The *Journal of Cotton Science* 3:35-44 (1999)
http://journal.cotton.org, © The Cotton Foundation 1999

ARTHROPOD MANAGEMENT

Damage to Cotton Fruiting Structures by the Fall Armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae)

R. G. Luttrell and J. S. Mink

INTERPRETIVE SUMMARY

Fall armyworm is a sporadic pest of cotton that feeds on leaves and fruiting structures. Research was conducted at Mississippi State Univ. to measure the amount of fruit feeding by fall armyworm at different stages of cotton crop development and to develop estimates of fruit damage rates for economic thresholds. Results indicated that fall armyworm larvae have the potential to damage cotton fruiting structures at rates comparable to those of the cotton bollworm and tobacco budworm, assuming similar survival rates. Development of economic thresholds for fall armyworm will require additional studies to relate current or revised sampling procedures to expected fruit damage. Relationships between insect density and fruit damage in this study should be helpful in the design of these studies.

ABSTRACT

Cotton at three stages of crop phenological development was infested with eggs and third instar larvae of the fall armyworm, *Spodoptera frugiperda* (J.E. Smith), to determine the effect of larval feeding on fruit damage and yield. Regression analyses indicated that numbers of damaged squares and bolls were significantly ($P \leq 0.05$) influenced by the number of egg masses and third instars placed on the plants. More damage resulted with infestations of third instars than with eggs. Fruiting structures that were penetrated tended to have lower probabilities of survival to harvest than did non-penetrated or undamaged fruit. In a subsequent study with individual larvae confined for 48 h by cotton bags on fruiting structures, third instars damaged 0.63 squares, 0.72 small bolls, and 0.40 large bolls; fourth instars damaged 0.71 squares, 0.76 small bolls, and 0.63 large bolls; and fifth instars damaged 0.83 squares, 0.81 small bolls, and 0.66 large bolls. Damage to squares by all instars resulted in a significant ($P \leq 0.05$) reduction in survival of fruit to harvest. Feeding on small bolls by fourth and fifth instar larvae, but not third instar larvae, resulted in significant ($P \leq 0.05$) reductions in probability of harvest. Feeding on large bolls did not reduce the probability of survival of fruit to harvest.

The fall armyworm prefer species in the grass family as hosts (Luginbill, 1928), but damaging populations can occur on other economically important plants, such as cotton and soybean (Bass, 1978; Pitre, 1979; Young, 1979; Pitre and Hogg, 1983). Studies have shown that one fall armyworm strain—the corn-cotton strain—prefers cotton as a host, while another strain prefers grasses (Pashley and Martin, 1987; Pashley et al., 1992). The fall armyworm is a sporadic pest that does not overwinter in most areas of the USA (Luginbill, 1950). Population densities vary tremendously from year to year and place to place, but damaging populations infrequently develop on cotton in the Midsouth.

As corn acreage increases in traditional cotton-production regions such as the Midsouth, there is concern that the fall armyworm will become a pest of increasing importance on cotton. Another concern, as it relates to fall armyworm, is the growing popularity of transgenic cottons, which express endotoxin proteins of *Bacillus thuringiensis kurstaki*. The fall armyworm is one of the least susceptible lepidopterans to the endotoxin proteins expressed in cotton (MacIntosh et al., 1990; Wan, 1994). Damaging densities of fall armyworm on these transgenic cottons will likely need to be treated with conventional insecticides.

R. G. Luttrell, Department of Entomology and Plant Pathology, Mississippi Agricultural and Forestry Experiment Station, Box 9775 Mississippi State University, Mississippi State, Mississippi 39762; and J. S. Mink, Zeneca Ag. Products, Rt. 1, Box 65, Leland, MS 38756. Received 2 July 1998.
Correspondence - K. Knighten, Department of Entomology and Plant Pathology, Box 9775, Mississippi State, MS 39762, (ksk2@ra.msstate.edu).

The fall armyworm does not routinely infest cotton in the Midsouth, and little research has been conducted to quantitatively describe feeding and damage of this pest on cotton. Quantifiable economic thresholds are not available and control recommendations are based largely on subjective opinions and personal experiences. Several papers on the biology and ecology of fall armyworm on cotton have been published during the past decade. They included studies on the distribution of fall armyworm egg masses on cotton (Ali et al., 1989), survival of fall armyworm immatures on cotton (Ali and Luttrell, 1990), distribution of fall armyworm larvae within the cotton canopy (Ali et al., 1990a), and developmental rates of fall armyworm feeding on cotton (Ali et al., 1990b). Mink and Luttrell (1989) and Smith et al. (1993) have reported on commonly used insecticides for control of fall armyworm. Chandler (1995) reported on the potential use of insect growth regulators for *Spodoptera* spp.

Earlier literature contains numerous reports of fall armyworm damaging cotton (Dew, 1913; Walton and Luginbill, 1916; Luginbill, 1928; Vickery, 1929; Pitre, 1979; Clower, 1984; Smith, 1985), but no quantitative information exists on the amount and type of damage caused by fall armyworm feeding on this crop. This type of information is available for fall armyworm feeding on corn and sorghum (Henderson et al., 1966; Morrill and Greene, 1974; Cruz and Turpin, 1983). A considerable amount of information can be found in the literature describing damage to cotton by other lepidopteran pests, particularly bollworm (*Helicoverpa zea* Boddie) and tobacco budworm (*Heliothis virescens* F.) (Adkisson et al., 1964; Kincade et al., 1967; Hartstack et al., 1978). These studies were conducted to measure the effects of feeding of fall armyworm larvae on damage and retention of cotton fruiting structures. The results should be useful to those interested in the development of economic thresholds (Stern et al., 1959) for this pest on cotton.

MATERIALS AND METHODS

Fall armyworm larvae were confined on individual cotton fruiting structures to measure fruit retention from different levels of feeding damage. All studies were conducted in a field of 'Stoneville 506' cotton planted during early May 1986 and 1987 and maintained under normal growing conditions on the Plant Science Research Farm at Mississippi State Univ., Mississippi State, MS.

Presquaring cotton was thinned to 10 plants m^{-1} plant density (74,100–98,800 plants ha^{-1}). Additional thinning to 5 plants m^{-1} (49,500 plants ha^{-1}) was done 1 wk prior to insect infestation in order to facilitate plant handling during artificial infestations. Applications of the insecticides cypermethrin (0.32 kg [AI] ha^{-1}) and azinphosmethyl (1.35 kg [AI] ha^{-1}) were made before and after infestations when necessary to protect the cotton against bollworm, tobacco budworm, and boll weevils (*Anthonomous grandis grandis* Boheman). The study plots were sprayed with a non-persistent insecticide (mevinphos 1.35 kg [AI] ha^{-1}) 1 d prior to infestation to reduce the number of predators present.

Egg masses were obtained from a fall armyworm colony maintained at the USDA-ARS Crop Science Research Laboratory, Mississippi State, MS. This colony was initiated with insects collected from corn. Subsequent studies, that involved infesting cotton with fall armyworm larvae, were conducted with insects originally collected from cotton. This was to ensure that the corn-cotton strain of fall armyworm (Pashley and Martin, 1987; Pashley et al., 1992) was used in the studies. For all studies, insects were reared by the procedures described by Davis et al. (1985) and fed a wheat germ-casein diet (Davis, 1989).

Infestation of Cotton with Egg Masses

In 1986 egg masses as uniform in size as possible (45 ± 9 eggs $mass^{-1}$) were obtained by placing a wire screen (0.32 × 0.32 cm) onto wax paper before oviposition and visually selecting the appropriate masses. Four egg mass densities (0 per plant, 3 per 10 plants, and 1 and 5 per plant) were applied by pinning the egg mass through the border of the wax paper to the midribs on the abaxial leaf surface in the middle portion of the plant. Cotton was infested at three stages of crop phenological development (squaring, flowering, and boll maturation). During the squaring stage, the fruit load on the plant averaged 12.8 squares, <1 bloom, and <1 boll per plant. At the flowering stage, the plants had an average of 14.6 squares, 1.9 blooms, and 9.1 bolls per plant. Fruit on plants at the boll maturation stage were mainly bolls (average of 1.9 squares, <1 bloom, and 16.0 bolls per plant).

To allow the fall armyworm larvae to disperse and behave as if an entire field was infested at uniform densities, we also infested 10 plants on each side of the plots with egg masses. Plots contained five plants, were at least 1 m long, and were replicated 10 times. The plots were monitored weekly after infestation by making whole plant observations until no fall armyworm larvae were found. Information was recorded on fall armyworm density and sizes (estimated larval instar), plant damage, and fruit production. Plants were hand harvested during the last week of September, and the harvested seed cotton was weighed to determine yield differences among treatments. The experiment was conducted in a split plot design with whole plots and sub-plots arranged in a randomized complete block design. Our whole plots were the stages of plant phenological development; egg mass densities were the sub-plots. Data were analyzed using analysis of variance and regression analysis (MSTAT, 1986) at $P \leq 0.05$.

Infestation of Cotton with Larvae

High mortality of egg masses from unknown causes occurred in our 1986 studies. Therefore, additional studies were conducted during 1987 with plants infested with third instar fall armyworm. During three phenological stages of plant development (squaring, flowering, and boll maturation), four densities of larvae (0, 2, 6, and 18 per plant) were placed on cotton-plant fruiting structures using low-tension forceps.

Each phenological stage was treated as a separate study. The fruiting structures on the plants during the squaring stage averaged 27.4 squares, <1 bloom, and <1 boll per plant. During the flowering stage, an average of 19.2 squares, 2.9 flowers, and 12.9 bolls per plant were observed in the plots. Fruit on the plants at the boll maturation stage of crop development consisted mainly of bolls (averaging 1.9 squares, <1 bloom, and 16.0 bolls per plant). If a plant did not contain adequate fruiting structures in which to place the larvae (1 larva per fruiting structure), larvae were placed on leaves in a randomized complete block design.

Each plot was 3 rows wide and 6 m long. All plants within each plot were infested, but observations were restricted to 10 consecutive plants in the center row. Infestation during the squaring stage was replicated seven times in natural uncaged environments.

During the flowering stage, four replicates of natural uncaged environments and four replicates of caged environments using 6.1 × 6.1 × 2.1 m field cages (32-mesh screen) were infested. During the boll maturation stage, only four replications in caged environments were infested.

Plants were mapped by recording the main stem and branch node position of all fruit prior to infestation, at 3 and 7 d post-infestation, and at harvest. Data were also recorded for each selected fruit class (small square = square with bract width <0.5 cm, medium square = square with bract width 0.6 cm to 1.2 cm, large square = square with bract width >1.2 cm, flowers, small bolls = boll diameter 1.5 cm to 2.5 cm and large bolls = boll diameter >2.5 cm) including the total number of fruit, damage to the fruit, fall armyworm larvae density, and type of fall armyworm injury. The types of damage caused by fall armyworm are described in detail by Mink (1988) and include "calyx feeding," "penetration" (feeding had resulted in a hole in the corolla of squares or carpel wall of bolls, "bract plus calyx feeding," "bract feeding plus penetration," "calyx feeding plus penetration," "bract plus calyx feeding plus penetration," and "total destruction" (extensive internal feeding and hollowing out of fruiting structure).

Mapping the plants prior to infestation provided sufficient information to follow all fruiting structures from infestation until harvest. Fruit survival to harvest also was recorded for each damage class. The plots were hand harvested on 1 and 8 October when about 75 and 95% of the total bolls were open in the uninfested plots, respectively. The data were analyzed using analysis of variance (ANOVA) and regression techniques (MSTAT, 1986).

To determine the impact of the different types of fall armyworm injury on each cotton fruiting structure, the types of damage within fruiting structure classes were grouped across larval density treatments in each experiment, and the probability of harvest was determined. The types of damage were categorized into two groups, "vegetative" (feeding restricted to bract and/or calyx) and "penetrative" (feeding had resulted in a hole in the corolla of squares or carpel wall of bolls). The undamaged fruit within each age class were used as a standard with which to compare among the damage categories.

An additional category, total damage (total number of fall armyworm damaged fruit within a fruit class), was included in the analysis for comparison purposes. These individual comparisons were performed using a K-sample binomial test for equal proportions (Marascuilo and McSweeney, 1975). This pair-wise comparison procedure adjusts alpha levels for each comparison to control experiment-wise Type I error ($P \leq 0.05$).

Caging Larvae on Individual Fruit

Third, fourth, and fifth instar larvae were caged individually on cotton fruiting structures in 5.5 x 7.0 cm cotton cloth bags. Four separate groups of larvae were used in order to avoid removing a bag more than once in 24h. The observation periods for the four groups were 6 and 30, 12 and 36, 18 and 42, and 48h. Damage to young fruiting structures late in the growing season is generally considered to have little effect on yield. Thus, the age classes of fruit included in the present experiments were large squares (1 to 1.5 cm bract width), small bolls (ca. 1.5 to 2.5 cm in diameter), and large bolls (>2.5 cm in diameter). Larvae were placed on undamaged fruiting structures by transferring them from their artificial diet with low-tension forceps. Preliminary studies indicated that fall armyworm larvae transferred from artificial diet survived and damaged cotton equally as when they had been allowed to feed on cotton fruiting structures 48 h prior to infestation (Mink, 1988). After larvae were placed on the fruit, the cotton bags were placed around the fruiting structures and closed with a drawstring. A cloth laundry tag (2 x 4 cm) was attached around the stem of the fruiting structure to aid in post treatment observations. All infestations were made either early in the morning or late in the afternoon to reduce the effects of high temperature on survival of larvae.

Separate experiments were conducted for each age class of fruit. All of the experiments were conducted in a randomized complete block design with three treatments (larval instar) and four replications. Each treatment included 25 individually caged larvae on plants in a 20-m section of row (200 plants per plot). A single plant generally had only one caged insect.

All data were analyzed by ANOVA and means were separated by Duncan's (1955) multiple range test. Means were significantly different at $P \leq 0.05$. The experiment with squares was conducted in July (14 and 25) when the plants were in the squaring stage and the fruit on the plant consisted of mainly squares and a few blooms. The experiment on bolls was conducted during the first week of September when the plants contained a few squares and flowers but mainly small and large bolls.

Bags were removed at either 24 or 48 h to determine the status of the insect and to note the types of damage to the fruiting structure. Damage was categorized as vegetative, penetration, and total destruction. Another category, no damage, was also included. Observations were again made at harvest (13 and 14 October) by removing and counting the tags that were associated with harvestable cotton bolls when ca. 90% of the fruit in the untreated check (bagged fruit without an insect) were mature.

RESULTS

Infestation of Cotton with Egg Masses

Each egg mass contained 45 ± 9 eggs. Percent survival for egg masses was determined as follows: number of larvae observed / (45 x number of egg masses per 10 plants). Fall armyworm survival was only 0.07 % (1587 larvae found after 22,680 larvae infested) 3 d after the egg masses were placed on the cotton plants. Regression analyses indicated that several plant-damage variables in both the squaring and flowering stages of crop development were significantly influenced by number of egg masses placed on the plants (Table 1). The number of damaged squares, damaged bolls, and total damaged plant structures were related significantly to egg mass density in both the squaring and flowering stages of plant phenological development. The number of leaves damaged by fall armyworm larvae was significantly influenced by density of egg masses in the squaring stage, as was the number of flowers damaged in the flowering stage.

Table 1. Cotton plant variables found to be significantly related (P ≤ 0.05) to *S. frugiperda* egg mass density.

Variable	Regression† slope (SE)	Regression intercept	Correlation coefficient	*P*
Infestation at squaring stage of development				
Damaged leaves	0.483 (0.225)	0.29	0.329	0.038
Damaged squares	1.536 (0.179)	0.23	0.813	0.000
Damaged bolls	0.049 (0.024)	0.01	0.316	0.046
Total damage‡	2.101 (0.217)	0.52	0.844	0.000
Infestation at flowering state of development				
Damaged squares	0.933 (0.312)	0.06	0.436	0.004
Damaged flowers	0.919 (0.057)	0.10	0.479	0.001
Damaged bolls	1.358 (0.216)	0.34	0.713	0.000
Total damage‡	2.482 (0.435)	0.49	0.679	0.000

† Regression equation is in the form of y = a + bx where y = variable observed (number per 10 plants), a = regression intercept, b=regression slope, and x=number of egg masses (average of 45 ± 9 eggs) placed on each plant.

‡ Total damage includes squares and a few small bolls. Total damage at the flowering stage included squares, flowers, and bolls.

Infestation of Cotton with Larvae

Infesting cotton plants with third instar larvae produced more damage than when plants were infested with egg masses. Fall armyworm damage 7 d after infestation did not differ from that recorded 3 d after infestation. After 3 d, survival of fall armyworm larvae was 2.5 % (123 larvae found of 4940 infested) and no larvae survived to 7 d postinfestation. Factors responsible for this low survival were not identified.

During the squaring stage of crop development, fall armyworm larvae caused significant levels of damage to small, medium, and large squares (Table 2). Small and medium squares exhibited several types of damage although bract feeding was the most common type of damage observed. The total number of fruit damaged was significantly influenced by fall armyworm density in all three fruit classes (Table 1). As the density of larvae increased, more damage was observed.

Infestations of fall armyworm larvae at the flowering stage also produced several plant damage variables that were significantly affected by density of fall armyworm larvae (Table 2). The fruit age classes primarily affected were small and large bolls (based on regression slopes). Medium squares and blooms were not influenced by fall armyworm density. During the boll maturing stage, the majority of fruit on the plants was large bolls. Feeding damage on large bolls was increased significantly by density of fall armyworm larvae. However, this increased level of damage did not result in reductions in harvestable fruit (Fig. 1).

Table 2. Cotton plant variables found to be significantly related (P ≤ 0.05) to *S. frugiperda* larval density.

Variable	Regression† slope (SE)	Regression intercept	Correlation coefficient	*P*
Infestation at squaring stage of development				
Damaged‡ small squares	0.397 (0.090)	0.67	0.656	0.000
Damaged medium squares	1.513 (0.299)	9.24	0.704	0.000
Damaged large squares	0.016 (0.008)	0.00	0.372	0.051
Infestation at flowering stage of development§				
Damaged large squares	0.074 (0.017)	-0.17	0.755	0.000
Damaged small bolls	0.219 (0.102)	0.23	0.613	0.011
Damaged large bolls	0.472 (0.102)	-0.57	0.776	0.030
Infestation at maturation stage of development				
Damaged large bolls	0.221 (0.056)	0.07	0.726	0.001

† Regression equation is in the form of y = a + bx where y = variable observed (number per 10 plants), a = regression intercept, b = regression slope and x = number of larvae placed on each plant.

‡ Damage includes vegetative feeding and penetration. Vegetative damage was feeding injury to the surface of the fruit. Penetration damage resulted in a hole in the carpel walls of the fruit.

Yield was not significantly influenced by number of larvae placed on plants at P ≤ 0.05 in any experiment, although the slopes of regressions tended to be negative between fall armyworm larvae and the amount of cotton harvested as number of fall armyworm larvae increased (Mink, 1988). Regression of numbers of larvae placed on plants against yield showed no significant effect [Total yield = -6.34 (number of larvae placed on plants) + 592, *P* = 0.07]. Analysis of variance

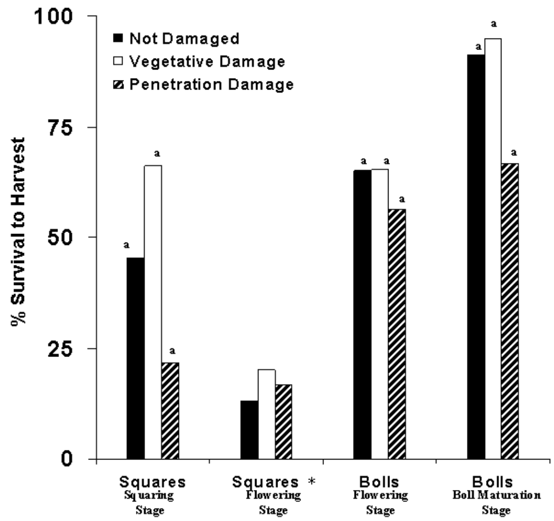

Figure 1. Percent of cotton squares and bolls damaged by *S. frugiperda* that survived to harvest. *Number of squares damaged at the flowering stage were insufficient to perform individual comparisons.

indicated no significant differences in % survival of fruit to harvest for the three types of fall armyworm feeding damage during the flowering stage of plant phenological development in caged and uncaged plots (data shown only for uncaged plots in this report refer to Mink (1988) for more detail).

As might be expected during plant phenological development, feeding damage by larvae was limited to large squares during squaring and to large bolls during boll maturation because these were the primary fruiting structures available during those stages (Fig. 1). During the flowering stage, larvae damaged both squares and bolls, but more bolls than squares were damaged during this stage. The number of damaged squares was insufficient to perform the K-sample binomial test to determine differences in probabilities of harvest. However, the probabilities of harvest calculated for squares could be useful in estimating economic thresholds on cotton.

Caged Larvae on Individual Fruit

Mortality of fall armyworm larvae when caged individually on cotton fruiting structures was low (<10%, 816 of 900 survived to 48 h). No significant differences existed in mortality among instars, so the effects of damage are not adjusted for mortality. Large larvae caused more damage than did small

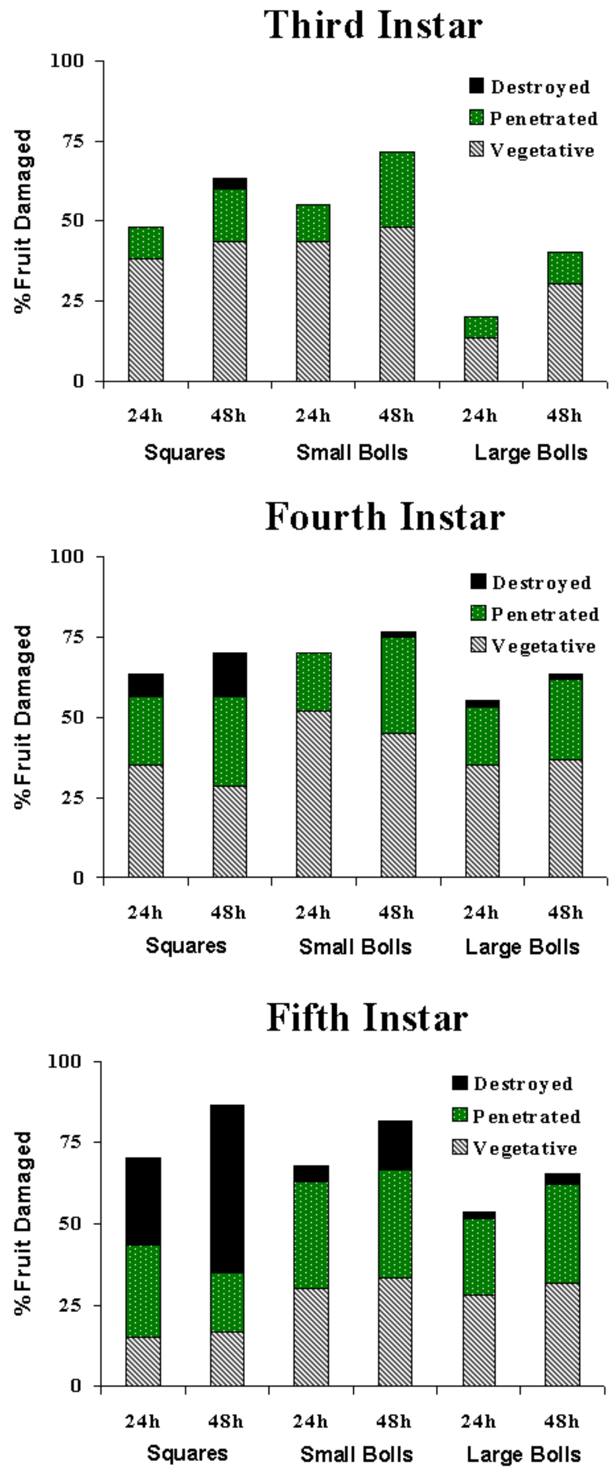

Figure 2. Type and amount of damage resulting from feeding of *S. frugiperda* larvae individually caged for 24 and 48 h on cotton squares and large bolls.

larvae except for large bolls (Fig. 2). The percentage of squares damaged increased significantly from 21 ± 19.7% (mean ± standard deviation) to 63 ± 11.9% for third instars, 46 ±

9.5% to 71 ± 5.0% for fourth instars, and 52 ± 3.3% to 86 ± 5.2% for fifth instars, respectively, from 6 to 48 h of exposure (data not shown for 6 hr of exposure in Fig. 2). Third instars penetrated the squares in less than 6 h, but did not completely destroy any squares until 36 h post-infestation. Penetration of squares by fourth instars also occurred within 6 h, and destruction of squares occurred within 18 h. Fifth instars were able to destroy squares in less than 6 h of exposure. Fifth instars destroyed significantly more fruit than the other instars at 18, 24, 30, 42 and 48-h post-infestation (data shown only for 24 and 48 h in Fig. 2). However, there were no significant differences at harvest in the survival of squares exposed to fourth (25.3 ± 14.8%) and fifth (22.5 ± 13.6%) instars (Fig. 3). Significantly more squares damaged by third instars were harvested (43.5 ± 23.6%) than those damaged by fourth and fifth instars. All instars significantly reduced the survival of squares to harvest, compared with those that were not exposed to larvae (83.5 ± 12.0% survival of undamaged squares). Since it is probable that "destroyed" and "penetrated" squares did not contribute to harvest, the effect of "vegetatively" damaged squares on harvest can be estimated. Of the squares "vegetatively" damaged by third instars and fourth instars, 54 and 81% were not harvested, respectively. However, only 24% of those vegetatively damaged by fifth instars were not harvested.

As with the squares, significantly more small bolls were destroyed by fifth instars at both post treatment measurements (6.0 ± 4.0% at 24 h, and 15.0 ± 5.0% at 48h.). Third instars showed no destroyed bolls (0.0 ± 0.0%) at both measurement times (Fig. 2). This damage was reflected in the number of small bolls surviving to harvest (Fig. 3), as well as in the overall trend for fifth instars to damage more fruiting structures. Only 34 ± 10.0% of the small bolls infested with fifth instars survived to harvest (Fig. 3). This was significantly lower than that observed for survival of small bolls damaged by fourth (50.0 ± 10.0%) and third (73.0 ± 8.4%) instars. The percentage of small bolls exposed to third instars and surviving to harvest was not significantly different from the untreated check (65.0 ± 4.0%). It appeared that "penetration" and "destruction" of small bolls by fourth and fifth instars resulted in the fruit not being harvested, while "vegetative" damage did not reduce the probability of harvest. "Penetration" damage by third instars appeared to have less effect in reducing the probability of harvest. There may have been a difference in the depth of penetration by the different instars, but this was not recorded.

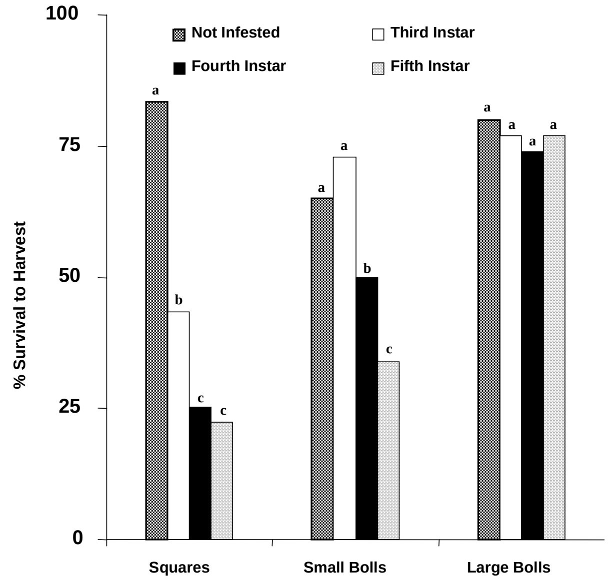

Figure 3. Effect of feeding by third, fourth and fifth instar *S. frugiperda* caged individually for 48 hr on cotton fruiting structures on number of fruit surviving to harvest.

As observed with small bolls and squares, the fourth and fifth instars significantly damaged more large bolls than third instars at both 24 and 48 h post-infestation (Fig. 2). However, the impact of this damage was not reflected in the percentage of bolls surviving to harvest since none of the instars caused damage which significantly reduced the percentage of large bolls harvested (77.0 ± 6.0) as compared to that for the untreated check (80.0 ± 7.2) (Fig. 3). Neither "penetration" nor "vegetative" damage of a large boll appeared to reduce the probability of harvest of large bolls.

DISCUSSION

Although survival of fall armyworm on cotton was low in all studies, this insect exhibited the potential to cause damage to cotton fruiting structures. This was illustrated in that damage was found to all age classes of fruit when the cotton plants were infested with the egg masses and resulting larvae dispersed on the plant normally.

In the infestation of cotton with larvae, preferences for various age classes of fruit by third instars may have been masked by the procedures used to infest the plants. After infesting the plants, however, the larvae were free to move normally. In these studies, damage was again observed on virtually all age classes of fruit present on the plant. Ali et al. (1990a) found that first and second instars of the fall armyworm feed primarily on leaves, but third instars gravitate to cotton fruiting structures. Later instars feed predominately on cotton fruiting structures.

Fall armyworm fed on all age classes of cotton fruiting structures, but the damage did not always have an effect on survival of fruit to harvest. Although "penetration" of bolls did not always reduce probability of harvest, it may cause a decrease in quality and quantity of lint or increase the probability of disease under different environmental conditions. These effects were not recorded in this study.

Information resulting from these studies can be used to construct simple thresholds (Poston et al., 1983) for fall armyworm on cotton. Our present study determined information at each phenological stage of development, on the number of fall armyworm larvae present, the number and type of damaged fruit in a particular age class, and the probabilities of each damage category within a fruit age class being harvested. These data are an important first step in calculating simple thresholds for fall armyworm on cotton.

Fall armyworm larval damage to cotton fruiting structures may be put into perspective by comparison with larval damage of *H. virescens* and *H. zea*. Nicholson (1975) reported that *H. virescens* larvae damaged 0.51 squares d^{-1} $larva^{-1}$ and 0.1 bolls d^{-1} $larva^{-1}$ during their total development on the cotton plant, and *H. zea* larvae damaged 0.55 squares d^{-1} $larva^{-1}$ and 0.15 $bolls^{-1}$ d^{-1} $larva^{-1}$. These data indicate that *H. virescens* and *H. zea* larvae damage more squares d^{-1} $larva^{-1}$ than fall armyworm larvae. Fall armyworm larvae caused damage to squares when egg masses and third instars were placed on plants at the squaring and flowering stages of crop development (Tables 1 and 2), but the amount of damage was low. Low survival rates of eggs and small larvae contributed to the low damage rates measured in regressions with infestation densities. Calculated number of damaged squares per fall armyworm egg mass infested at the squaring stage was less than 0.2 for the entire observation period (3 wk of observations). Higher survival rates would have increased this estimated damage potential.

The damage rates for *H. virescens* and *H. zea* reported by Nicholson (1975) are conservative estimates relative to those measured for the individual caged fall armyworm larvae on cotton fruiting structures in our study. In Nicholson's studies, larvae were allowed to move freely and select feeding sites on the plant, and the average values were calculated across all larval instars. Early instar *H. virescens* and *H. zea* prefer squares to bolls and thus spend more time feeding on squares than on bolls. If *H. virescens* and *H. zea* larvae had been caged on the fruiting structures, as were the fall armyworm larvae in our study, there might have been more damage to bolls.

The estimated damage to bolls by feeding of fall armyworm larvae in the studies reported here ranged from 0.40 bolls per 2 d per infested larva for third instars feeding on large bolls to 0.81 bolls per 2 d per infested larva for fifth instars feeding on small bolls.

A relative comparison of boll damage may be postulated if one assumes that first and second instars of both species do not feed on bolls and that the average length of the larval stage is 15 d with 3 d in each of five instars. Based on these assumptions, fall armyworm larvae would damage 0.23 bolls d^{-1} $larva^{-1}$ throughout the entire larval stage if feeding rates for large bolls are used. This estimated damage rate is actually higher than those reported by Nicholson (1975) for *H. virescens* (0.1 $bolls^{-1}$ d^{-1} $larva^{-1}$) and *H. zea* (0.15 $bolls^{-1}$ d^{-1} $larva^{-1}$). These estimates suggest that feeding by fall armyworm larvae on bolls may be as damaging as that by *H. virescens* and *H. zea*. A more detailed examination of thresholds for fall armyworm on cotton is found in Mink (1988).

The current recommended threshold for *H. virescens* and *H. zea* on cotton in Mississippi is four larvae per 100 plants (Layton, 1997). This action level is based on detection of small larvae in the terminals. Survival of larvae in the absence of insecticide and expected levels of control are important considerations in the development of thresholds. Studies by Mink and Luttrell (1989) indicated that fall armyworm larvae would be more difficult to control than *H. virescens* and *H. zea* because they are found lower within the plant canopy (Ali et al., 1990a). Fall armyworm survival on cotton is low and the detection of egg masses and small larvae requires more attention that detection of *H. virescens* and *H. zea* eggs and larvae (Ali and Luttrell, 1990). Most often, fall armyworm infestations are recognized after the larvae have developed to late instars and have begun to feed on fruiting structures. The need to control late instars of the fall armyworm larvae when large populations are present on cotton seems to be just as great as the need to control late instars of *H. virescens* and *H. zea*. Current recommendations for detection of fall armyworm in Mississippi are based on examinations of blooms and bolls. Feeding on the bracts of bolls in the lower part of the plant and detection of larvae in blooms will trigger insecticide applications. These sampling procedures are expensive and time consuming but are warranted when high population densities of fall armyworm are present and when cotton is an attractive crop for fall armyworm oviposition (Pitre, 1979; Ali et al., 1989).

ACKNOWLEDGMENTS

The authors thank Frank Davis, Blake Layton, Henry Pitre, and Mike Williams for reviews of early drafts of this manuscript. The Cotton Foundation and Mississippi Agricultural and Forestry Experiment Station provided funds for this research. This is manuscript J93-07 in the journal series of the Mississippi Agricultural and Forestry Experiment Station.

REFERENCES

Adkisson, P.L., C.F. Bailey and R.L. Hanna. 1964. Effect of the bollworm, *Heliothis zea*, on yield and quality of cotton. J. Econ. Entomol. 57:448–450.

Ali, A., R.G. Luttrell, H.N. Pitre and F.M. Davis. 1989. Distribution of fall armyworm (Lepidoptera: Noctuidae) egg masses on cotton. Environ. Entomolg. 18:881–885.

Ali, A. and R.G. Luttrell. 1990. Survival of fall armyworm (Lepidoptera: Noctuidae) immatures on cotton. Fla. Entomol. 73:459–465.

Ali, A., R.G. Luttrell and H.N. Pitre. 1990a. Feeding sites and distribution of fall armyworm (Lepidoptera: Noctuidae) larvae on cotton. Environ. Entomolg. 19:1060–1067.

Ali, A., R.G. Luttrell and J.C. Schneider. 1990b. Effects of temperature and larval diet on development of the fall armyworm (Lepidoptera: Noctuidae). Ann. Entomol. Soc. Am. 83:725–733.

Bass, M.H. 1978. Fall armyworm: Evaluation of insecticides for control. Auburn Univ. Agric. Exp. Stn., Leaflet 93:7.

Chandler, L.D. 1995. Compatibility of insect growth regulators and bacterial insecticides for management of Spodoptera spp. p.1043–1045. *In* D.A. Richter and J. Armour (ed.) Proc. Beltwide Cotton Conf., San Antonio, TX. 5–8 Jan. 1995. Natl Cotton Council Am., Memphis, TN.

Clower, D.F. 1984. Thrips, whiteflies and *Spodoptera* problems in the Midsouth. p. 182–183. *In* J.M. Bown and T.C. Nelson (ed.). Proc. Beltwide Cotton Conf., Atlanta, GA. 8–12 Jan. 1984. Natl Cotton Council Am., Memphis, TN.

Cruz, I. and F.T. Turpin. 1983. Yield impact of larval infestations of the fall armyworm (Lepidoptera:Noctuidae) to midwhorl growth stage of corn. J. Econ. Entomol. 76:1052–1054.

Davis, F.M., T.G. Oswalt and S.S. Ng. 1985. Improved oviposition and egg collection system for the fall armyworm (Lepidoptera:Noctuidae). J. Econ. Entomol. 78:725-729.

Davis, F.M. 1989. Rearing the southwestern corn borer and fall armyworm at Mississippi State University. p. 27–36 *In* Toward insect resistant maize for the third world: Proceedings of the international symposium on methodologies for developing host plant resistance to maize insects. CIMMYT. Mexico City, Mexico.

Dew, J.A. 1913. Fall armyworm, *Laphygma frugiperda*. J. Econ. Entomol. 6:361-388.

Duncan, D.B. 1955. Multiple range and multiple F test. Biometrics 11:1-41.

Hartstack, A.W., R.L. Ridgway and S.L. Jones. 1978. Damage to cotton by the bollworm and tobacco budworm. J. Econ. Entomol. 71:239-243.

Henderson, C.F., H.G. Kinzer and E.G. Thompson. 1966. Growth and yield of grain sorghum infested in the whorl with fall armyworm. J. Econ. Entomol. 59:1001-1003.

Kincade, R.T., M.L. Laster and J.R. Brazzel. 1967. Damage to cotton by the tobacco budworm. J. Econ. Entomol. 60:1163–1164.

Layton, M.B. 1997. Cotton insect control guide, 1997. Publ. 343, Mississippi State Univ.

Luginbill, P.A. 1928. The fall armyworm. USDA Tech. Bull. 34. U.S. Gov. Print Office.

Luginbill, P.A. 1950. Habits and control of the fall armyworm. USDA Farmers' Bull. 1990. U.S. Gov. Print Office.

MacIntosh, S.C., T.G. Stone, S.R. Sims, P.L. Hurst, J.T. Greenplate, P.G. Marrone, F.J. Perlak and R.L. Fuchs. 1990. Specificity and efficacy of purified *Bacillus thuringiensis* proteins against agronomically important insects. J. Invertebr. Pathol. 56:258–266.

Marascuilo, L.A. and M.McSweeney. 1975. Nonparametric and distribution-free methods for the social sciences. Wadsworth Publ Co., Inc. Belmont, CA.

Mink, J.S. 1988. Damage potential and chemical control of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), on cotton. M.S. Thesis, Mississippi State Univ.

Mink, J.S. and R.G. Luttrell. 1989. Mortality of fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) eggs, larvae and adults exposed to several insecticides on cotton. J. Entomol. Sci. 24:563–571.

Morrill, W.L. and G.L. Greene. 1974. Survival of fall armyworm larvae and yields of field corn after artificial infestations. J. Econ. Entomol. 67:119-123.

MSTAT. 1986. Microcomputer statistical program: User's guide. Michigan State Univ. East Lansing, MI.

Nicholson, W.F. 1975. Feeding of *Heliothis virescens* (F.) and *H. zea* (Boddie) on cotton with emphasis on development of a simulation model of larval feeding. Ph. D. Diss., Mississippi State Univ., Mississippi State, MS.

Pashley, D.P. and J.A. Martin. 1987. Reproductive incompatibility between host strains of the fall armyworm (Lepidoptera:Noctuidae). Ann. Entomol. Soc. Am. 80:731–733.

Pashley, D.P., A.M. Hammond, and T.N. Hardy. 1992. Reproductive isolating mechanisms in fall armyworm host strains (Lepidoptera: Noctuidae). Ann. Entomol. Soc. Am. 85:400–405.

Pitre, H.N. 1979. Fall armyworm on sorghum: other hosts. Bull. 876. Mississippi Agric. For. Exp. Stn. Mississippi State, MS.

Pitre, H.N. and D.B. Hogg. 1983. Development of the fall armyworm on cotton, soybean and corn. J. Georgia Entomol. Soc. 18:182-187.

Poston, F.L., L.P. Pedigo and S.M. Welch. 1983. Economic injury levels: reality and practicality. Bull. Entomol. Soc. Am. 29:49–53.

Smith, R.H. 1985. Fall and beet armyworm control. p.134–136. *In* J.M. Brown and T.C. Nelson (ed.) Proc. Beltwide Cotton Conf., New Orleans, LA. 6–11 Jan. 1985. Natl Cotton Council Am., Memphis, TN.

Smith, T.W., M.J. Sullivan, and S.G. Turnipseed. 1993. Control of fall armyworm in South Carolina cotton—producer/consultant dilemma. p. 869–870. *In* D.J. Herber and D.A. Richter (ed.) Proc. Beltwide Cotton Conf., New Orleans, LA. 10–14 Jan. 1993. Natl Cotton Council Am., Memphis, TN.

Stern, V.M., R.E. Smith, R. van den Bosch and K.S. Hagen. 1959. The integrated control concept. Hilgardia 29:81–101.

Vickery, R.A. 1929. Studies of the fall armyworm in the Gulf Coast district of Texas. Tech. Bull. 138. USDA, Washington, DC.

Walton, W.R. and P. Luginbill. 1916. The fall armyworm or grass worm and its control. Farmers' Bull. 752. USDA. Washington, DC.

Wan, L. 1994. Susceptibility and avoidance to *Bacillus thuringiensis* endotoxin in noctuid larvae attacking cotton and soybean. M.S. Thesis, Mississippi State Univ. Mississippi State, MS.

Young, J.R. 1979. Fall armyworm: Control with insecticides. Fla. Entomol. 62:130-133.