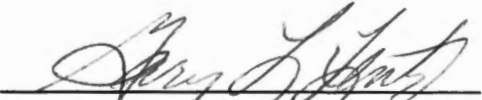


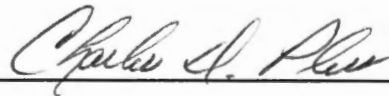
To the Graduate Council:

I am submitting herewith a thesis written by Jerry L. Harris entitled "Impact of cotton tillage systems on in-season and overwintering survival and emergence of *Heliothis virescens*." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Entomology and Plant Pathology.



Gary L. Lentz, Major Professor

We have read this thesis
and recommend its acceptance:





Accepted for the Council:



Associate Vice Chancellor and
Dean of The Graduate School

**IMPACT OF COTTON TILLAGE SYSTEMS ON
IN-SEASON AND OVERWINTERING
SURVIVAL AND EMERGENCE OF
*Heliothis virescens***

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Jerry L. Harris

December 1998

Ag-VetMed

Thesis

98

.H377

ACKNOWLEDGMENTS

The author would like to extend a special thank you to Dr. Gary Lentz for serving as my major professor during this thesis research. His leadership, knowledge and friendship was very appreciated.

The author would also like to thank Dr. Charles Pless for serving as my academic advisor. His advice and guidance was appreciated.

I would also like to thank Dr. Thomas Mueller for serving on my committee. His advice and guidance was also appreciated.

The completion of this research would not have been possible without the staff at WTES. A special thanks to Nancy Van Tol. I would also like to thank Zach Holt, Holly Holt, Bill Cearley, Jeff Jones, Chris Hilliard, Clint Wilson, Tiffany Thompson, and Kelli Ross.

The author wishes to express sincere thanks to my family for all of the support they have shown, especially my father, J.P. (Pete), and mother, Loyce.

ACKNOWLEDGEMENTS

I would like to thank Cotton Incorporated and the Tennessee State Support Committee for funding this research.

I would also like to thank Dow AgroSciences for supplying the tobacco budworm larvae for this research.

ABSTRACT

Cotton has been used as a fabric for thousands of years, and today cotton is an important crop grown in the United States with more than 6,000,000 hectares planted in 1996. Cotton is not indigenous to the United States and was relatively free of insect pests until the boll weevil was found in Texas in 1892. Extensive use of calcium arsenate for control of the boll weevil up to 1945 is correlated with the tobacco budworm, *Heliothis virescens* (F.), emergence as a pest species.

Tobacco budworms cause damage to cotton by feeding on the fruiting structures of the plant. Approximately 15 d after hatching, larvae stop feeding, move downward and tunnel into the soil, forming a cell in which they change to the pupal stage.

Research was conducted at the West Tennessee Experiment in 1997 and 1998 to evaluate the impact of tillage systems on the survival and emergence of tobacco budworm. The objectives of this research were to: 1) determine the impact of tillage on in-season emergence and survival of tobacco budworm and to understand the influence of climatic conditions, 2) determine the impact of tillage on overwintering emergence and survival of tobacco budworm and to understand the influence of climatic conditions.

The two tillage treatments for this research were a total no-till production system and a double disked treatment at planting with subsequent weed flushes

controlled with herbicides. The double disked treatment was conducted just prior to planting for the in-season study and the previous spring for the overwintering study.

In all of the in-season cohorts a higher percentage of moths emerged in the no-till system, but this difference was not statistically significant at the $p < .05$ level. More moths emerged later in the growing season and there was significant differences between the different infestation date cohorts. Two variables, degree day-60's, and precipitation, explained 60% of variation in emergence percentage, and these were significant at the $p < .05$ level.

There were no significant differences in emergence percentage between the two tillage treatments in the overwintering study. Precipitation, days that the temperature reached 0°C , and duration from infestation to emergence in d were studied to find any significant influences on spring emergence percentage. None of these environmental factors significantly influenced emergence percentage.

This research indicated that very low numbers of tobacco budworm can successfully overwinter in cotton fields independent of tillage system. Crop growth and precipitation also influence tobacco budworm emergence more than tillage system during the growing season. A producer can continue to utilize a no-till cotton production system and receive this systems benefits without increasing tobacco budworm numbers.

TABLE OF CONTENTS

CHAPTER	PAGE
I. LITERATURE REVIEW.....	1
II. IMPACT OF TILLAGE ON IN-SEASON SURVIVAL AND EMERGENCE OF <i>Heliothis virescens</i> , THE TOBACCO BUDWORM, IN COTTON.....	14
i. Introduction.....	14
ii. Materials and Methods.....	16
a. 1997.....	16
b. 1998.....	19
iii. Results and Discussion.....	20
a. 1997.....	20
b. 1998.....	26
c. Summary.....	31
III. EFFECTS OF TILLAGE ON OVERWINTERING POPULATIONS OF <i>Heliothis virescens</i> IN COTTON.....	35
i. Introduction.....	35
ii. Materials and Methods.....	37
iii. Results and Discussion.....	38
IV. REFERENCES CITED.....	42
VITA.....	53

LIST OF TABLES

TABLE	PAGE
1. Effects of tillage systems on survival and emergence of early season (June 16 cohort) <i>Heliothis virescens</i> (West Tennessee Experiment Station, Jackson, TN, 1997).....	21
2. Effects of tillage systems on survival and emergence of mid-season (July 3 cohort) <i>Heliothis virescens</i> (West Tennessee Experiment Station, Jackson, TN, 1997).....	23
3. Effects of tillage systems on survival and emergence of mid-season (July 11 cohort) <i>Heliothis virescens</i> (West Tennessee Experiment Station, Jackson, TN, 1997).....	23
4. Effects of tillage systems on survival and emergence of late season (July 31 cohort) <i>Heliothis virescens</i> (West Tennessee Experiment Station, Jackson, TN, 1997).....	24
5. Effects of tillage systems on season-long survival and emergence of <i>Heliothis virescens</i> (West Tennessee Experiment Station, Jackson, TN, 1997).....	24
6. Effects of tillage systems on survival and emergence of early season (June 08 cohort) <i>Heliothis virescens</i> (West Tennessee Experiment Station, Jackson, TN, 1998).....	27
7. Effects of tillage systems on survival and emergence of mid-season (June 26 cohort) <i>Heliothis virescens</i> (West Tennessee Experiment Station, Jackson, TN, 1998).....	27
8. Effects of tillage systems on survival and emergence of mid-season (July 13 cohort) <i>Heliothis virescens</i> (West Tennessee Experiment Station, Jackson, TN, 1998).....	28
9. Effects of tillage systems on survival and emergence of late season (July 24 cohort) <i>Heliothis virescens</i> (West Tennessee Experiment Station, Jackson, TN, 1998).....	28

10. Effects of tillage systems on survival and emergence of late season (August 14 cohort) <i>Heliothis virescens</i> (West Tennessee Experiment Station, Jackson, TN, 1998).....	29
11. Effects of tillage systems on season-long survival and emergence of <i>Heliothis virescens</i> in 1998 (West Tennessee Experiment Station, Jackson, TN, 1998).....	29
12. Effects of tillage systems on season-long survival and emergence of <i>Heliothis virescens</i> in 1997 and 1998 (West Tennessee Experiment Station, Jackson, TN, 1998).....	32
13. Effects of tillage systems on survival and emergence of overwintering (September 16 cohort) <i>Heliothis virescens</i> (West Tennessee Experiment Station, Jackson, TN, 1997).....	39
14. Effects of tillage systems on survival and emergence of overwintering (October 24 cohort) <i>Heliothis virescens</i> (West Tennessee Experiment Station, Jackson, TN, 1997).....	41
15. Effects of tillage systems on overwintering survival and emergence of <i>Heliothis virescens</i> (West Tennessee Experiment Station, Jackson, TN, 1997).....	41

LIST OF FIGURES

FIGURE	PAGE
1. Seasonal emergence of <i>Heliothis virescens</i> in 1997 (West Tennessee Experiment Station, Jackson, TN, 1997).....	25
2. Seasonal emergence of <i>Heliothis virescens</i> in 1998 (West Tennessee Experiment Station, Jackson, TN, 1998).....	30
3. Regression equation for in-season emergence of <i>Heliothis virescens</i> from West Tennessee cotton (West Tennessee Experiment Station, Jackson, TN, 1998).....	33

CHAPTER I

LITERATURE REVIEW

Cotton, *Gossypium hirsutum* L., has been used as a fabric for nearly 5,000 years. The oldest archaeological record of cotton textiles was discovered at Mohenjo-daro in the valley of the Indus River in West Pakistan and is believed to date back to 3,000 B.C. (Brown and Ware 1958). Today cotton is an important crop grown in the United States, with more than 6,000,000 hectares planted in 1996 (Williams 1997). It is doubtful that cotton was indigenous to the United States, and the exact time of its introduction is unrecorded (Handy 1896). There is evidence that cotton was grown in the Virginia colony in 1607 (Brown and Ware 1958). During the colonial period two kinds of cotton were mentioned. One had naked black seed, and the other had fuzzy green seed. The green-seed variety was apparently better in production and this is the seed that Whitney's gin was invented to mill (Brown and Ware 1958). As the southern colonies developed, more cotton was grown on the "upland" soils away from the coast, and since the green-seed plants were better in production this became known as Upland cotton. Due to plant breeding efforts, many types of Upland cotton, including Deltapine, Stoneville, Fox and others, are the parents of today's high yielding varieties commonly grown throughout the cotton belt.

Many factors go into producing a profitable cotton crop. The successful production of cotton is largely controlled by climatic conditions such as sunshine, temperature, wind, rainfall and humidity (Collings 1926). Although climatic conditions are out of the producers control, other inputs can be manipulated for a high and profitable yield. Fertilizers have played an important part in the development of agriculture in the South, as have disease, weed and insect control.

A reported 465 species of insects feed on the cotton plant (Collings 1926). Cotton is attractive to insects because of its large succulent leaves, the presence of nectaries on leaves and flowers and the abundance of fruiting structures (Roberts and Lentz 1995). Insects and mites that feed on cotton have either been introduced from foreign cotton regions or have spread to cotton from other plants since cotton is not a native species (Brown and Ware 1958). A 6.61% reduction in yield was caused by insects and mites throughout the cotton belt in 1996 (Williams 1997). Among the key pests are the boll weevil, *Anthonomus grandis grandis* Boheman; tarnished plant bug, *Lygus lineolaris* Palisot de Beauvois; cotton aphid, *Aphis gossypii* Glover; twospotted spider mite, *Tetranychus urticae* Koch; three species of stink bugs; and five species of thrips (Carter et al. 1982). In 1996 these six groups of insects and mites combined for a 3.7% reduction in yield in the United States.

The second most injurious species of insect on cotton in 1996 was the boll weevil, which accounted for a 1.86% yield loss and infested 2.8 million

hectares (Williams 1997). An invader from Mexico, the boll weevil was found in a cotton field near Brownsville, Texas in 1892 and had gradually spread north and east until it had infested nearly the entire cotton belt (Collings 1926). Today the boll weevil eradication program has freed 1.8 million hectares in 8 states of this pest. This program is scheduled to begin in Tennessee with fall diapause sprays in 1998 (Cunningham and Grefenstette 1998). The favorite food of the boll weevil is the pollen in the unopened flower bud, or square, where the insect feeds and causes the square to flare its bracts and eventually abort. Oviposition also occurs in squares and young bolls and has the same effect as feeding (Carter et al. 1982). Calcium arsenate was used for chemical control until 1945, and then the shift was made to the chlorinated hydrocarbons (Brown and Ware 1958). Today the organophosphate group of insecticides is the control measure most often recommended. As of the present, the boll weevil has been the greatest single factor in causing shifts of emphasis in cotton production in this country (Brown and Ware 1958).

The most destructive insect pest in 1996 was the Heliothine complex which caused a 2.3% reduction in yield (Williams 1997). The Heliothine complex (Lepidoptera: Noctuidae) is made up of two species, the bollworm, *Helicoverpa zea* Boddie, and the tobacco budworm, *Heliothis virescens* Fabricius. In addition to cotton, these pests attack corn, tomatoes, soybeans, grain sorghum and tobacco (Warren 1979). The bollworm has been known to be a pest of cotton since the early 1800s, and the tobacco budworm was apparently

first identified on cotton by Folsom during the 1934 growing season (Pfrimmer et al. 1981). These insects feed on the terminal bud, squares, flowers, bolls and leaves of the cotton plant. Feeding damage can not be distinguished between the bollworm and the tobacco budworm, although the tobacco budworm prefers squares to bolls and feeds on leaves more readily (Folsom 1936). Quaintance and Brues (1905) reported the average consumption per bollworm larva to be 8 squares, 1 flower, and $1\frac{2}{3}$ bolls. The average damage of the tobacco budworm larva has been reported to be 10.0 squares, 1.2 blooms and 2.1 bolls (Kincade et al. 1967). Adkisson et al. (1964) estimated that 1.5 to 2.0 larvae per 3 meters of row would cause significant yield loss. The current economic threshold in Tennessee is 4 larvae per 100 plants.

Bollworm and tobacco budworm occur mid-season to late season. Emergence of adults from overwintered pupae is low and previous studies have reported a 2.6% survival for bollworm and 3.8% for tobacco budworm (Stadelbacher and Martin 1980). This generation of larvae feeds on wild host plants until agronomic crops are available. The host association of these insects also changes with geographic location (Neunzig 1963). The bollworm has been collected on plants from nine families, and the tobacco budworm has occurred on plants belonging to 12 families (Chamberlin and Tenhet 1926, Barber 1937). The F_1 generation of moths moves into crops in June (Stadelbacher 1981). In most years populations build up in other crops and then migrate into cotton in

damaging levels in July and August. Peak oviposition occurs with peak bloom of any particular host (Adkisson et al. 1964).

The tobacco budworm usually lays eggs in the upper $\frac{1}{3}$ of the cotton plant (Hillhouse and Pitre 1976). The egg is yellowish-white when deposited and darkens prior to hatching after ca. 3 d (Neunzig 1964). The eruciform larva feeds for ca. 15 d, depending on climatic conditions, and develops through six instars before dropping to the ground to pupate. The larva burrows into the soil to form its pupal cell and emergence tunnel, and the entrance is backfilled with soil (Hardwick 1965). Pupation can last from 13 d during the growing season until several months during diapause conditions. The obtect pupa then splits the pupal case along the median dorsal line of the thorax and the imago crawls forward until it is free (Callahan 1958). Once emerged from the soil the imago searches for a place to hang and dry its wings. The imago is usually nocturnal in its oviposition habits although it is crepuscular in its feeding habits. According to literature, imagos mate between 30-60 h after emerging (Agee 1969). Under laboratory conditions adults have lived up to 2 weeks and by the fifth d females had produced ca. 1,000 eggs (Proshold et al. 1982, Shorey et al. 1968).

Identification of the two species can be difficult, especially the early instar. Neunzig (1964) found the only reliable way to distinguish between the bollworm and tobacco budworm in the first or second instar stage was the arrangement of the setae, in particular the L1 with regard to the spiracle. Older larvae can be distinguished by whether the spines extend onto the pinacula of abdominal

segment 8 (Carter et al. 1982). The tobacco budworm has been reported as being harder to kill since 1964 (Pfrimmer et al. 1981). Thus, proper identification is critical to control, especially with pyrethroid-resistant strains of tobacco budworm being discovered throughout the cotton belt (Leonard 1991).

Control of the tobacco budworm is usually accomplished by either chemical, biological, host-plant resistance or cultural control. Prior to the 1940s the tobacco budworm was a minor and sporadic pest of cotton (Bradley et al. 1987). Extensive use of calcium arsenate for control of the boll weevil up to 1945 is correlated with the tobacco budworm emergence as a pest species (Bottrell and Adkisson 1977). This was attributed to the fact that synthetic insecticides were detrimental to beneficial predators and parasitoids. Beginning in 1947 organochlorine insecticides became widely used as insecticides on both boll weevil and tobacco budworm. It was recorded that tobacco budworm populations would flare up after an organochlorine spray was used, and in some years as many as 15-25 sprays would be necessary (Bradley et al. 1987).

Resistance to organochlorine insecticides developed in both boll weevils and tobacco budworms and soon the organophosphate insecticides became widely used. Organophosphate insecticides have two distinct features. They are generally much more toxic to vertebrates than the organochlorines and they are chemically unstable and nonpersistent in the environment (Ware 1994). The most recent class of insecticides to be used against the Heliothine complex is the pyrethroids. Since their introduction in 1978, they have taken a major

portion of the market because they are very effective against Heliothines, relatively non-toxic to mammals and they are not environmentally persistent (Bradley et al. 1987). Due to the extensive use of pyrethroid insecticides since their introduction, a number of states throughout the cotton belt have reported resistant strains of tobacco budworm (Elzen 1993). Research and extension entomologists have developed a series of integrated management strategies to further delay the development of widespread pyrethroid resistance. Pyrethroid resistance management plans recommend a restricted use window from July 1 to August 15 for these products (Leonard et al. 1991). The longevity of this plan depends on the development of alternative active ingredients for control outside this window since previous classes of insecticides already have some resistance problems. Many different insecticides are currently effective against the Heliothine complex, but they are also detrimental to the beneficial insect fauna.

The use of naturally occurring predaceous arthropods is a major component of integrated pest management (IPM) (McDaniel and Sterling 1982). Whitcomb and Bell (1964) recorded over 600 species of predators of *Heliothis* spp. in Arkansas cotton fields. Studies have shown that these predators reduced *Heliothis* eggs and larval populations by as much as 96% (Ables et al. 1978). Variation is due to the amount of predators in the field and the abundance of alternate prey, especially the cotton aphid.

Another important component of biological control is insect pathogens. Several viral, fungal and bacterial species cause diseases in the tobacco

budworm. The bacterium, *Bacillus thuringiensis* (Bt), has been the most exploited. Bt was first registered as a microbial pesticide in 1959 (Yearian et al. 1986). Genetic engineering techniques have isolated a specific gene from *Bacillus thuringiensis* var. *kurstaki* Berliner and transferred these Bt genes into the DNA of cotton plants (Buehler 1993). The Bt cotton expresses insecticidal activity in every plant tissue and may provide protection against the Heliothine complex (Fischhoff 1992). The producer may not have to apply topical insecticides, therefore protecting beneficial arthropods and making the cotton crop more profitable simultaneously.

Several cultural practices to control the tobacco budworm have been used in the past. The effect of fertilizers, especially nitrogen (Beckham 1969, Adkisson 1958) and irrigation timing (Slosser 1980), have all been studied. Tillage has been studied since 1928 as a control of the Heliothine complex (Barber 1937). Later studies (Fife and Graham 1966, Hopkins et al. 1972, Leonard et al. 1992) all indicated that cultivation of soil containing pupae of Heliothines limits or eliminates emergence of the moths. Growers frequently till their soils to prepare a seed and root bed and to control weeds (Troeh et al. 1980). Conventional tillage is the combined primary and secondary tillage operation normally performed in preparing a seedbed for a given crop grown in a given geographical area and has been the cause of several problems (Mannering et al. 1987). Tillage represents a significant investment in labor, equipment and fuel. Intensive tillage also encourages rapid decomposition of

soil organic matter and has a negative long-term impact on soil structure or tilth (Hutchinson 1993). Soil organic matter significantly increases the soil's cation exchange capacity, the soil's ability to hold nutrients, and the subsequent loss of organic matter equals a loss in the soil's productivity (Foth and Ellis 1997).

Ojeniyi and Dexter (1979) found that multiple passes with a tillage implement reduced the aggregate size and sorted the sizes so that the smaller ones tended to migrate toward the bottom of the tilled layer thus forming a traffic pan and restricting the depth that a plant's roots can grow. Tillage also destroys plant residue and greatly increases soil erosion rates (Hutchinson 1993). Because of these problems many cotton producers have switched to some conservation tillage technique.

Conservation tillage is defined as any tillage and planting system that maintains at least 30% of the soil surface covered by residue after planting to reduce soil erosion (Mannering et al. 1987). No-till is a form of conservation tillage where the soil is left undisturbed prior to planting. In 1997, Tennessee cotton producers planted over 206,500 ha with 48,600, or 23%, planted no-till (Danekas 1997). No-till systems potentially reduce costs of labor, equipment and fuel, but in many instances savings in these areas are offset by higher costs for pest control, especially weeds (Hutchinson 1993). A ten-year study on cotton yields at the Milan Experiment Station, Milan, Tennessee, concluded that the no-till production system averaged 1020 kg/ha of lint, while the conventional tillage system averaged 1002 kg/ha (Bradley 1993). Variation in this study was due to

rainfall, with the no-till system producing more during dry seasons and the conventional system performing better during the seasons with ample rainfall. In addition, no-till is a more flexible approach to meeting federal program compliance for highly erodible land like the loess soils of West Tennessee (Naderman 1993).

Although conservation tillage is an excellent production system, it provides a favorable microenvironment for insect populations by increasing host plant density and mediating soil moisture and temperature extremes (Leonard et al. 1992). Information regarding cotton insect pests within different tillage systems is severely lacking (Sullivan and Smith 1993). Black cutworm, *Agrostis ipsilon* Hufnagle, and varigated cutworm, *Peridoma saucia* Huber, damage was mainly due to the presence of a cover crop (Leonard et al. 1992, Roach 1981a). Tobacco thrips, *Frankliniella fusca* Hinds, were less abundant in no-till than in surface-tilled plots in Georgia (All et al. 1992), but research in Texas showed that thrips numbers were not influenced by tillage systems (De Spain et al. 1992). Little information is currently available on the effect that tillage has on boll weevil and secondary pest numbers (Sullivan and Smith 1993). Gaylor and Foster (1987) suggested that predator populations in cotton were not affected by tillage systems, however, ground-dwelling predators were increased in conservation tillage systems.

The tobacco budworm pupates in the soil during the growing season and also overwinters as a pupa in the soil. The pupal cells are situated 1.25 cm to

15.25 cm below the surface of the soil and cultivation destroys most of the cells and tunnels, therefore, adversely altering the insect's microenvironment (Fife and Graham 1966). Induction of diapause for the tobacco budworm is related to the temperature and photoperiod that prevail during the developmental stages (Graham and Fife 1972). In Virginia and Georgia, Barber and Dickie (1937) reported 57-97% of overwintering pupae were killed by hand spading, 92% by spring plowing, 98% by fall plowing and 82% by fall disking. In North Carolina, 0.7-9.2% of the larvae with the potential for diapause emerged in the spring as moths (Caron et al. 1978). Slosser et al. (1975) found that rainfall, freezing soil temperatures, and duration of exposure (time) accounted for 89.8% of the variation in overwinter survivorship. This is consistent with previous work that showed normal tillage with irrigation may give 100% control of *Heliothine* overwintering pupae (Fife and Graham 1966). Young and Price (1977) found that no larvae from tilled plots emerged as moths the next spring and they concluded that it would appear that land tilled during the fall and winter months is not a suitable place for overwintering *Heliothines*. Roach (1981b) showed that the number of tobacco budworm moths emerging in all of the tillage treatments was very low. To summarize, overwintering emergence has ranged from 0-31% depending on location, tillage system and weather conditions at the time of the study (Caron et al. 1978). Although previous work has been conducted, overwintering of tobacco budworm on a loess soil of West Tennessee has not been studied. Because of the lack of data in the upper mid-south, there is

currently no explanation as to what effect no-till crop production is having on the next year's population of tobacco budworms.

Roach and Hopkins (1979) indicated that some soil moisture is helpful to soil burrowing and emergence while too much or too little can prove to be detrimental. It is believed that a certain amount of moisture is necessary to form a sound pupal tunnel, where too much moisture would cause the tunnel to collapse as would too little moisture. Roach and Campbell (1983) described an inverse relationship between moth emergence and soil compaction. All of the factors, except freezing temperatures, detrimental to overwintering populations would also affect in-season emergence of the tobacco budworm.

Hopkins et al. (1972) found up to a 79% reduction in moth emergence when plots were tilled once a week throughout the growing season in South Carolina. This same study also indicated that herbicide applications did not have an apparent effect on pupation since an average of 90% of the larvae pupated regardless the treatment. Another study revealed that there were no significant differences in the numbers of tobacco budworms found in no-till plots versus conventional plots, but did indicate higher emergence of moths in the no-till system (Roach 1981a). Gaylor et al. (1984) stated that conservation tillage systems studied in small plots were not found to significantly influence pupal survival during the growing season in Alabama. A study of this type, comparing the survival and emergence of tobacco budworm in a conventional tillage system

at planting and treating subsequent weed flushes with herbicides to a total no-till production system, has never been conducted in the upper mid-south.

Because the tobacco budworm is the number one pest of cotton, a thorough understanding of the population dynamics of this pest is needed. Insecticide resistant strains of the tobacco budworm are beginning to show up in producers' fields and careful attention needs to be given to crop production systems that may increase the probability of these larvae becoming imagos.

The objectives of this research were to:

1. determine the impact of tillage on in-season survival and emergence of *Heliothis virescens*, the tobacco budworm, in cotton (Chapter 2),
2. determine the impact of tillage on survival and emergence of overwintering *Heliothis virescens* in cotton (Chapter 3).

CHAPTER II

IMPACT OF TILLAGE ON IN-SEASON SURVIVAL AND EMERGENCE OF *Heliothis virescens*, THE TOBACCO BUDWORM, IN COTTON

I. INTRODUCTION

The bollworm/budworm complex produced the greatest insect damage throughout the cotton belt in 1996, causing over a 2% reduction in yield. Over 2.4 million hectares were treated at a cost of almost \$77 million. In Tennessee, over 42,000 hectares were infested with the complex; of these 23,371 required treatment. Tennessee producers lost 8,593 bales to bollworms/budworms in 1996, costing the state's growers nearly three million dollars in lost revenue (Williams 1997).

Use of *Bt* cotton is not an economically feasible option for most Tennessee producers, so control of the tobacco budworm, *Heliothis virescens*, is usually achieved by applying a recommended insecticide, usually pyrethroids, when populations reach economic threshold levels. Pyrethroid resistant strains of *H. virescens* have already been detected in neighboring states of Arkansas and Mississippi (Elzen 1993). Only time will tell if resistant strains will develop in Tennessee. Cost per insecticide application has also increased in recent years. In 1994, the cost per application of insecticide for bollworm/budworm was \$8.99; the cost rose to \$9.83 in the 1996 production year (Williams 1995, 1997). With

increased resistance to insecticides and increased insecticide costs, tillage may be a viable option to control the bollworm/budworm complex.

Tobacco budworms cause damage to cotton by feeding on the fruiting structures of the plant. Approximately 15 d after hatching, larvae quit feeding, move downward and tunnel into the soil, forming a cell in which they change to the pupal stage. During the growing season, the pupal stage lasts about 13 d, and the moth then emerges from the cell (Hardwick 1965). In-season survival and emergence have been studied on conventional-tilled soils in Georgia, Virginia and in the Carolinas, but the survival and emergence of moths from no-till cotton fields in the upper mid-south have not been studied (Barber 1937, Hopkins et al. 1972). In the past, no information was available to determine whether no-till cotton influenced tobacco budworm outbreaks. This research should provide information critical to formulating a recommendation on tillage as a means to suppress potential tobacco budworm infestations. The objectives of the study were:

1. to compare the survival and emergence of in-season populations of tobacco budworms in two different tillage systems, and
2. to understand the influence of climatic conditions on survival and emergence.

ii. MATERIALS AND METHODS

In 1997 and 1998, a series of experiments was conducted at the West Tennessee Experiment Station, Jackson, TN, to determine the impact of tillage on in-season tobacco budworm survival and emergence. The plots were laid out in a randomized complete block design with eight replications.

a. 1997

Fertilizer (34:0:0 at 112 kg/ha) was applied on May 15 and again (0:0:60 at 244 kg/ha) on May 29. 'Deltapine 50' cotton seed was planted on May 16, at 17 kg/ha in 101 cm rows and at a depth of 2.54 cm. Aldicarb (0.57 kg AI/ha) and pentachloronitrobenzene (PCNB) (11.36 kg/ha) were applied in furrow at planting for insect and disease control, respectively. The plots that were to be in the conventional tillage production system were double disked on the date also. On May 22, the plots were sprayed with a preemergence application of fluometuron (2.81 l/ha), pendimethalin (1.2 l/ha) and metholachlor (1.8 l/ha). Two tank mix applications of pyrithiobac (84 g/ha) and quizalofop (0.71 l/ha) were made on June 4 and July 8 for a variety of both broadleaf and grass weed species. The last herbicide application was made on August 4 with lactofen (0.91 l/ha) and cyanazine (2.3 l/ha) being applied post-direct for morningglory, cocklebur, pigweed and various grasses. Mepiquat chloride (1.2 l/ha) was applied on August 4, to control plant height. One insecticide application was made for boll

weevil. Azinphos-methyl (1.2 l/ha) was tank mixed with clethodim (0.73 l/ha) for grass control and was applied on August 1.

The plots were 12 rows and 9.14 m long. Each plot was artificially infested with late instar tobacco budworm on several dates during the summer. The plots were in their respective tillage systems the previous season. Replications 1-4 were planted in cotton while replications 5-8 were planted in soybeans in 1996. Infestations consisted of placing 25 laboratory-reared larvae, approximately 10 d old, in inverted diet cups in a 1.2 m X 1.2 m area on the soil surface and placing a 355-ml drink cup on top to control escapes. A plot flag wire was cut off to a length of around 0.3 m and placed through the cup to keep it from becoming dislodged by the wind, and it marked the infestation site, which would be excavated later. Four or five d after infesting the plots, the drink cups were removed to expose the pupa to the elements. At this time a count was made to determine the number of larvae which died, pupated in the diet cup or were missing. Since the larva fills the burrow with soil, the ones counted as missing were considered to have pupated in the soil (Hardwick 1965). Ten d after infesting the plots the 1.2 m X 1.2 m area was covered with either a 1.2 m X 1.2 m X 0.91 m pyramid cage or a 1.5 m X 1.5 m X 1.8 m cage to collect the moths that might emerge. The cages were checked every day, and the emerged moths were counted and sexed. The moths were sexed by squeezing the abdomen to expose the claspers (harpes) in the males (Agee 1969). After

emergence had terminated, the 1.2 m X 1.2 m section of the plot was excavated to search for pupae or pupal cases.

A total of four cohorts was evaluated during the summer of 1997, these were infested on June 16, July 3, July 11 and July 31. When emergence was completed in each block, percent emergence was calculated by dividing the number of moths emerged by the number of larvae that pupated, multiplied by 100. This method was used for all tests.

Larvae were reared in the laboratory on a lima bean diet as described by Pantana (1969). The ingredients for a 3.8 l mix of diet are as follows:

Soaked lima beans	1,200 grams.
Brewer's yeast	120 grams.
Methyl-p-hydroxybenzoate	12 grams.
Ascorbic acid	12 grams.
Gelcarin	30 grams.
Water	2,400 ml.
Formaldehyde	4 ml.

The beans were soaked in water in 3.8 l containers at least 24 to 48 h before the diet was to be made. Brewer's yeast, methyl-p-hydroxybenzoate, ascorbic acid and water were blended for one minute and then the soaked beans were added to the mix to be blended for three to four extra minutes. The gelcarin was added to 1,000 ml of water and after boiling was added to the above mixture. The mix was blended for four more minutes and was then manually poured into the 29.57-ml diet cups to cool. After cooling, three larvae were put on the diet and a diet cup lid was placed on top. The larvae were held 10 d in diet cups in a growth chamber operated at 27 °C, 60% R.H. and 24:0 L:D photoperiod.

Larvae which were 10 d old were used to infest the tillage plots. Larvae that were not used were placed back in the growth chamber to pupate in the diet cups. When the larvae had pupated, they were washed and surface sterilized with a 5% sodium hypochlorite solution. When the pupae were dry, they were placed in the bottom of a 3.8 l jar with paper towel strips taped to the inside to facilitate moth wing expansion and drying. When several moths had emerged they were transferred to a separate jar with other moths to mate and oviposit on suspended paper towel strips. The paper towel strips with eggs on them were transferred into another jar to dry and to allow the eggs to hatch. As eggs hatched, larvae were then put on diet to continue the culture.

b. 1998

Fertilizer (34:0:0 at 168 kg/ha) was applied on May 21 and again (15:15:15 at 280 kg/ha) on May 22. 'Paymaster 1215RR' cotton seed was planted on May 20, at 17 kg/ha in 101 cm rows at a depth of 2.54 cm. Aldicarb (0.57 kg AI/ha) and pentachloronitrobenzene (PCNB) (11.36 kg/ha) were applied in furrow at planting for insect and disease control, respectively. The plots that received the conventional tillage treatment were double disked just prior to planting on May 20. A preemergence application of fluometuron (3.5 l/ha), metolachlor (1.7 l/ha) and pendimethalin (2.5 l/ha) was applied at planting with a burndown of glyphosate (2.34 l/ha). A total of five applications of glyphosate (2.34 l/ha) were made over the top on June 1, June 26, July 15, July 26 and

August 3. An insecticide spray schedule was started on July 21 for a boll weevil infestation and was continued five times every four d with dicrotophos (.54 l/ha).

Each plot was infested on several dates during the summer. Infestations consisted of placing 25 laboratory reared larvae, approximately 10 d old, in inverted diet cups in a 1.2 m X 1.2 m area on the soil surface. A 15.25 cm tall galvanized steel, sheet metal frame was placed around the area to prevent escapes. The same procedure as the previous year was used to determine the number that pupated. Instead of the plots being excavated after emergence had ended, one cohort was excavated four d after infestation to determine how deep the larvae had burrowed to pupate in each tillage system. The larvae were reared using the same procedures as the previous year.

A total of five cohorts was evaluated during the summer of 1998, these were infested on June 08, June 26, July 13, July 24 and August 14. The process to determine emergence was the same as in the previous year.

iii. RESULTS AND DISCUSSION

a. 1997

The results for the first study, the June 16 cohort, are presented in Table 1. There was no significant difference between the percentage of moths that emerged from the conventionally tilled plots and from the no-till plots. Percent emergence is the number that SAS (1989) statistical software used to detect

Table 1. Effects of tillage systems on survival and emergence of early season (June 16 cohort) *Heliothis virescens* (West Tennessee Experiment Station, Jackson, TN, 1997).

Tillage system	Number of larvae	Number of pupated larvae	Total number of moths emerged	Average percentage of moths emerged	Male moths	Female moths
Conventional ²	65	54	2	3.17±5.49a ¹	2	0
No-Till	65	47	3	6.87±7.82a	1	2

¹ Means separated by LSD (p<.05)

² Double disked

significant differences between the two tillage systems by the LSD test. In each of the three remaining cohorts there were no significant differences between the two tillage systems in terms of the average percentage of moths that emerged (Tables 2, 3 and Table 4).

It was anticipated that larvae could burrow more easily into soil in the conventional tillage plots. On the contrary, in all of the cohorts except the June 16 cohort, more larvae pupated in the no-till production system. A possible reason for the higher number pupating in the conventional tillage treatment of cohort I is that the tillage plots had been tilled only 30 d previously. The sex ratio of the moths emerging from each tillage system did not differ from the expected 50:50.

Table 5 illustrates the season totals for all four cohorts. More moths emerged and a higher average percentage of moths emerged from the no-til plots, but this difference was not significant at the $p < .05$ level. Figure 1 illustrates a higher percentage of moths emerging later in the growing season in each tillage system. There was a significantly greater percent emergence in the July 31 cohort than in the others. In the July 3 and July 11 cohorts, emergence was not significantly different from each other. The June 16 cohort emergence was significantly lower than all.

Table 2. Effects of tillage systems on survival and emergence of mid-season (July 3 cohort) *Heliothis virescens* (West Tennessee Experiment Station, Jackson, TN, 1997).

Tillage system	Number of larvae	Number of pupated larvae	Total number of moths emerged	Average percentage of moths emerged	Male moths	Female moths
Conventional ²	100	84	12	12.19±5.91a ¹	6	6
No-Till	100	96	17	17.95±7.61a	9	8

¹ Means separated by LSD (p<.05)

² Double disked

23

Table 3. Effects of tillage systems on survival and emergence of mid-season (July 11 cohort) *Heliothis virescens* (West Tennessee Experiment Station, Jackson, TN, 1997).

Tillage system	Number of larvae	Number of pupated larvae	Total number of moths emerged	Average percentage of moths emerged	Male moths	Female moths
Conventional ²	100	93	11	11.97±7.58a ¹	5	6
No-Till	100	98	18	18.25±7.40a	9	9

¹ Means separated by LSD (p<.05)

² Double disked

Table 4. Effects of tillage systems on survival and emergence of late season (July 31 cohort) *Heliothis virescens* (West Tennessee Experiment Station, Jackson, TN, 1997).

Tillage system	Number of larvae	Number of pupated larvae	Total number of moths emerged	Average percentage of moths emerged	Male moths	Female moths
Conventional ²	60	49	11	23.66±12.08a ¹	5	6
No-Till	60	58	18	31.02±8.32a	9	9

¹ Means separated by LSD (p<.05)

² Double disked

24

Table 5. Effects of tillage systems on season-long survival and emergence of *Heliothis virescens* (West Tennessee Experiment Station, Jackson, TN, 1997).

Tillage system	Number of larvae	Number of pupated larvae	Total number of moths emerged	Average percentage of moths emerged	Male moths	Female moths
Conventional ²	325	280	36	13.39±10.43a ¹	18	18
No-Till	325	299	56	19.30±10.99a	28	28

¹ Means separated by LSD (p<.05)

² Double disked

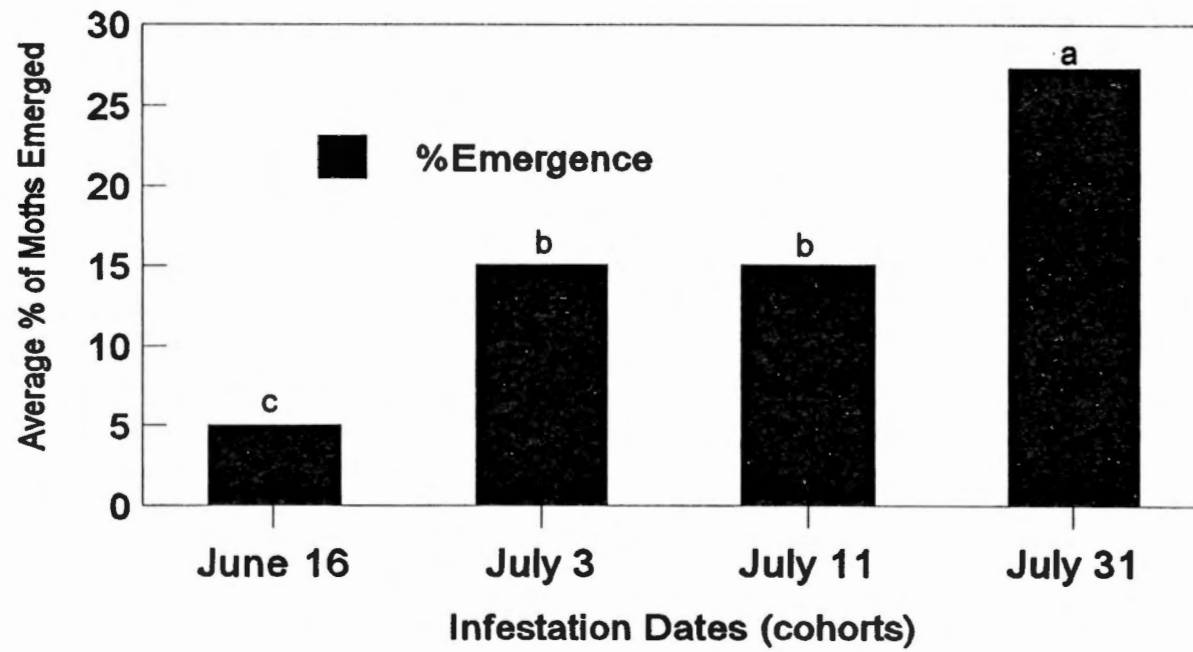


Figure 1. Seasonal emergence of *Heliothis virescens* in 1997 (West Tennessee Experiment Station, Jackson, TN, 1997).

b. 1998

The results from the first cohort on June 8 are presented in Table 6. There was no significant difference between the conventional and no-till treatments in the percentage of moths emerged. In each of the four remaining cohorts, there were no significant differences between the two tillage systems in terms of the average percentage of moths that emerged (Table 7, 8, 9, and 10).

The number of pupated larvae did not follow the same pattern as the previous year. More larvae pupated in the conventional treatment in the June 8, July 24, and August 14 cohorts while more larvae pupated in the no-till treatment in the June 26 and July 13 cohorts. Sex ratio of the moths during the tests in 1998 were close to the expected 50:50.

Table 11 illustrates the season totals for all five cohorts. More moths emerged and a higher percentage of moths emerged in the no-till treatment, but this difference was not significant at the $p < 0.05$ level. As in the previous year, there were significant differences between the infestation dates with higher emergence later in the growing season (Figure 2). Emergence in the August 14 cohort was significantly higher than in the other cohorts while the July 24 and July 13 cohorts did not significantly differ from each other. The June 26 and June 8 cohorts did not significantly differ from each other, but were significantly different from the other test dates.

Table 6. Effects of tillage systems on survival and emergence of early season (June 08 cohort) *Heliothis virescens* (West Tennessee Experiment Station, Jackson, TN, 1998).

Tillage system	Number of larvae	Number of pupated larvae	Total number of moths emerged	Average percentage of moths emerged	Male moths	Female moths
Conventional ²	120	112	3	2.68±3.34a ¹	2	1
No-Till	120	109	9	8.63±7.46a	4	5

¹ Means separated by LSD (p<.05)

² Double disked

27

Table 7. Effects of tillage systems on survival and emergence of mid-season (June 26 cohort) *Heliothis virescens* (West Tennessee Experiment Station, Jackson, TN, 1998).

Tillage system	Number of larvae	Number of pupated larvae	Total number of moths emerged	Average percentage of moths emerged	Male moths	Female moths
Conventional ²	140	106	5	4.98±3.64a ¹	3	2
No-Till	140	111	10	8.50±3.98a	5	5

¹ Means separated by LSD (p<.05)

² Double disked

Table 8. Effects of tillage systems on survival and emergence of mid-season (July 13 cohort) *Heliothis virescens* (West Tennessee Experiment Station, Jackson, TN, 1998).

Tillage system	Number of larvae	Number of pupated larvae	Total number of moths emerged	Average percentage of moths emerged	Male moths	Female moths
Conventional ²	140	123	24	18.87±6.50a ¹	12	12
No-Till	140	131	31	23.34±10.82a	15	16

¹ Means separated by LSD (p<.05)

² Double disked

28

Table 9. Effects of tillage systems on survival and emergence of late season (July 24 cohort) *Heliothis virescens* (West Tennessee Experiment Station, Jackson, TN, 1998).

Tillage system	Number of larvae	Number of pupated larvae	Total number of moths emerged	Average percentage of moths emerged	Male moths	Female moths
Conventional ²	140	110	22	19.28±1.54a ¹	10	12
No-Till	140	101	25	25.73±8.45a	11	14

¹ Means separated by LSD (p<.05)

² Double disked

Table 10. Effects of tillage systems on survival and emergence of late season (August 14 cohort) *Heliothis virescens* (West Tennessee Experiment Station, Jackson, TN, 1998).

Tillage system	Number of larvae	Number of pupated larvae	Total number of moths emerged	Average percentage of moths emerged	Male moths	Female moths
Conventional ²	120	85	45	52.48±25.12a ¹	28	17
No-Till	120	69	33	54.18±19.89a	18	15

¹ Means separated by LSD (p<.05)

² Double disked

29

Table 11. Effects of tillage systems on season-long survival and emergence of *Heliothis virescens* in 1998 (West Tennessee Experiment Station, Jackson, TN, 1998).

Tillage system	Number of larvae	Number of pupated larvae	Total number of moths emerged	Average percentage of moths emerged	Male moths	Female moths
Conventional ²	660	540	99	18.29±17.49a ¹	55	44
No-Till	660	517	108	25.68±23.46a	53	55

¹ Means separated by LSD (p<.05)

² Double disked

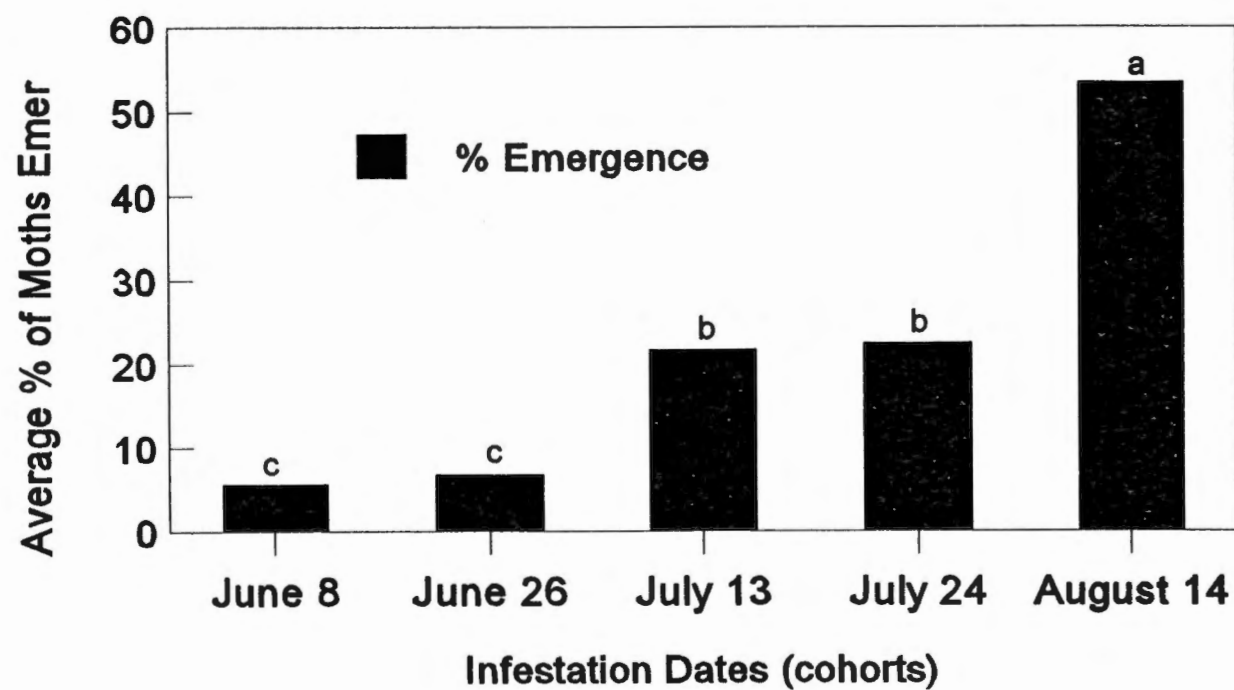


Figure 2. Seasonal emergence of *Heliothis virescens* in 1998 (West Tennessee Experiment Station, Jackson, TN, 1998).

c. Summary

Plots were infested with 985 larvae during the two seasons of this study. More moths emerged and a higher mean emergence percentage occurred in the no-till treatment for all nine infestation dates, while more larvae pupated in the conventional tillage treatment (Table 12). The mean time from infesting the plots to emergence of the moths was 17 d. The mean depth that the larvae burrowed was 1.09 cm in each tillage system.

Since there were significant differences in percent emergence between the cohorts a multiple regression test was performed. Two variables, degree day-60's, (DD-60's), and precipitation, explained 60% of the variation in emergence percentage, and these were significant at the $p < .05$ level. Degree days are measured by taking the average of a day's high temperature and low temperature in fahrenheit and subtracting 60 from this number. Sixty is used because cotton only grows above 60°F. Degree day-60's were measured from planting to the first day of emergence for each cohort. Precipitation was measured from infestation to the first day of emergence for each cohort. This analysis produced a regression equation of $y = -9.062 (3.99) + .027 (.003) \text{ DD-60's} - 1.357 (.54) \text{ Prec}$ (Figure 3). This may explain why tobacco budworm populations are greater later in the season. The heavier crop canopy may offer protection from extremes in temperature or the increase in root density may stabilize the soil. More research needs to be conducted to explain why this increase in emergence occurs later in the year. It is easier to explain why

Table 12. Effects of tillage systems on season-long survival and emergence of *Heliothis virescens* in 1997 and 1998 (West Tennessee Experiment Station, Jackson, TN, 1997).

Tillage system	Number of larvae	Number of pupated larvae	Total number of moths emerged	Average percentage of moths emerged	Male moths	Female moths
Conventional ²	985	820	135	16.19+14.89a ¹	73	62
No-Till	985	816	164	22.95+19.17a	82	83

¹ Means separated by LSD (p<.05)

² Double disked

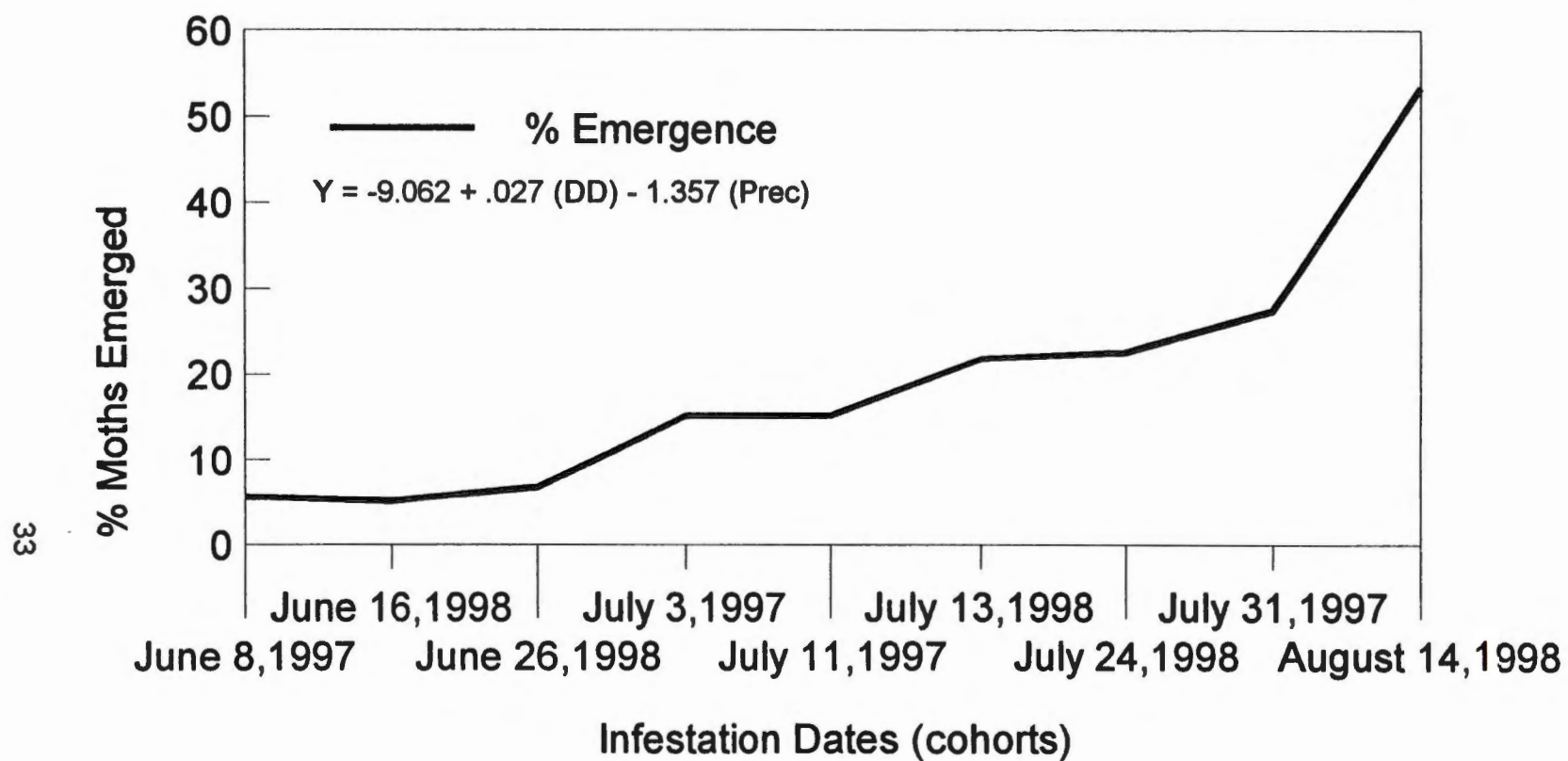


Figure 3. Regression equation for in-season emergence of *Heliothis virescens* from West Tennessee cotton (West Tennessee Experiment Station, Jackson, TN, 1997-1998).

precipitation would hamper emergence. Precipitation likely fills in or collapses the tunnels that the larva digs, and through which the imago must emerge. The moth could have more difficulty emerging and could die before reaching the surface.

This research indicates that no-till production does not allow significantly larger tobacco budworm moth populations to develop compared to a double disked production system where the only tillage is done prior to planting and weeds are controlled with herbicides. Rather than tillage practice, tobacco budworm pressure is controlled by the crop growth stage and precipitation. This accounts for local populations but does not account for populations that migrate in from other cotton or tobacco producing areas.

CHAPTER III

EFFECTS OF TILLAGE ON OVERWINTERING POPULATIONS OF *Heliothis virescens* IN COTTON

i. INTRODUCTION

Since 1928, tillage has been shown to decrease overwintering populations of the tobacco budworm, *Heliothis virescens* (Barber 1937). Stadelbacher and Martin (1980) reported spring emergence of tobacco budworm moths from overwintered populations to be between 3.6 and 3.9% in the Mississippi delta area.

Tobacco budworms overwinter as pupae in the soil. The pupal cells are situated 1.25 cm to 15.25 cm below the soil surface and their tunnels extend to or near the soil surface. Tillage destroys these tunnels and cells, and the insect's microenvironment is adversely affected (Fife and Graham 1966). Tobacco budworms overwinter in a diapausing condition. Photoperiod has been reported to be the primary factor in diapause induction (Roach and Adkisson 1971). Wellso and Adkisson (1966) found that the induction of pupal diapause is dependent on the parent and egg stages being exposed to longer day-lengths than the subsequent larval stages. Short day-lengths (10 hr) at temperatures of 24 and 18°C, acting on all developmental stages, induced diapause, and a 14-hr day largely prevented diapause at temperatures from 21 to 27°C (Phillips and

Newsom 1966). Termination of diapause was greatly influenced by temperature, but not photoperiod, and the number of d for diapause termination was inversely related to the temperature in a study conducted by Roach and Adkisson (1971).

Overwintering survival of *Helicoverpa zea* has been documented to range from 0%-31% in the southeastern United States (Caron et al. 1978). Several factors determine the survival rate of tobacco budworms that overwinter.

Slosser (1975) reported that duration of pupation, soil temperatures, incident solar radiation and rainfall accounted for 96.4% of the variation in the spring emergence in a study in Arkansas. Normal tillage of the soil plus irrigation may give 100% control of overwintering pupae (Young and Price 1977). At present, no data have been collected concerning the numbers of tobacco budworms overwintering and surviving to emerge the next spring from the loess soils of western Tennessee. This research should provide information on the effects that tillage and climatic conditions have on the overwintering survival and spring emergence of tobacco budworms in Tennessee. The objectives of the study were:

1. to compare the survival and spring emergence of overwintering populations of tobacco budworms in two different tillage systems, and
2. to determine the influence of climatic conditions on survival and emergence and of overwintering populations of tobacco budworms.

ii. MATERIALS AND METHODS

During the winter of 1997-1998, a series of experiments was conducted at the West Tennessee Experiment Station, Jackson, TN, to determine the impact of tillage the previous spring on overwintering tobacco budworm survival and emergence. The plots were laid out in a randomized complete block design with various replications.

The plots were located in cotton from the previous summer and the stalks were not mowed. The plots were 12 rows wide and 9.14 m long. Plots receiving the conventional tillage treatment were double disked on May 22, 1997 and immediately planted. Larvae were reared in the laboratory on a lima bean diet as described by Pantana (1969) and prepared according to the procedures in Chapter 2 except for the photoperiod and temperature. The larval rearing environment was 60% R.H. and 18°C and 10:14 L:D photoperiod to induce diapause. Infestations consisted of placing 25 fifth-instar laboratory-reared larvae into inverted 29.57-ml diet cups in a 1.2 m X 1.2 m area on the soil surface and placing a 15 cm galvanized steel, sheet metal frame in the soil to prevent escapes. The first infestation occurred on September 16, 1997, and the cups were removed on September 26, 1997, to expose the larvae to the elements. At this time a count was made to see how many larvae died, pupated in the diet cup or were missing. Since the larva fills the burrow with soil, the ones counted as missing were considered to have pupated in the soil (Hardwick

1965). The process to determine emergence percentage was the same as in Chapter 2. Fifty larvae were put aside on September 16, 1997 in the field to determine the percent of diapausing individuals. Diapause was determined to be 14% for both cohorts. The pyramid cages described in Chapter 2 were placed on the plots on March 25, 1998.

The second infestation consisted of thirty-seven larvae in inverted diet cups in each of eight sheet-metal frames in two blocks being infested on October 24, 1997. Diet cups were removed on March 25, 1998, but had been dislodged during the winter and were not on top of the tunnels the larvae made the previous fall. The 1.5 m X 1.5 m X 1.8 m cages were placed on plots on the same date. This cohort was assumed to have all of the larvae to pupate and percentage that went into diapause was figured by multiplying 37 by the diapause percentage (14%). Both infestations were excavated on May 19, 1998, to locate pupae or pupal cases.

iii. RESULTS AND DISCUSSION

The results for the first study, the September 16 cohort, are presented in Table 13. There was no significant difference between the conventional and no-till treatments in the percentage of moths emerged, although the no-till treatment had more pupae to survive and emerge the following spring. The second study, the October 24 cohort, had one moth to emerge from each tillage treatment,

Table 13. Effects of tillage systems on survival and emergence of overwintering (September 16 cohort) *Heliothis virescens* (West Tennessee Experiment Station, Jackson, TN, 1997).

Tillage system	Number of larvae	Number of pupated larvae	Number of pupae in diapause (14%)	Average percentage of moths emerged
Conventional ²	100	89	12.46	8.11 $\pm$ 16.23a ¹
No-Till	100	86	11.76	9.40 $\pm$ 18.80a

¹ Means separated by LSD (p<.05)

² Double disked

thus, the emergence percentages were the same (Table 14). This date may be too late in the year for pupae to enter diapause and survive the winter. Plots were infested with a 248 larvae per tillage treatment for the entire overwintering study (Table 15). A higher percentage of moths emerged from the no-till treatment, but this was not significantly higher than the conventional treatment.

Precipitation, days that the temperature reached 0°C, and duration from infestation to emergence in days were studied to find any significant influences on emergence percentage. None of these environmental factors significantly influenced emergence percentage, thus, the second objective of this study has not been completed. This study needs to be done on a larger scale than two infestations and over several years to determine overwintering emergence percentage and what environmental conditions significantly influence spring emergence.

Table 14. Effects of tillage systems on survival and emergence of overwintering (October 24 cohort) *Heliothis virescens* (West Tennessee Experiment Station, Jackson, TN, 1997).

Tillage system	Number of larvae	Number of pupae in diapause (14%)	Total number of moths emerged	Average percentage of moths emerged
Conventional ²	148	20.72	1	4.83±9.65a ¹
No-Till	148	20.72	1	4.83±9.65a

¹ Means separated by LSD (p<.05)

² Double disked

41

Table 15. Effects of tillage systems on overwintering survival and emergence of *Heliothis virescens* (West Tennessee Experiment Station, Jackson, TN, 1997).

Tillage system	Number of larvae	Number of pupated larvae	Number of pupae in diapause (14%)	Average percentage of moths emerged
Conventional ²	248	148+89=237	33.18	4.66±12.49 a ¹
No-Till	248	148+84=232	32.48	5.30±14.05a

¹ Means separated by LSD (p<.05)

² Double disked

REFERENCES CITED

- Ables, J.R., S.L. Jones, and D.W. McCommas, Jr.** 1978. Response of selected predator species to different densities of *Aphis gossypii* and *Heliothis virescens* eggs. *Environ. Entomol.* 7: 402-404.
- Agee, H.R.** 1969. Mating behavior of bollworm moths. *Ann. Entomol. Soc. Am.* 62: 1120-1122.
- Adkisson, P.L.** 1958. The influence of fertilizer applications on populations of *Heliothis zea* (Boddie), and certain insect predators. *J. Econ. Entomol.* 51: 757-759.
- Adkisson, P.L., C.F. Bailey and R.L. Hanna.** 1964. Effect of bollworm, *Heliothis zea*, on yield and quality of cotton. *J. Econ. Entomol.* 57: 448-450.
- Adkisson, P.L., R.L. Hanna and C.F. Bailey.** 1964. Estimates of the numbers of *Heliothis* larvae per acre in cotton and their relation to the fruiting cycle and yield of the host. *J. Econ. Entomol.* 57: 657-663.
- All, J.N. and G.J. Musick.** 1986. Management of vertebrate and invertebrate pests. pp. 347-387. *In* M.A. Sprague and G.B. Triplett (eds.), No-tillage and Surface-tillage Agriculture: The Tillage Revolution. John Wiley and Sons, Inc., New York.
- Barber, G.W. and F.F. Dicke.** 1937. The effectiveness of cultivation as a control for the corn earworm. *USDA Tech. Bull.* 561: 1-16.
- Beckham, C.M.** 1969. Effect of nitrogen fertilization on the abundance of cotton insects. *J. Econ. Entomol.* 63: 1219-1220.

- Bottrell, D.G and P.C. Adkisson.** 1977. Cotton insect pest management. *Ann. Rev. Entomol.* 22: 451-481.
- Bradley, J.F.** 1993. Success with no-till cotton, pp. 46-48. *In* M.R. McClelland et al. (eds.), *Conservation Tillage Systems for Cotton: A Review of Research and Demonstration Results from Across the Cotton Belt*, University of AR Div. of AG. Special Report 160.
- Bradley Jr., J.R., M.L. Laster, H.N. Pitre, S.H. Roach, J.W. Smith.** 1987. Interactions of insecticides and arthropod natural enemies of *Heliothis* spp. pp- 7-15. *In* Schneider et al. (eds.), *Theory and Tactics of Heliothis Population Management: II-Insecticidal and Insect Growth Regulator Control*. Southern. Coop. Series, Bull. No. 329.
- Brown, H.B. and J.O. Ware.** 1958. *Cotton*. McGraw-Hill Book Company, Inc., New York. 566pp.
- Buehler, R.E.** 1993. Development of new cotton lines expressing insect control protein from *Bacillus thuringiensis*, p. 616. *In* D.J. Herber (ed.), *Proc. Beltwide Cotton Conf., National Cotton Council of America, Memphis, TN*.
- Callahan, P.S.** 1958. Behavior of the imago of the corn earworm, *Heliothis zea* (Boddie), with special reference to emergence and reproduction. *Ann. Entomol. Soc. Am.* 51: 271-283.
- Caron, R.E., J.R. Bradley, Jr., R.H. Pleasants, R.L. Rabb, and R.E. Stinner.** 1978. Overwintering survival of *Heliothis zea* produced on late-planted field corn in North Carolina. *Environ. Entomol.* 7:193-196.

Carter, C.C., T.N Hunt, D.L. Kline, T.E. Reagan, and W.P. Barney. 1982.

Insect and Related Pests of Field Crops. NC Agric. Ext. Serv. AG-271.

214pp.

Chamberlin, F.S and J.N. Tenhet. 1926. The seasonal history and food habits

of the tobacco budworm, *Heliothis virescens* Fab., in the southern

tobacco-growing region. J. Econ. Entomol. 19:611-614.

Collings, G.H. 1926. The Production of Cotton. John Wiley and Sons, Inc.,

New York. 256pp.

Cunningham, G. and B. Grefenstette. 1998. Boll weevil eradication - a

beltwide prospectus, pp. 999-1000. *In* Dugger and Richter (eds.), Proc.

Beltwide Cotton Conf., National Cotton Council of America, Memphis, TN.

Danekas, G.W. 1997. Farm Facts. Tennessee Agricultural Statistics Service.

97: 14.

De Spain, R.R., J.H. Benedict, J.A. Landivar, B.R. Eddleman, S.W. Goynes,

D.R. Ring, R.D. Parker, and M.F. Treacy. 1992. Influence of tillages and insect

management systems, in a cropping system study on the lower gulf coast

of Texas, pp. 811-812. *In* D.J. Herber (ed.), Proc. Beltwide Cotton Conf.,

National Cotton Council of America, Memphis, TN.

Elzen, G.W. 1993. Tobacco Budworm insecticide resistance in the Mississippi

Delta, 1992, pp 25-27. *In* D.J. Herber (ed.), Proc. Beltwide Cotton Conf.,

National Cotton Council of America, Memphis, TN.

- Fife, L.C. and H.M. Graham.** 1966. Cultural control of overwintering bollworm and tobacco budworm. J. Econ. Entomol. 59: 1123-1125.
- Fischhoff, D.A.** 1992. Management of lepidopteran pests with insect resistant cotton: recommended approaches, pp. 751-753. In D.J. Herber (ed.), Proc. Beltwide Cotton Conf., National Cotton Council of America, Memphis, TN.
- Folsom, J.W.** 1936. Notes on little-known cotton insects. J. Econ. Entomol. 29: 282-285.
- Foth, H.D. and B.G.** 1997. Soil Fertility 2nd Ed. CRC Press Inc., Boca Raton, FL. 290pp.
- Gaylor, M.J., A.J. Fleischer, D.P. Muehleisen, and J.V. Edelson.** 1984. Insect populations in cotton produced under conservation tillage. J. Soil and Water Conser. January-February: 61-64.
- Gaylor, M.J. and M.A. Foster.** 1987. Cotton pest management in the southeastern United States as influenced by conservation tillage practices, pp. 29-43. In G.J. House and B.R. Stinner (eds.), Arthropods in Conservation Tillage Systems, Entomol. Soc. Amer. Publ. 65, Lanham, MD.
- Graham, H.M. and L.C. Fife.** 1972. Overwintering of *Heliothis* spp. in the lower Rio Grande Valley, Texas. Ibid. 65: 708-711.

- Handy, R.B.** 1896. History and general statistics of cotton, pp. 17-66. *In* A.C. True (ed.), The Cotton Plant: It's History, Botany, Chemistry, Culture, Enemies, and Uses, U.S. Department of Agriculture, Ext. Station Bull. No. 33. Washington D.C. 433pp.
- Hardwick, D.F.** 1965. The Corn Earworm Complex. Memoirs of the Entomological Society of Canada, No. 40. 247pp.
- Hillhouse, T.L. and H.N. Pitre.** 1976. Oviposition by *Heliothis* on soybeans and cotton. J. Econ. Entomol. 69: 144-146.
- Hopkins, A.R., H.M. Taft, and W. James.** 1972. Comparison of mechanical cultivation and herbicides on emergence of bollworms and tobacco budworms. J. Econ. Entomol. 65: 870-872.
- Hutchinson, R.L.** 1993. Overview of conservation tillage, pp. 1-9. *In* M.R. McClelland et al. (eds.), Conservation Tillage Systems for Cotton: A Review of Research and Demonstration Results from Across the Cotton Belt, University of AR Div. of Ag. Special Report 160.
- Kincade, R.T., M.L. Laster, and J.R. Brazzel.** 1967. Damage to cotton by the tobacco budworm. J. Econ. Entomol. 60: 1163-1164.
- Leonard, B.R., R.L. Hutchinson, and J.B. Graves.** 1992. Conservation tillage systems and cotton insect pest management in Louisiana, pp. 807-810. *In* D.J. Herber (ed.), Proc. Beltwide Cotton Conf., National Cotton Council of America, Memphis, TN.

- Leonard, B.R., E. Burris, J.B. Graves, and G. Elzen.** 1991. Tobacco budworm: Insecticide resistance and field control in the Macon Ridge region of Louisiana, 1990, pp. 642-648. *In* D.J. Herber (ed.), Proc. Beltwide Cotton Conf., National Cotton Council of America, Memphis, TN.
- Mannering, J.V., D.L. Schertz, and B.A. Julian.** 1987. Overview of conservation tillage, pp. 3-17. *In* T.J. Logan et al. (eds.), Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides, Lewis Publishers, Inc., Chelsea, MI.
- McDaniel, S.G. and W.L. Sterling.** 1982. Predation of *Heliothis virescens* (F.) eggs on cotton in east Texas. Environ. Entomol. 11: 60-66.
- Naderman, G.** 1993. Equipment/residue management, pp. 13-17. *In* M.R. McClelland et al. (eds.), Conservation Tillage Systems for Cotton: A Review of Research and Demonstration Results from Across the Cotton Belt, University of AR Div. of Ag. Special Report 160.
- Neunzig, H.H.** 1964. The eggs and early-instar larvae of *Heliothis zea* and *Heliothis virescens* (Lepidoptera:Noctuidae). Ann. Entomol. Soc. Am. 57: 98-102.
- Neunzig, H.H.** 1963. Wild host plants of the corn earworm and the tobacco budworm in eastern North Carolina. J. Econ. Entomol. 56: 135-139.
- Ojeniyi, S.O. and A.R. Dexter.** 1979. Soil factors affecting the macro-structures produced by tillage. Trans. Am. Soc. Agric. Eng. 4: 55-57.

- Pantana, R.** 1969. Rearing cotton insects in the laboratory. USDA Production Research Report 108: 1-6.
- Pfrimmer, T.R., E.A. Stadelbacher, and M.L. Laster.** 1981. *Heliothis* spp. seasonal incidence on cotton in the Mississippi Delta. Environ. Entomol. 10: 642-644.
- Phillips, J.R. and L.D. Newsom.** 1966. Diapause in *Heliothis zea* and *Heliothis virescens* (Lepidoptera:Noctuidae). Ann. Entomol. Soc. Am. 59: 154-159.
- Proshold, F.I., C.P. Karpenko, and C.K. Graham.** 1982. Egg production and oviposition in the tobacco budworm: Effect of age at mating. Ann. Entomol. Soc. Am. 75: 51-55.
- Quaintance, A.L. and C.T. Brues.** 1905. The Cotton Bollworm. USDA Bur. Entomol. Bull. No. 50. 155pp.
- Roach, S.H.** 1981a. Reduced- vs. conventional tillage practices in cotton and tobacco: A comparison of insect populations and yield in northeastern South Carolina. J. Econ. Entomol. 74: 688-695.
- Roach, S.H.** 1981b. Emergence of overwintered *Heliothis* spp. moths from three different tillage systems. Environ. Entomol. 10: 817-818.
- Roach, S.H. and P.L. Adkisson.** 1971. Termination of pupal diapause in the bollworm. J. Econ. Entomol. 64: 1057-1059.
- Roach, S.H. and R.B. Campbell.** 1983. Effects of soil compaction on bollworm (Lepidoptera: Noctuidae) moth emergence. Environ. Entomol. 12: 1882-1885.

- Roach, S.H. and A.R. Hopkins.** 1979. *Heliothis* spp.: Behavior of prepupae and emergence of adults from different soils at different moisture levels. Environ. Entomol. 8: 388-391.
- Roberts, P. and G. Lentz.** 1995. Cotton insect and mite management, pp. 19-26. *In* Cotton Production in Tennessee. The University of TN Ag. Ext. Service PB1514.
- SAS Institute.** 1989. SAS/STAT user's guide, ver. 6. 4th ed., vol. 1. SAS Institute, Cary, NC. 943pp.
- Shorey, H.H., K.L. Morin, and L.K. Gaston.** 1968. Sex pheromones of noctuid moths. XV. Timing of development of pheromone-responsiveness and other indicators of reproductive age in males of eight species. Ann. Entomol. Soc. Am. 61: 857-861.
- Slosser, J.E.** 1980. Irrigation timing for bollworm management in cotton. J. Econ. Entomol. 73: 346-349.
- Slosser, J.E., J.R. Phillips, G.A. Herzog, and C.R. Reynolds.** 1975. Overwinter survival and spring emergence of the bollworm in Arkansas. Environ. Entomol. 4: 1015-1024.
- Stadelbacher, E.A.** 1981. Role of early-season wild and naturalized host plants in the buildup of F₁ generation of *Heliothis zea* and *H. virescens* in the delta of Mississippi. Environ. Entomol. 10: 766-770.

- Stadelbacher, E.A. and D.F. Martin.** 1980. Fall diapause, winter mortality and spring emergence of the tobacco budworm in the delta of Mississippi. Environ. Entomol. 9: 553-556.
- Sullivan, M.J and T.W. Smith Jr.** 1993. Insect management in reduced-tillage southeastern cotton, pp. 39-41. *In* M.R. McClelland et al. (eds.), Conservation Tillage Systems for Cotton: A Review of Research and Demonstration Results from Across the Cotton Belt, University of AR Div. of Ag. Special Report 160.
- Troch, F.R., J.A. Hobbs, and R.L. Donahue.** 1980. Soil and Water Conservation for Productivity and Environmental Protection. Prentice-Hall, Inc., Englewood Cliffs, NJ. 718pp.
- Warren, L.O.** 1979. Introduction, p. 11. *In* Economic Thresholds and Smpling of *Heliothis* Species on Cotton, Corn, Soybeans, and Other Host Plants, Southern Coop. Series, Bull. No. 231.
- Ware, G.W.** 1994. The Pesticide Book. Thomson Publications, Fresno, CA. 386pp.
- Wellso S.G. and P.L. Adkisson.** 1966. A long-day short-day effect in the photoperiodic control of the pupal diapause of the bollworm, *Heliothis zea* (Boddie). J. Insect Physiol. 12: 1455-1465.
- Whitcomb, W.H. and K. Bell.** 1964. Predaceous insects, spiders, and mites of Arkansas cotton fields. Ark. Agric. Exp. Stn. Bull. 690. 84pp.

- Williams, M.R.** 1995. Cotton insect losses 1994, pp. 746-753. *In* D.J. Herber (ed.), Proc. Beltwide Cotton Conf., National Cotton Council of America, Memphis, TN.
- Williams, M.R.** 1997. Cotton insect losses 1996, pp. 834-848. *In* Dugger and Richter (eds.), Proc. Beltwide Cotton Conf., National Cotton Council of America, Memphis, TN.
- Yearian, W.C., J.J. Hamm, and G.R. Carner.** 1986. Efficacy of *Heliothis* pathogens, pp. 92-103. *In* S.J. Johnson et al. (eds.), Theory and Tactics of *Heliothis* Population Management: I-Cultural and Biological Control, Southern Coop. Series Bull. No. 316.
- Young, J.H. and R.G. Price.** 1968. Effect of irrigation and submersion in water on pupal survival of the bollworm. J. Econ. Entomol. 61: 959-961.
- Young, J.H. and R.G. Price.** 1977. Overwintering on *Heliothis zea* in southwestern Oklahoma. Environ. Entomol. 6: 627-628.

VITA

Jerry Lee Harris was born on June 27, 1974, in Hohenwald, Tennessee. He attended Lewis County High School and graduated in 1992. In December 1996, he received a Bachelor of Science degree in Agriculture from The University of Tennessee at Martin. Immediately following graduation, he accepted a research assistantship in the Department of Entomology and Plant Pathology at The University of Tennessee, Knoxville, TN, under the supervision of Dr. Gary L. Lentz. He received his Master of Science degree in December 1998.

Jerry L. Harris is a member of the Entomological Society of America, the Tennessee Entomological Society and the Tennessee Agricultural Production Association.

5325 1472 21

08-04-99

MRB

INFORMATION
CONSERVATION, INC.