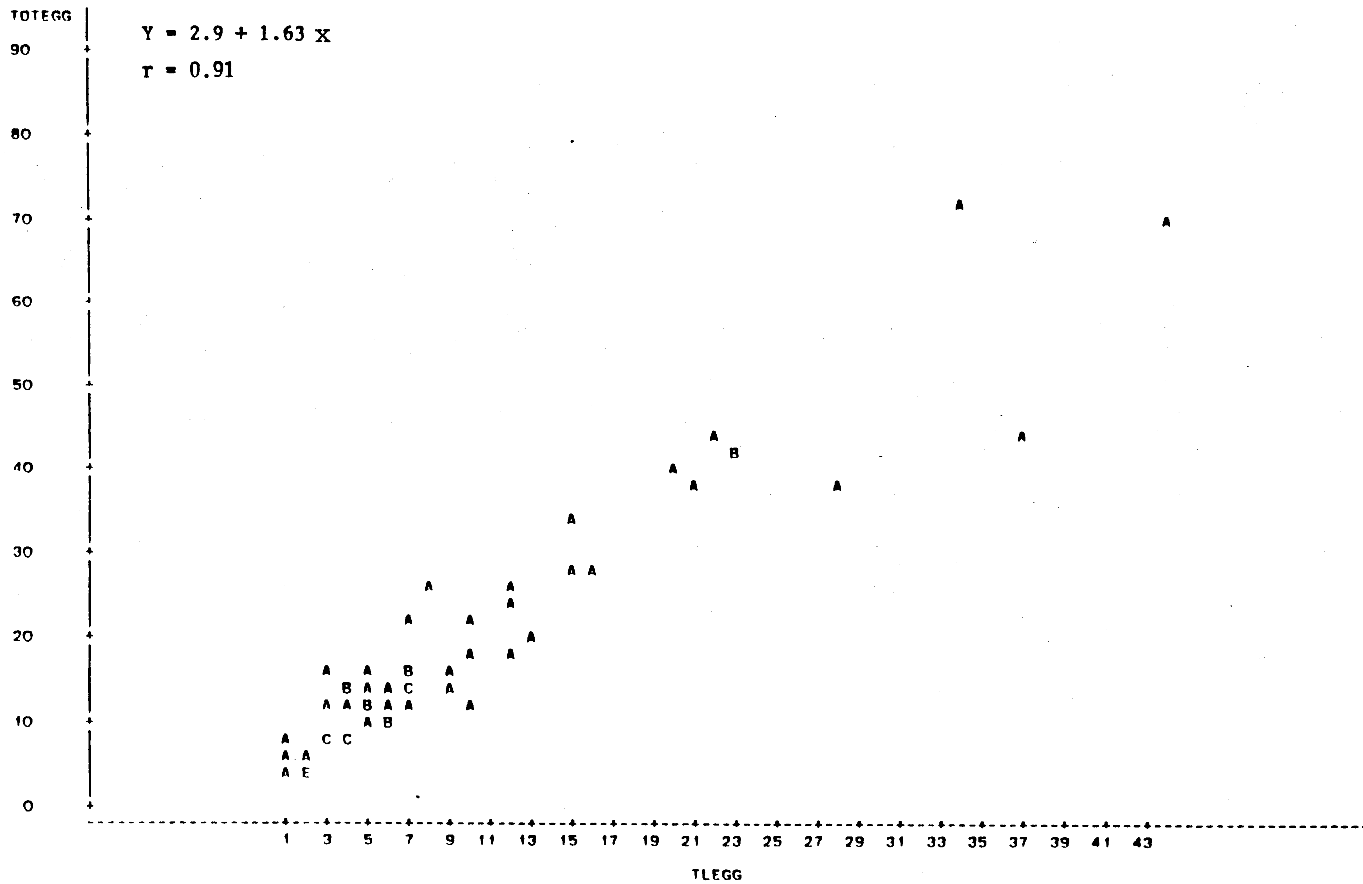
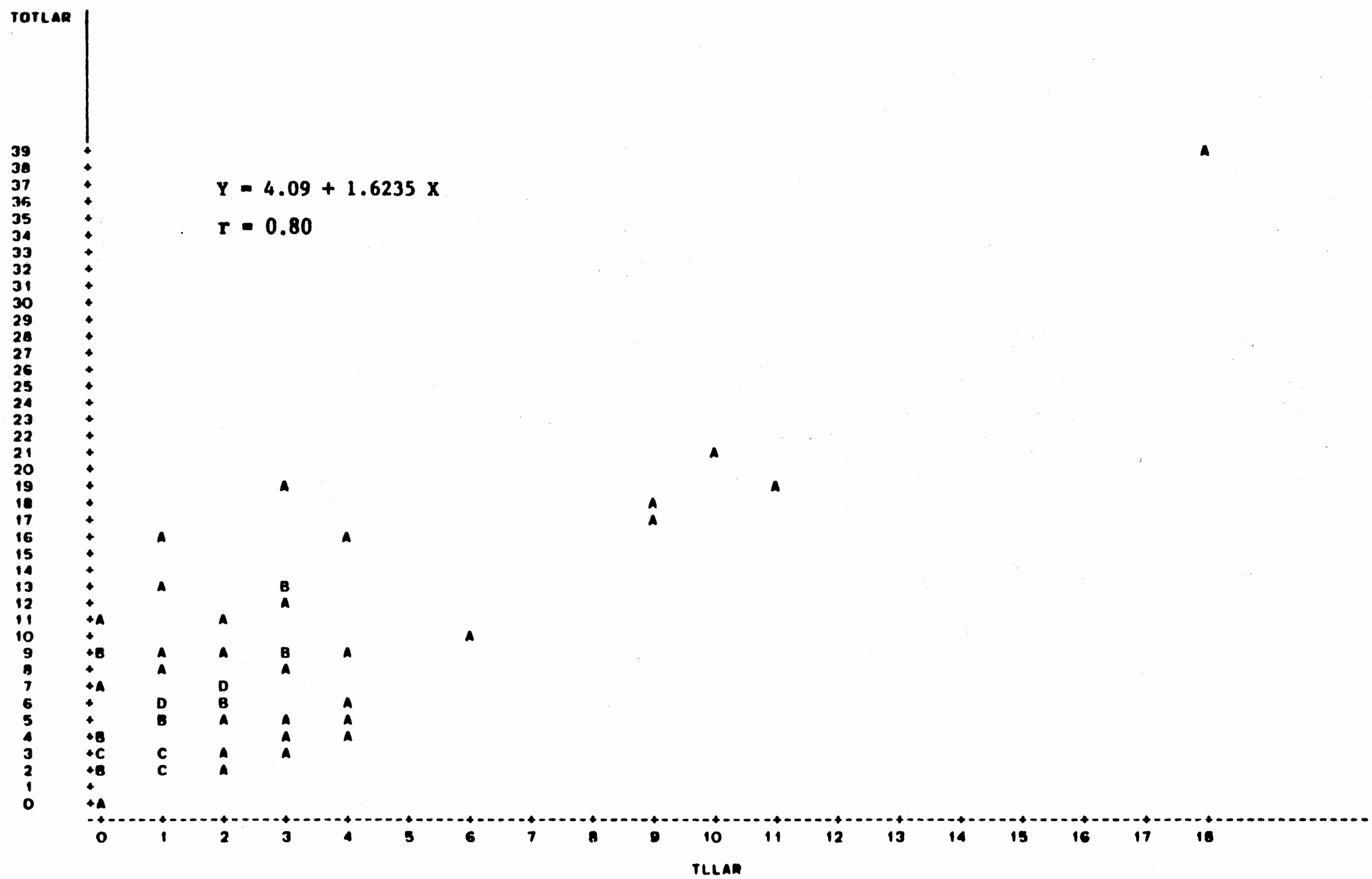


Figure 12. Regressions of total bollworm larvae on plant and larvae on leaves during planting dates 1, 2, and 3.

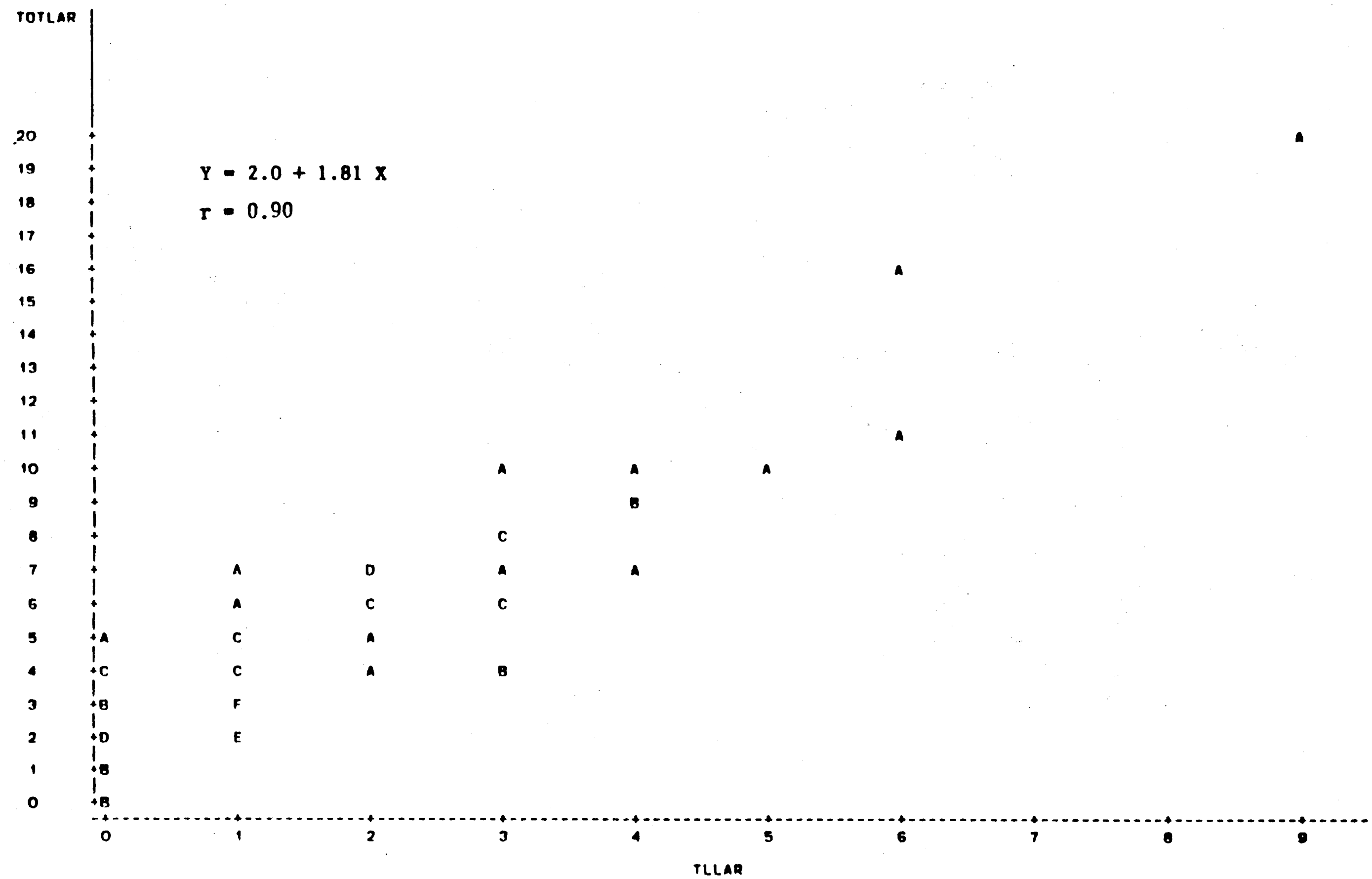
PLTDATE=1

PLOT OF TOTLAR*TLLAR   LEGEND: A = 1 OBS, B = 2 OBS, ETC.



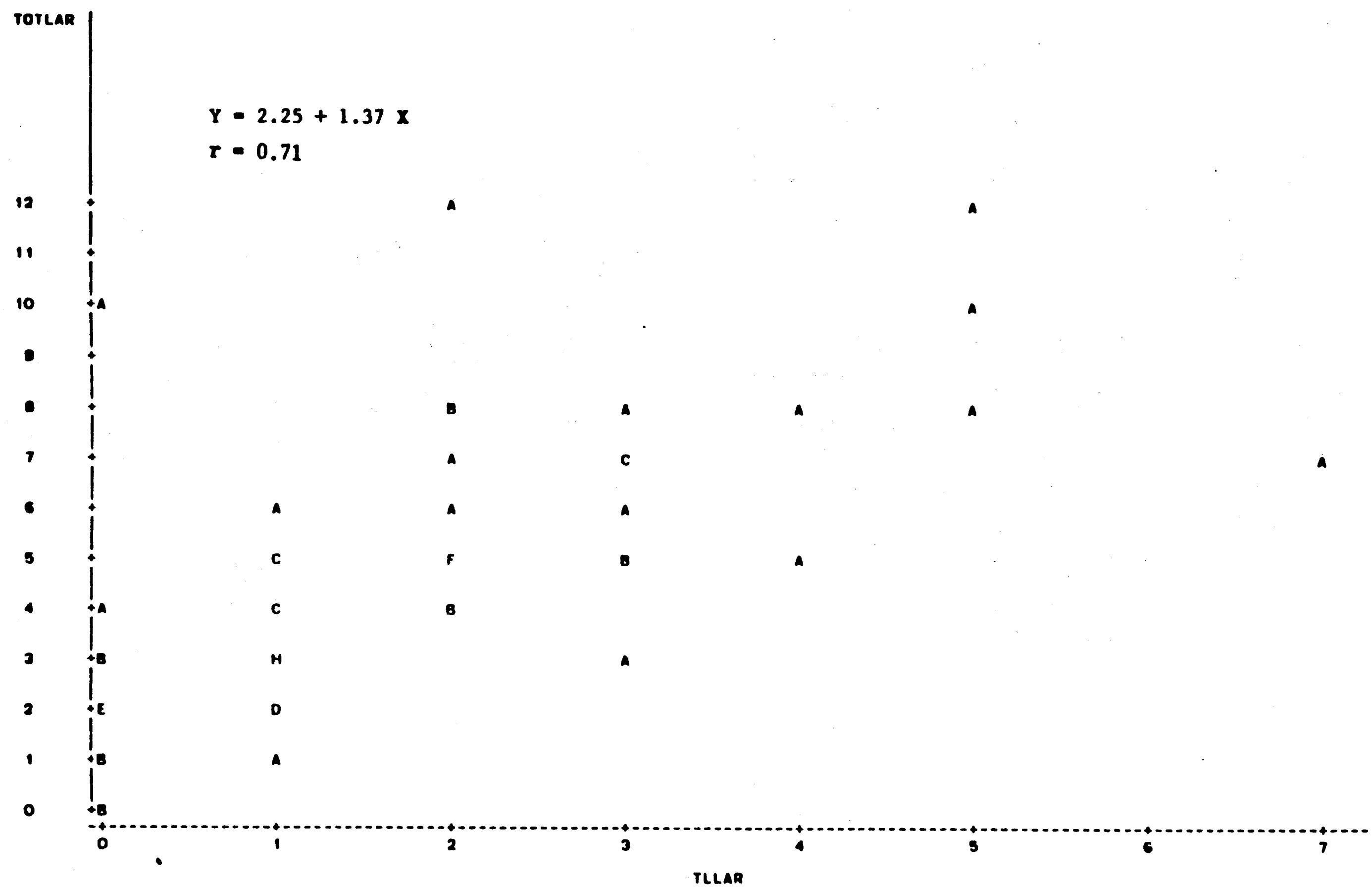
PLTDATE=2

PLOT OF TOTLAR*TLLAR LEGEND: A = 1 OBS, B = 2 OBS, ETC.



PLTDATE=3

PLOT OF TOTLAR*TLLAR LEGEND: A = 1 OBS, B = 2 OBS, ETC.



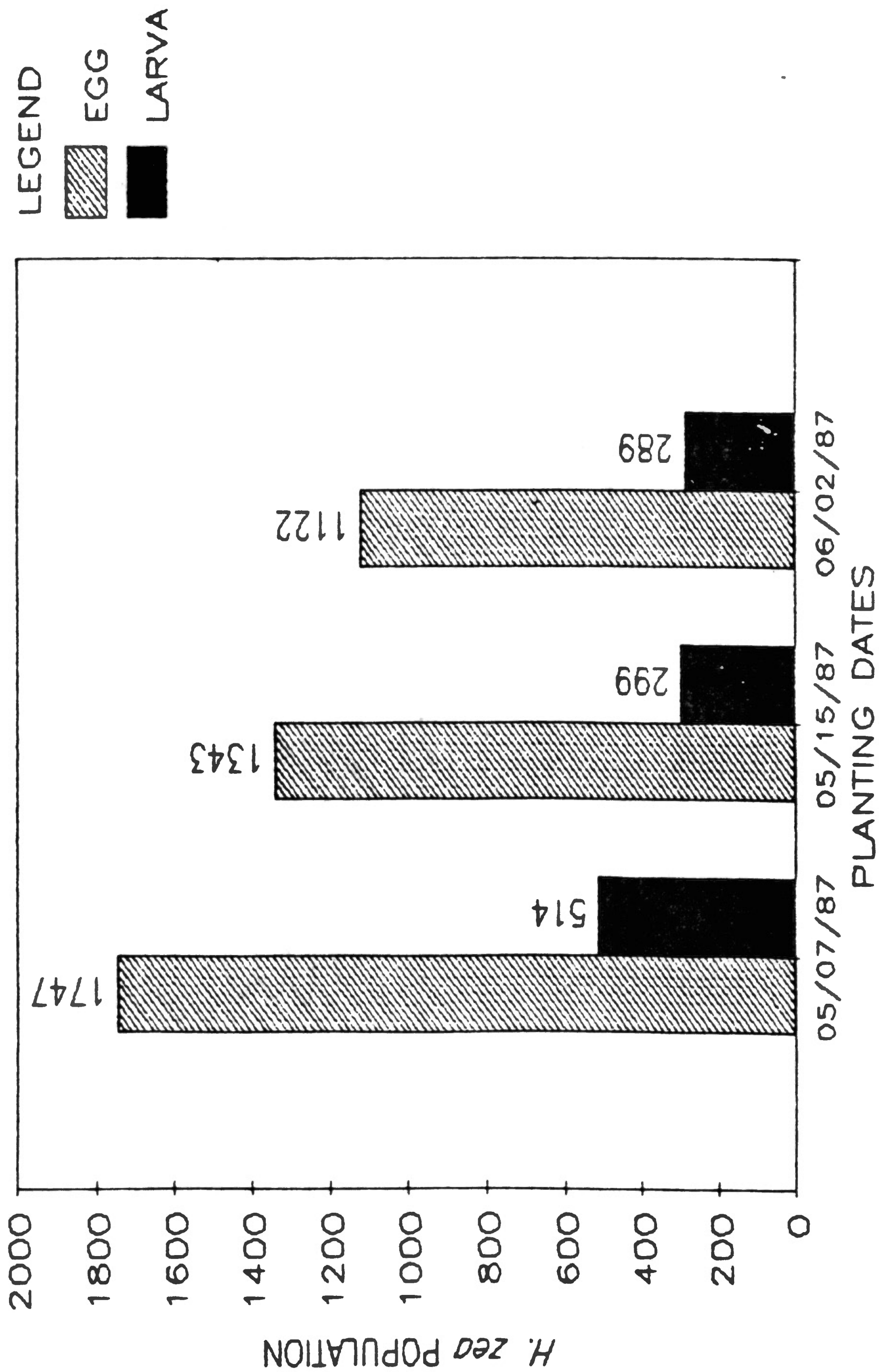
each planting date was examined over all cages, correlations of total eggs and total larvae within the whole plant, plant divisions, and plant parts were low ($0.01 < r < 0.70$), which may result from the low percentages of fertile eggs. This fact was observed in laboratory experiments when the same kind of moths was used. General trends of the total eggs and larvae on the plant in each planting date is shown in Figure 13. In all planting dates, more eggs were laid during the second infestation (peak of blooming) than during the first infestation. These results agree with previous investigations which reported that larger canopy and blooming period were highly attractive to oviposition by bollworm moths.

Conclusions

Under artificial infestations of bollworm in field cages, the majority of eggs were laid on the upper part of the plant. If the terminal and the upper part of the plant were considered as a plant division, the proportions of eggs would be 55, 71, and 51% for the first, second, and third planting dates, respectively. The greatest proportions of eggs were observed during the second infestation period, which coincided with the blooming phase. Leaves were the most common place for egg deposition. The greatest numbers of eggs on fruiting structures were observed on bracts.

The plant terminal alone is probably not a good place to scout for larvae. If the terminal and upper parts of the plant were considered as a plant division, the proportion of larvae would be 50, 63, and 69% for the first, second, and third planting dates, respectively. The greatest proportion of larvae were found on the upper part of

Figure 13. Total bollworm eggs and larvae on cotton during three planting dates.



LEGEND
EGG
LARVA
1747
514
1343
299
1122
289
05/07/87
05/15/87
06/02/87
PLANTING DATES
H. zea POPULATION
2000
1800
1600
1400
1200
1000
800
600
400
200
0

the plant, during the second infestation period, which coincided with a larger canopy and more fruiting structures available. A greater number of larvae on squares occurred during peak of squaring. The decreasing order of preference for fruiting structures was squares, flowers, and bolls. The high percentages of larvae found on leaves were due to the fact that the larvae counts coincided with maximum numbers of neonate larvae hatched on leaves. The lag time between oviposition and hatching period was not enough for the occurrence of migration of larvae to other suitable feeding sites.

High correlations were obtained among eggs on leaves and total numbers of eggs on the whole plant. However, these correlations were much lower when eggs on the terminal were regressed with total eggs on the plant. Total larvae on the upper of the plant yielded higher correlation coefficients than larvae on the terminal. This was true in all infestations and planting dates.

CHAPTER V

OVIPOSITION AND FEEDING PREFERENCES OF THE BOLLWORM, *HELIOTHIS ZEA* (BODDIE) (LEPIDOPTERA: NOCTUIDAE), ON COTTON

Introduction

Knowledge of the behavior of adult and immature stages of the bollworm, *Heliothis zea* (Boddie) is a prerequisite to developing an understanding of its population dynamics and biology. Literature concerning oviposition and feeding behavior of bollworms on cotton does exist but is not consistent. For example, Wilson et al. (1980) found that the largest percentages of eggs were laid on leaves. However, Farrar and Bradley (1985a) reported that oviposition location varied considerably from year to year. Both upper and lower surfaces of leaves were the most common site in two years, whereas in a third, terminals were the most favored. Quaintance and Brues (1905), and Mistric (1964) reported that fruiting structures had the highest percentages of eggs laid. However, Bernhardt and Phillips (1982) found the highest numbers of eggs on leaves before peak of squaring, followed by a high number on dried flowers late in the season. For *Heliothis armigera* Hubner, Parson (1940) and Beeden (1974) found the largest numbers of eggs on leaves, whereas Matthews and Tunstall (1968) reported that the largest percentages were found on stems.

In relation to feeding behavior, Quaintance and Brues (1905) reported that the sequential preference for damaging cotton plant parts by the bollworm, under laboratory experiments, was flowers, squares, bolls, terminals, and leaves. However, under field conditions, bollworm larvae were found mainly on squares and small bolls. Wilson et al. (1980) said that first and second instars caused great damage to median squares, and third, fourth, and fifth instars preferred flowers. Reese et al. (1981) found that anthers and filaments were the parts of squares most often eaten by bollworms. Parrott et al. (1978) found that tobacco budworm larvae usually spend two or three days feeding on the main stem terminals and leaves before moving to fruiting structures.

Burkett et al. (1983), when working with *H. zea* on tomatoes, *Lycopersicon esculentum* Mill., reported that survival of first instar larvae placed on flowers was higher than for larvae placed on terminals or leaves. They concluded that terminal feeding was almost exclusively confined to larvae which were initially placed on terminals. Ramalho et al. (1984) reported that second instar larvae of the tobacco budworm were mostly found on the upper third of the plant during the early season. However, during mid and late seasons, they were found in the middle and upper portions of the cotton plant. They concluded that the distribution of tobacco budworm larvae was a function of the instars and the phenological stage of the plant. Farrar and Bradley (1985a) reported on *Heliothis* spp., that first and second instars were more commonly found on squares and terminals during a three-year study. They also found that the preference for flowers was less distinct for the budworm than for the bollworm.

Bollworm oviposition and feeding preference sites, under laboratory experiments, have not been intensively studied. The studies presented here were undertaken, therefore, to determine the oviposition and feeding preferences of the bollworm on cotton leaves, squares, flowers, bolls, and main stem terminals.

Materials and Methods

Studies on the oviposition and feeding behaviors of the bollworm on the commercial cotton cultivar "Tamcot CAMD-E" were conducted in the laboratory with temperature 26 ± 2°C, relative humidity 55 ± 5%, and 14:10(L-D) photoperiod.

Oviposition Studies

Two laboratory experiments were conducted to study oviposition preferences of bollworm moths on different cotton plant parts. The first experiment was carried out under free-choice conditions, i.e., all treatments and replicates were placed in big cages and infested with bollworm adults. The second experiment was conducted under no-choice conditions, i.e., only one treatment was placed in a small cage and infested with bollworm adults. A detailed description of the methodology for each experiment will be presented below.

For the free-choice study, two wood-framed screen cages, measuring 2 m x 1 m at the base, and 0.7 m in height, with a 1 mm mesh nylon screen, were used. Water-filled cups of 120 ml capacity, with a hole of 1 cm on the lid, were used to accommodate plant parts. Two similar plant parts were placed in the cup with the stems inserted through the hole into the water, with a hole of 1 cm on the lid, were used to accommodate plant parts. Two similar plant parts were placed in the cup with the stems inserted through the hole into the water in order to maintain freshness. This experiment had eight replicates and five treatments in a randomized complete block design. The treatments were cotton plant parts, such as squares, flowers, bolls, leaves, and terminals. Each experimental unit consisted of five plastic cups, with two equal plant parts inserted in each cup. Each cage with four replicates were infested with five bollworm couples. They were allowed to stay in the cages for a two-day period.

For the no-choice study, wood-framed cages, measuring 0.6 m x 0.6 m at the base, and 0.5 m in height, with 1 mm mesh nylon screen, were used. In each cage, 20 plastic cups with two like plant parts each, as previously described, were infested with two bollworm pairs. They were allowed to stay in the cages for a two-day period. The treatments were the same as described in the free-choice study. This experiment was a randomized complete block design with four replicates and five treatments.

Plant parts were collected from the field and then taken to the laboratory. Each plant part and its associated stem were cut to a length of 15 cm. They were individually examined for eggs, larvae, and predators before being placed into the cups. Two days after infestation, each plant part was checked for bollworm eggs. The number of eggs on two plant parts in each cup was recorded. Data subjected to analyses of variance and means, when appropriate, were separated according to Duncan's Multiple Range Test (Duncan, 1955).

Feeding Studies

In these studies, 30 plastic boxes, measuring 32 cm in diameter, and 8 cm high, were used to accommodate plant parts and larvae. Each box was covered with another similar box and sealed with tape in order to avoid escapes. Plant parts were also collected from the field as described for the oviposition study.

For the first instar, eight plant parts, leaf (LF), terminal (TL), white flower (WF), red flower (RF), square with 4 mm in diameter (4S), 6 mm (6S), 8 mm (8S), and 10 mm (10S) in diameter, were randomly distributed in an equal distance in the box. The stems of each plant were covered with a wet cotton pad in order to keep them fresh during the experiment. Each box was infested with four neonate larvae placed at the center of the box. The larvae were allowed to stay in the boxes for a period of 48 hours. After that, plant parts were checked and recorded for number of larvae found on them.

A similar procedure described above was used for the second instar. Each box was infested with two second instar-larvae, placed at the center of the box. They were also allowed to stay in the boxes for a period of 48 hours. After that, plant parts were checked for damage or lack of damage caused by larvae on plant parts.

From third to sixth instars, plant parts such as squares of 6 mm in diameter (6S), 8 mm (8S), 10mm (10S), white flowers (WF), red flowers (RF), small bolls (< 1.5 cm in diameter SB), median bolls (> 1.5 cm and < 2.5 MB), and large bolls (> 2.5 cm in diameter LB) were used. Since cannibalism usually occurs with third and more advanced instars, only one larva was placed in each box. The recording procedure was the same used for the second instars, i.e., numbers and kind of plant parts damaged.

Standard analysis of variance (ANOVA) techniques were used. Graphs were prepared to illustrate numbers of plant parts damaged. Confidence intervals for the probability of plant parts damaged by each instar were developed based on the normal approximation to the binomial distribution, according to Remington and Schork (1970).

Results and Discussion

The ovipositional responses of H. zea to various cotton plant parts, under free-choice and no-choice experiments, are shown in Table XIII. Terminals and leaves were the most preferred sites for oviposition. Number of eggs on terminals and on leaves showed no statistical differences at 5% for both free-choice and no-choice experiments. In the free-choice study, high numbers of eggs laid on the screens of cages were observed. This had not been seen in the no-choice experiment, except for cages that contained flowers, squares, or bolls. This fact probably explains the general tendency of bollworm moths to lay their eggs on screen surfaces when other favorable sites are not available. In both experiments, there were no differences among the numbers of eggs placed on flowers, squares, and bolls. However, they were different from terminals and leaves.

In the free-choice study, a total of 239 eggs were deposited on terminals, 168 eggs on leaves, and 55, 49, and 27 on white flowers, squares and bolls, respectively. Since each treatment consisted of a row of five cups, with two equal plant parts in each, this comprised a total of 80 plant parts in the experiment for each treatment. The

TABLE XIII

MEAN NUMBER OF BOLLWORM EGGS ON COTTON PLANT PARTS IN FREE-CHOICE AND NO-CHOICE EXPERIMENTS

Plant Part	Free Choice*	No Choice
Terminal	6.0 A	42.5 A
Leaf	4.2 A	39.4 A
Flower	1.4 B	11.2 B
Squares	1.2 B	15.0 B
Boll	0.7 B	5.8 B

*Means in the same column followed by same letter are not significantly different (P = 0.05).

average number of eggs on each terminal was about three, two on leaves and less than one on the other plant parts. The highly significant F value in the oviposition tests indicated that bollworm moths prefer to lay eggs on plant parts such as leaves and terminals. Terminals and leaves have more tender succulent tissues with soft textured trichomes which could influence ovipositional behavior.

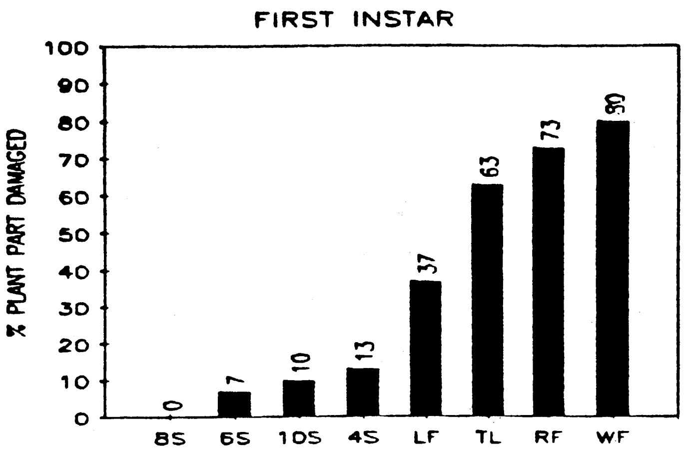
In the no-choice study, a total of 5,475 eggs was recorded on five types of plant parts during the experimental period. Of that total, 2,041 were placed on terminals, 1,893 on leaves, 720 on squares, 539 on white flowers, and 282 on bolls. This experiment showed high numbers of eggs placed on the screen cages when less preferred plant parts such as squares, bolls, or flowers were tested. However, fewer eggs were observed on the screen when the plant parts were leaves or terminals.

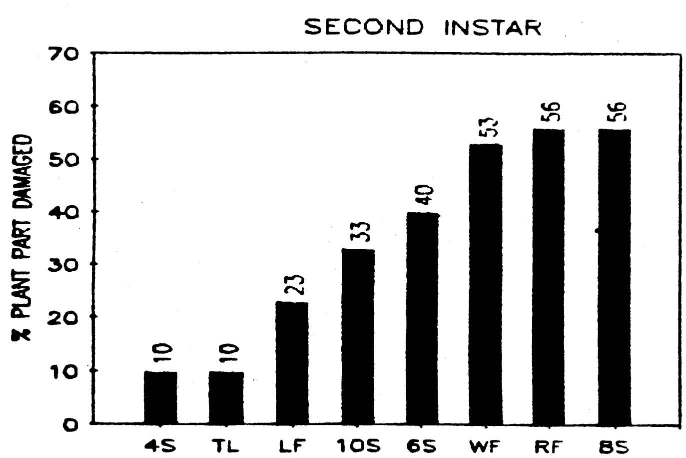
The feeding responses of bollworm larvae to various cotton plant parts are shown in Figures 14 and 15. The first instar showed a high preference of WF and RF. Since first instar larvae did not cause visual damage to plant parts, the recording procedure was based on the presence of larvae. Thus, 80 and 73% of all WF and RF had at least one first instar.

From second to sixth instars, the evaluation was based on the number of plant parts damaged. The second instar damaged 56% of all 8S, RF, and 53% of all WF. Leaf, TL, and 4S were the least preferred plant parts. The damage caused by second instar was easily seen by scratches on the plant part surfaces.

Third instars caused damage to 83% of WF and RF, and 70% to 10S. Large bolls were the least preferred. This instar caused extensive

Figure 14. Percentages of plant parts damaged by larval instars 1 to 3. 4S (squares 4 mm in diameter); 6S (squares 6 mm in diameter); 8S (squares 8 mm in diameter); 10S (squares 10 mm in diameter); WF (white flowers); RF (red flowers); SB (small bolls); MB (median bolls); LB (large bolls); LF (leaves); TL (terminals).


FIRST INSTAR
% PLANT PART DAMAGED
100
90
80
70
60
50
40
30
20
10
0
0
7
10
13
37
63
73
80
8S
6S
10S
4S
LF
TL
RF
WF


SECOND INSTAR
% PLANT PART DAMAGED
70
60
50
40
30
20
10
0
10
10
23
33
40
53
56
56
4S
TL
LF
10S
6S
WF
RF
8S

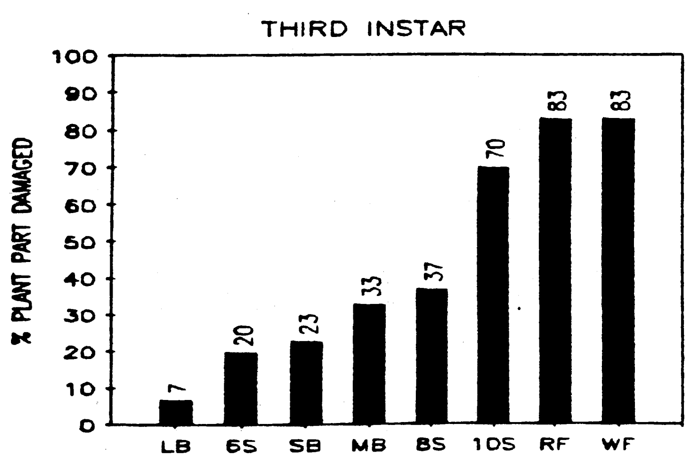
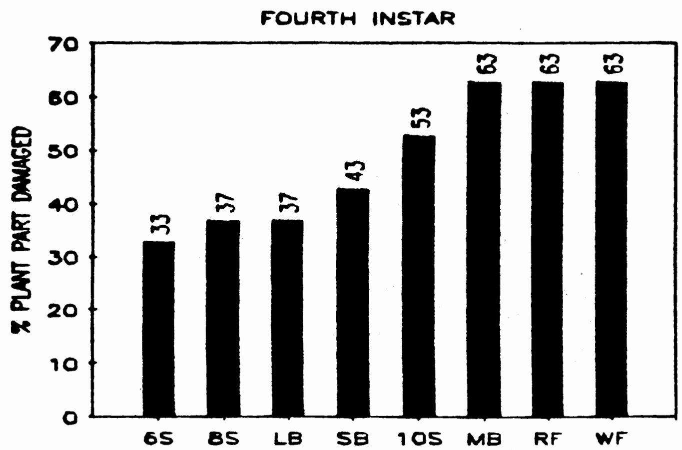
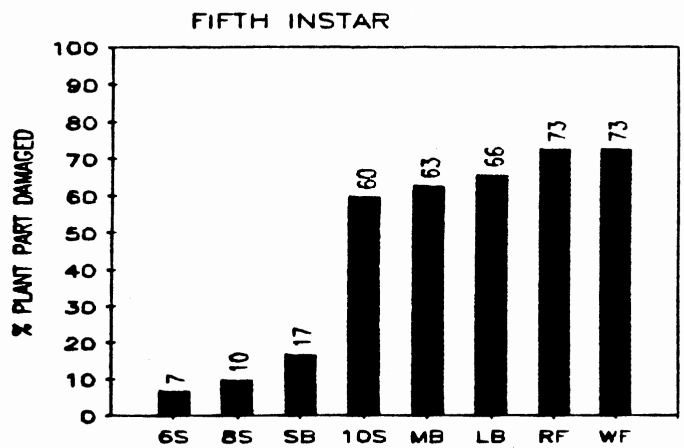
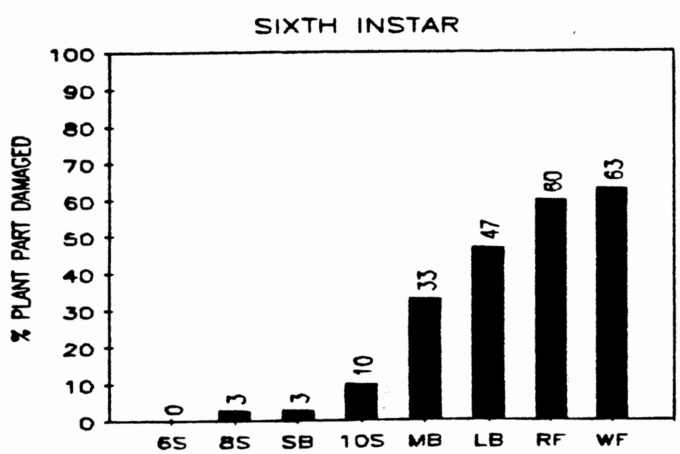

THIRD INSTAR
% PLANT PART DAMAGED
100
90
80
70
60
50
40
30
20
10
0
7
20
23
33
37
70
83
83
LB
6S
SB
MB
8S
10S
RF
WF

Figure 15. Percentages of plant parts damaged by larval instars 4 to 6. 4S (squares 4 mm in diameter); 6S (squares 6 mm in diameter); 8S (squares 8 mm in diameter); 10S (squares 10 mm in diameter); WF (white flowers); RF (red flowers); SB (small bolls); MB (median bolls); LB (large bolls); LF (leaves); TL (terminals).


FOURTH INSTAR
% PLANT PART DAMAGED
0
10
20
30
40
50
60
70
33
37
37
43
53
63
63
63
6S
8S
LB
SB
10S
MB
RF
WF


FIFTH INSTAR
% PLANT PART DAMAGED
0
10
20
30
40
50
60
70
80
90
100
7
10
17
60
63
66
73
73
6S
8S
SB
10S
MB
LB
RF
WF


SIXTH INSTAR
% PLANT PART DAMAGED
0
10
20
30
40
50
60
70
80
90
100
0
3
3
10
33
47
60
63
6S
8S
SB
10S
MB
LB
RF
WF

damage to many plant parts in each box. Fourth instars presented a high potential of destruction by feeding on over 30% of all plant parts. Highest preferences were observed for MB, RF, WF, and 10S. Damage by fifth instars to 10S, MB, LB, RF, and WF was the greatest observed in all boxes. However, these larvae showed little indication of feeding on 6S, 8S, and SB. There was a decreasing preference for SB and a high preference for LB. This instar showed a tendency to feed mostly on large bolls.

A reduction in the feeding activity of sixth instars relative to earlier stages was clearly seen. Plant parts such as WF, RF, and LB were highly preferred. In spite of sluggish behavior, these larvae caused heavy damage, especially to large bolls.

Confidence intervals for the probabilities of plant parts being damaged showed that the highest probabilities were observed for RF and WF in all instars. This was followed by 10S, MB, and LB (Table XIV).

These studies showed that TL and LF are the most favorable places for egg deposition by bollworm. Flowers, squares, and bolls were not significantly different. There is no specific study on the oviposition behavior of the bollworm on cotton plant parts. Only one study was conducted by Farrar and Bradley (1985b) with H. virescens. Previous investigations did not specify terminals as oviposition sites, but considered upper or upper half of the plant as a place for oviposition. This fact has caused some misinterpretation because the upper part of a plant includes terminal, leaves, squares, bolls, and flowers. This study strongly supports the findings in Chapters III and IV, which showed that main stem terminals and leaves are highly preferred places for egg deposition by bollworm moths.

TABLE XIV

CONFIDENCE INTERVAL* FOR PROBABILITY OF COTTON PLANT PARTS TO BE DAMAGED BY SIX LARVAL INSTARS OF THE BOLLWORM

Plant Part	Instar					
	I	II	III	IV	V	VI
4S	0.13±0.12	0.10±0.11	---	---	---	---
6S	0.10±0.11	0.40±0.18	0.20±0.14	0.33±0.17	0.07±0.10	0.0
8S	0.0	0.56±0.18	0.36±0.17	0.36±0.18	0.10±0.11	0.30±0.06
10S	0.10±0.11	0.33±0.17	0.70±0.16	0.53±0.16	0.60±0.18	0.10±0.11
LF	0.37±0.17	0.23±0.15	---	---	---	---
TL	0.63±0.17	0.10±0.11	---	---	---	---
WF	0.80±0.14	0.53±0.18	0.83±0.13	0.63±0.17	0.73±0.16	0.63±0.17
RF	0.73±0.16	0.60±0.18	0.83±0.13	0.63±0.17	0.73±0.16	0.60±0.18
SE	---	---	0.23±0.15	0.43±0.18	0.17±0.13	0.03±0.06
MB	---	---	0.33±0.17	0.63±0.17	0.63±0.17	0.33±0.17
LB	---	---	0.07±0.10	0.37±0.17	0.66±0.17	0.46±0.17

*Probability based on 30 occurrences; standard error based on normal approximation to the binomial distribution.

There is no consistent information on larval feeding sites of _Heliothis_ spp. In this study, 11 plant parts were used as feeding sites of six larval instars. It was clear that all larval instars preferred to damage WF and RF in all tests. Terminals were good feeding sites for first instars. All instars preferred to feed most heavily on the anthers of WF and RF. Most of the corolla tubes and petals were not destroyed by any instar during the feeding period.

Less than 10% of all different sizes of squares were preferred by first instars. It was clear that first instars do not prefer to feed on squares with the same degree as they do on WF, RF, TL, and LF. First and second instars were found on 37% of the leaves, but damaged only 25% of them. There was an increasing preference for 10S from the second to the fifth instars, with a high decline in the sixth instars. Median bolls presented similar results, except for third instars which were more preferable than LB.

Conclusions

The highly significant number of eggs on terminal and leaves indicated clearly that bollworm moths exhibit a high degree of preference for egg placement on these parts. These studies agree with previous results reported in Chapters III and IV.

Feeding sites for bollworm larvae were quite variable among instars and plant parts, except for white flowers and red flowers which were the most favorable feeding sites for all larval instars. Terminal and leaf were the second most damaged plant parts by the first instars. Squares of all sizes were not good feeding sites for first instar larvae. Squares presented an increasing degree of preference for the second to fifth instars. Terminals had low probabilities of being damaged by second instars. Large boll preferences increased from fourth to sixth instars, with a peak of damage in the fifth instars. Median bolls presented similar results, except the high preference shown by third instars. Small bolls were comparable to median bolls in the third instars. In the fourth instars, small bolls were comparable to large bolls. In the fifth and sixth instars, small bolls had low acceptance.

From the data presented here it is clear that egg placement can vary among plant parts. Consequently, caution should be taken in common scouting practices. Feeding preference sites are quite variable. It can vary not only among instars but also among cotton plant parts.

CHAPTER VI

LARVAL DEVELOPMENT AND SURVIVAL OF THE BOLLWORM, *HELIOTHIS ZEA* (BODDIE) (LEPIDOPTERA: NOCTUIDAE), ON COTTON PLANT PARTS

Introduction

Study of development and survival of the immature stages of the bollworm, *Heliothis zea* (Boddie), are important for an understanding of the biology and behavior of this pest. It is known that *Heliothis* spp. larvae have distinct feeding preferences, especially for cotton flowers and small bolls with dried flower corollas adhering to them (Farrar and Bradley, 1985b). Thus, it is essential that the effects of different parts of the plant on the development and survival of immature stages of the bollworm can be measured with information about developmental times, weight, and rate of survival.

Studies conducted by Reese et al. (1981) showed that more than 50% of damage occurs on squares less than 6 mm in diameter. In addition, they found that larvae feed most heavily on the anthers. However, Ramalho et al. (1984) found that young larvae of the tobacco budworm, *Heliothis virescens* (F), feed heavily on bracts of squares, and on carpel walls of bolls.

Burkett et al. (1983), studying the behavior of *H. zea* on tomatoes, *Lycopersicum esculentum* L., found that first instar larvae, when placed on flowers, fed there for at least four days. As the feeding declined on flowers, they started feeding on leaves and on fruits. Terry et al. (1987) found that H. zea larvae, fed on prebloom stages of soybean, weighed more than those fed on bloom or podfill stage plants. Quaintance and Brues (1905) reported that a bollworm larva may consume parts of 19 cotton squares during its larval life. They determined that the average consumption per larva is eight squares, one flower, and two bolls. However, Lincoln et al. (1967) showed that each bollworm larva can damage an average of 3.8 squares and 2.2 bolls. Isely (1935) stated that H. zea is essentially a borer and by preference feeds within the fruiting structures of plants or plant stems rather than externally upon them.

Farrar and Bradley (1985b) found that cotton flowers and artificial diet produce the highest percentages of larval establishment and shortest developmental times of bollworm. In addition, they found that the heaviest pupae were produced from treatment which included bolls. It is hypothesized that the survival and behavior of the bollworm might be strongly influenced by the site of initial contact of the larvae with the plant. These studies are an attempt to determine the effect of cotton plant squares, flowers, bolls, and main stem terminals on larval development and survival.

Materials and Methods

These studies were conducted in constant temperature chambers set at 26 ± 1°C (day) and 24 ± (night), 14:10 (L-D) photoperiod, and 65% R.H. Five plant parts, including leaves, squares, flowers, bolls, and main stem terminals, were used. In addition, an artificial diet

(Burton, 1970) was included to compare with plant parts. Plant parts were collected from the field and each prepared with a 12 cm stem section. They were individually examined for eggs, larvae, and predators before being placed into the cups. Rearing containers consisted of plastic cups (350 ml) each, with a 1 cm hole in the button. Two like plant parts were placed in the cup with stems inserted into another cup containing water.

This experiment consisted of six treatments (rows of cups in the chamber), and eight replicates (racks of cups in the chamber) in a randomized complete block design. Treatments consisted of the different plant parts and the artificial diet.

Initially, each cup with two plant parts was infested with three neonate larvae. The cups were covered with clear plastic lids through which pin-holes were made to allow air movement. Plant parts were replaced every three days, except flowers, which were replaced every day. Before the replacement of plant parts, the number of surviving larvae and their instars were recorded, based on head capsule measurements, according to Dyar (1890). From third to fifth instars, only one larva was put in each cup due to occurrence of cannibalism. If, in a cup, no living larva was found, a replacement was made by using a larva of the same instar, taken from a colony fed on the same type of plant part.

When at least two larvae in a given cup reached the third instars, they were considered established; the date of establishment and number of surviving larvae were then recorded. When larvae reached the fifth instars, they were transferred to a small cup (30 mL) with wheat germ to facilitate pupation, and 5 g of artificial diet in order to supply the final feeding requirements before pupation. The numbers of days required to reach the sixth instars were recorded, as well as pupal weights and time until adult emergence.

The experiments were analyzed by analyses of variance procedures (SAS Institute, 1985). Mean separations were determined by Waller-Duncan tests (P = 0.5) in a randomized complete block design.

Results and Discussion

The highest mortality (93.8%) observed in first instars was for those placed on bolls. The highest percentage of survival (54.7%) of first instars were on artificial diet. Survival larvae on leaves, squares, and flowers were not significantly different, but they were different than those on bolls (Table XV). The damage caused by first instars on any plant part was not easily seen without using a binocular microscope. The lowest rate of survival on bolls is probably due to toughness surface of bolls. The highest percentage of survival on terminals and leaves indicate that these plant parts offer a suitable feeding site for neonate larvae. These results agree with the findings in Chapter V, except for flowers which were the highly preferred feeding site for first instar larvae, whereas in the survival test flowers were inferior to terminals.

For the second instar, flowers, bolls, squares, and leaves proportionated the highest percentages of survival for the second instar, comparable to artificial diet. The lowest percentages of survival were recorded for larvae fed on terminals and leaves, which were not significantly different. In the third instars, bolls, flowers, squares, and leaves had the highest rate of survival. The lowest rate

TABLE XV

PERCENTAGES* OF SURVIVAL OF BOLLWORM LARVAE FED ON DIFFERENT COTTON PLANT PARTS AND ARTIFICIAL DIET

Plant Part	Instar				
	First	Second	Third	Fourth	Fifth
Artif. Diet	54.7 A	66.1 A	96.9 A	100.0 A	100.0 A
Terminal	44.5 B	44.5 B	75.0 B	87.5 AB	78.1 C
Leaf	40.6 BC	63.4 AB	81.2 AB	90.6 AB	96.8 AB
Squares	35.2 C	68.7 A	84.4 AB	78.1 B	84.3 C
Flower	35.2 C	78.6 A	90.6 AB	93.7 A	87.5 BC
Boll	6.2 D	78.1 A	93.7 A	100.0 A	96.8 AB

*Within each column, means followed by the same letter are not significantly different ($P < 0.05$; Duncan's (1955) new multiple range test).

of survival was observed on terminals. Survival on terminals was not significantly different from survival on leaves, squares, and flowers. The third instars showed high preference for feeding on the stems of plant parts. Stems of leaves and terminals were usually bored into by these larval instars. Consequently, stem dissections were usually required in order to find a hidden larva.

Survival of fourth instars was high on bolls, flowers, leaves, and terminals. There were no differences among bolls, flowers, leaves, terminal, and artificial diet. The lowest survival rate was found on larvae fed on squares, which was significantly different from that on bolls, artificial diet, and flowers. The reason why survival rates of larvae fed on terminals and leaves was high is probably due to the use of the stems of these plant parts as a food source. This may indicate that the stems of these plant parts supply these larvae with essential food sources for their survival. The fifth instars showed high rates of survival on bolls and leaves. The lowest percentages of survival were found on terminals and squares. Survivals on bolls, flowers, leaves, and artificial diet were not significantly different.

Larval establishment was highly significant for larvae fed on flowers, squares, and leaves when compared with those fed on bolls. The lowest percentages of establishment were obtained in larvae fed on bolls (Table XVI). This may indicate that larvae fed on bolls did not reach the third instars as fast as when fed on other plant parts.

Larvae fed on terminals, leaves, and squares took the longest time to reach the sixth instars. They were not significantly different from each other. The shortest time was obtained from larvae fed on diet. Pupae from artificial diet, bolls, and leaves were the

TABLE XVI

TRENDS* OF BOLLWORM DEVELOPMENT FROM LARVA TO ADULT FED ON COTTON PLANT PARTS AND ARTIFICIAL DIET

Plant Part	Instar			
	% Larvae Establish.	No. Days 6th Instar	Pupa Weight (mg)	No. Days Adult Emerg.
Artif. Diet	47.9 A	11.1 D	482.1 A	30.6 D
Terminal	26.0 C	17.9 A	426.9 B	38.4 A
Leaf	33.3 BC	17.8 A	470.5 A	36.5 B
Squares	30.2 BC	18.1 A	432.0 B	36.5 B
Flower	35.0 B	12.8 C	435.7 B	32.0 C

*Within each column, means followed by the same letter are not significantly different ($P < 0.05$; Duncan's (1955) Multiple Range test).

heaviest. They were significantly different when compared to pupae from terminals, squares, and flowers.

The highest percentages of larval establishment corresponded to the shortest period for reaching the sixth instars. Larvae fed on bolls and leaves had the highest pupal weights. Consequently, the fastest adult emergences were observed on bolls.

Conclusions

The feeding sequence of neonate and more mature larvae instars begins with the response to certain tactile, chemical, olfactory, and gustatory stimuli that maintain the larvae on the host and stimulate them to feed. These studies present evidence that bollworm larvae can accept, establish, and develop on various cotton plant parts such as main stem terminals, leaves, squares, flowers, and bolls. The highest percentages of mortality occurred during the establishment period. The highest percentages of mortality, over 90%, occurred during the first instars on larvae fed on bolls. For the fifth and sixth instars, the highest mortality occurred on squares and terminals, respectively.

Larval establishment was high on artificial diet and flowers. Days to reach the sixth instars were shorter on flowers. Pupal weights were higher on diet, bolls, and leaves. Numbers of days for adult emergence were lower on artificial diet and on flowers.

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Doctor of Philosophy

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