

**ECOLOGY OF THE STALK BORER PAPAIPEMA NEBRIS  
(GUENEE), (LEPIDOPTERA:NOCTUIDAE), IN THE  
SOUTHWESTERN VIRGINIA NO-TILL CORN AGROECOSYSTEM**

by

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(ABSTRACT)

The stalk borer (SB), Papaipema nebris Gn. exhibited from 7 to 9 instars when reared on a meridic diet in a controlled environment. Both sexes went through variable numbers of instars before pupation. Head capsule width measurements did not form discrete sets, and overlap occurred between adjacent instars.

In feeding preference tests with first instar larvae using either leaf disks or stem sections, higher numbers of larvae fed on grasses, such as orchardgrass, Dactylis glomerata L. or fescue, Festuca arundinacea Schreb., compared to numbers feeding on other plants. In no-choice laboratory and field tests, larvae tunneled into plant stalks at the same frequency by which they would feed on foliage, showing a tendency to tunnel into plants they accept as hosts. Third or fourth instar larvae preferred to tunnel into orchardgrass and rye, Secale cereale L over the other plants present in field cage tests.

The SB prefers to oviposit on narrow leaved, perennial grasses, such as fescue and orchardgrass, over wide leaved annual grasses or broadleaf plants. Significantly higher numbers of eggs were laid on upright over prostrate plants in cage studies. The SB also preferred ovipositing on desiccating or dry plant material.

Higher numbers of SB infested corn seedlings were found next to field margins compared to numbers found within fields. Contour and transect maps of SB infested fields showed considerable aggregation over three years, and this distribution was confirmed by high variance to mean ratios, and small k values. SB distribution in no-till corn can be adequately described by the negative binomial model.

Field collections of SB in corn stalks showed 2, 3, or 4 instar larvae infesting the youngest seedlings. Variation existed in larval development from year to year. Linear regression covariance analysis showed that larval development was different between field collected larvae from year to year.

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## **I. INTRODUCTION AND LITERATURE REVIEW**

### 1.1. The reduced tillage corn agroecosystem

Corn is a major food and feed crop worldwide, and the leading feed crop in the United States (Chapman and Carter 1976). Its unparalleled cultivation throughout the world can be attributed to its extensive adaptability, and the nearly unbelievable increases in yield brought about through modern breeding programs. Corn will continue to be a very important crop throughout the world in the immediate future. The United States is the worlds largest producer of this grain crop, growing over 34 percent of the world's supply. It is the leading cash crop in the United States, with its value to producers approaching 7 billion dollars annually (Chapman and Carter 1976).

Corn is a warm season, annual crop that prefers well drained, loamy soils. Regions in the United States that have from 51 to 102 in of rain annually are most suitable for corn culture (Chapman and Carter 1976). The major areas of production in the United States include the corn belt, stretching across the Midwest through Iowa, Nebraska, Indiana and Illinois, extending south to eastern Texas, and east to the Atlantic Coastal States. Due to extensive crop breeding for adaptable varieties this crop is grown in all fifty states.

Much of the field corn grown in the United States through the 1950's, 60's and early 70's was produced using conventional tillage techniques. This involved turning or disking the soil before planting, and performing one or more cultivations between the rows for weed control.

More recently, however, more and more cropland is being treated under conservation tillage schemes. This involves the reduction or elimination of soil tillage before planting, and as a means of weed control. It has been estimated that about 80 percent of the farm acreage in the United States will be under some form of reduced tillage by the year 2000 (Hays and Young 1982, Phillips and Young 1983). The adoption of no-till farming practices for row crop production has been heralded as the greatest soil conservation practice adopted during this century. Conservation tillage involves the maintenance of adequate plant cover on the land in order to conserve water and soil resources, while reducing costs for labor, energy, and equipment (Phillips and Young 1973). The advantages of conservation tillage are numerous, and include erosion reduction, reduced fuel consumption, increased land utilization, reduced labor and equipment costs, and increased water retention by the soil (Hays and Young 1982, Chapman and Carter 1976, Price 1972). The disadvantages of conservation tillage include decreased soil temperature leading to slower seed germination, decreased soil aeration, increased weed, disease and insect problems, and a feeling among some growers of an aesthetically unacceptable look of fields under reduced tillage (Hays and Young 1982, Donaghy and Stabbe 1972, Elliot 1976, Elliot 1974, Fry 1982, Gregory 1974, Gregory and Musick 1976, Kells et al., 1980, Kuhlman 1982, Levine 1982, Pollard and Cussans 1976).

No-till field corn has been grown successfully in Virginia for over 15 years, and increases in yields have been attributed to this cropping method. In one 15 year study at Virginia Polytechnic Institute and

and State University, no-till corn planted into a rye cover out yielded conventionally tilled corn by 16 percent. A 3-year study at the University of Maryland showed no-till corn planted into grain/soybean stubble out yielded conventional till corn by 69 bushels per hectare (Vir. Coop. Ext. Serv. Pub. 424-030, 1985).

There are different subcategories of conservation tillage. Reduced tillage refers to a reduction in the number of conventional tillage trips taken over a field. A minimum of 20% of the previous crop residue is left on the soil after planting. Mulch - till involves incorporating only a portion of the previous crop residue, and a minimum of 33% of this residue is left on the soil after planting (Anon. 1983). Strip - till involves tillage of the soil only in a narrow band centered in the growing region, and a minimum of 50% of the previous crop residue is left on the soil surface after planting (Anon. 1983). Ridge - till refers to preparation of seedbed and planting in one operation on ridges. A minimum of 66% of the previous crop residue is left after planting (Anon. 1983). No - till, the most extreme form of conservation tillage, refers to when seedbed and planting are completed in one operation, and soil disturbance at planting is limited to the area contacted by the rolling coulter. A minimum of 90% of the previous years crop residue is left on the soil surface after planting (Anon. 1983). The great majority of corn under conservation tillage in Virginia is grown no-till, and this is the system used throughout this study. No - till agriculture is especially well adapted to sloping soils with silt loam surface textures found in the Appalachian regions of Virginia.



## 1.2 Weeds, diseases, and insects in the corn no-tillage agroecosystem

Weeds can represent a much greater threat to crops grown no-till compared to those grown conventionally (Phillips and Young 1973, Pollard and Cussans 1976, Price 1972). Reduced tillage will affect weed seed distribution and burial, the amount and condition of mulch on the soil surface, and the activity and persistence of herbicides, all of which can affect weed density (Phillips and Young 1973, Dawson and Bruns 1962). In one study undertaken in 1974 in the United Kingdom comparing weed compositions in fields of small grain direct drilled or conventionally tilled, the direct drilled fields showed decreased numbers of annual broadleaf weeds, increased numbers of perennial grasses, better control of some annual grasses, and decreased numbers of weed species (Elliot 1974). Generally, perennial weeds are much more difficult to control in no-till. Reduced emergence of broadleaf weeds was shown to occur in successive barley crops sown no-till (Pollard and Cussans 1976).

Decreasing mechanical weed cultivation has resulted in increased use of selective herbicides (Anderson, 1972). Herbicide persistence in no-till depends upon the chemical properties of the herbicide, the rate of application, soil PH, soil organic matter, the amount of surface plant residue, temperature, rainfall, and amount of microbial decomposition (Klingman et al., 1975, Kearney and Kaufman 1969, Anon. 1960). Decreased soil PH caused by no-till operations has been shown to significantly decrease the activity of triazine herbicides (Slack et al. 1978), and their persistence (Kells et al. 1980).

Since the 1960's major concerns have been expressed relative to the hypothesized insect and disease buildup in no-tillage agriculture (Gregory and Musick 1976, Gregory 1974). Increased mulch, as well as increased numbers of germinating, growing, and desiccating plants in fields with reduced tillage were believed to act as increased food sources for insect and disease organisms (Musick 1970, Musick and Petty 1974, Rubirk and McCartney 1982, Gregory and Musick 1976). No-till has generally increased damage from soil pests, due to decreased soil temperature leading to slower germination, increased soil moisture more favorable to seed diseases, and lack of mechanical destruction of soil insect pests (Hayes and Young 1982, Gregory and Musick 1976, Musick and Petty 1974, Miller 1969).

There has generally been a lack of an increase in economically important diseases with increases in no-till corn (Phillips and Young 1973). Price (1972) states that yields are not adversely affected by diseases in reduced or no-tillage systems. Northern corn leaf blight, yellow leaf blight, "Helminthosporium" leaf blight and corn rust were observed as equally injurious in no-till, minimum till, and conventionally tilled field corn in West Virginia (Elliot 1976). In a survey comparing conventionally tilled corn to reduced-tillage corn, Phillips and Young (1973) found increased disease incidence as a result of no-till practices in only 2 out of 26 diseases.

Adoption of conservation tillage systems has led to reports of increases in some diseases in corn. Anthracnose Colletotrichum graminicola (Ces) G. W. Wils and Goss's bacterial wilt Corynebacterium

nebraskense (Shuster et al.) Vidaver and Mandel, have become more prevalent in areas practicing conservation tillage (Fry 1982). Gray leaf spot in Virginia (Roane et al. 1974) and maize chlorotic dwarf virus and maize dwarf mosaic virus in Georgia (All et al. 1977) associated with lower yields have been shown to accompany increases in minimum tillage corn.

Increased soil plant debris and increased weed numbers, as well as lowered effectiveness of soil incorporated and sprayable insecticides, are often sighted as the reasons for a perceived increase in insect pest activity in no-till systems (Musick 1970, Musick and Petty 1974, Rubink and McCartney 1982, Gregory and Musick 1976). No-tillage corn following old sods is particularly susceptible to extensive damage from soil inhabiting insects such as white grubs or wireworms (Gregory and Musick 1976). Grasses, grass legume mixtures, hay and small grains preceding corn are all believed to be more conducive to the reproduction and survival of soil and above ground insect pests (Gregory and Musick 1976, Levine 1982, Stinner et al. 1984). Gregory (1974) speculated that one could expect increased damage from true armyworms, Psuedelatia unipuncta (Haworth), cutworms Agrotis spp., European corn borers, Ostrinia nubilalis (Hubner), and southwestern corn borers, Diatrea grandiosella (Dyar) in reduced tillage field corn after destruction of their alternate hosts with herbicides. Reported soil insect pests in no-till corn by order of importance include cutworms, wireworms, rootworms Diatrea spp., root aphids, Anuraphis maidiradicis (Forbes) white grubs, Popillia spp., and seed corn beetles, Stenolophus lecontei

(Chaudoir) (Musick and Petty 1974). The black cutworm, Agrotis ipsilon (Hugnagel), is potentially the most serious insect pest in reduced tillage corn. In Ohio, the black cutworm attacked 15% of plants in no-till fields and only 1% in adjacent conventionally tilled fields (Musick and Petty 1974). This insect prefers to lay its eggs in areas of high plant density and low growth forms (Bushing and Turpin 1976). Weedy areas in fields provide focal points for cutworm infestations, and corn or soybean debris increases cutworm damage.

Above ground insect pests perceived as more damaging under no-till include the armyworm, European corn borer, southwestern corn borer, stalk borer, Papaipema nebris (Guenee), and the corn flea beetle, Chaetocnema pulicaria Melsheimer (Musick and Petty 1974). In a few rare instances, insects are less damaging in no-till corn compared to conventionally tilled corn. Damage to corn seedlings by the lesser cornstalk borer, Elasmopalpus lignosellus (Zeller) was less in non-treated, no-till plots than in the insecticide treated, conventionally tilled plots (All and Gallagher 1977). Northern and western corn rootworms continue to be serious pests of corn, especially in the north central states. Although more eggs are laid by rootworm adults in no-till than in conventional till corn, approximately 4 times more eggs need to be laid in the no-till corn to give comparable damage as seen in conventional till (Musick and Collins 1971). Reduced damage by these soil inhabiting pests in no-till could be the result of increased feeding on crop debris and organic material.

### 1.3. The stalk borer (SB) Papaipema nebris.

#### 1.3.1. History and significance

The SB is the most important representative of its genus from an economic standpoint. First described by Guenee in 1852, it was identified in 1857 by Asa Fitch who observed the larvae boring into potato vines (Fitch 1857). Fitch described it as an undescribed Gortyna sp. C. V. Riley was the first to recognize the borer as Guenee's species in 1867 (Riley 1867). Reports continued through the years of crop and plant infestation, and in 1927 it was listed as one of the 10 most destructive insects of the year by the United States Bureau of Entomology, Insect Pest Survey (Decker 1931). The distribution of the SB proceeds from the Atlanta Coast west to the Rocky Mountains, and from southern Canada to the Gulf of Mexico (Decker 1931).

Since Decker's monograph on the SB in 1931 until 1983, literature citations on this insect have been rare. Following the increase in conservation tillage of corn in the last 20 years has been a concomitant increase in damage from this pest (Gregory and Musick 1976, Rubirk and McCartney 1982, Stinner et al. 1983, Levine 1983). This insect tends to reinfest the same fields year after year, which reinforces grower animosity and concern. This SB "syndrome" is believed to be caused by continuous cropping of corn, SB attraction to weedy areas, low rate of SB adult dispersion or migration out of an area, and low efficacy of insecticides against this pest. The SB has been particularly troublesome in recent years in Ohio (Gregory and Musick 1976, Rubirk and McCartney 1982, Stinner et al. 1983), Iowa (D. E.

Foster, pers. comm.), Illinois (Levine 1983, Levine et al. 1984) and Virginia (J. Roberts, pers. comm.) Little is known about this insect in Virginia.

### 1.3.2. Description and life history

The egg of the SB is globular in shape with many fine ridges radiating longitudinally from the upper polar region. When first laid they are pearly white in color, but soon change to a light to dark amber color prior to overwintering (Decker 1931).

First instar larvae are from 1.5 to 1.7 mm in length, head and thoracic plate very dark, almost black, with the body pale white. In all other instars excluding the last the larvae are pale maroon brown in color with pale white stripes running longitudinally along the body. The metathoracic segment and first three abdominal segments are colored a dark purple brown. The head is pale yellow, with thoracic legs and tubercles black. The prolegs are pale yellow, and the first two pairs are underdeveloped, causing the larvae to walk in a characteristic looping motion similar to that of many Geometridae. The ability to loop decreases with the age of the larvae.

Last instar larvae lose their purple brown markings, and appear dirty white in color with conspicuous setaceous black tubercles. Mature larvae can attain a length of 15 to 20 mm.

The pupae are typical noctuid like, 16 to 22 mm in length, and colored light to dark brown depending on age. Newly pupated individuals are a very light tan in color. The cremaster is short, and split into two short slightly curved spines. Individuals can be easily sexed while

in the pupal stage. Females have genital openings as simple slit-like structures, cephalad of the eighth abdominal spiracle, with the cephalic margins of the ninth and tenth abdominal segments curved cephalad towards the genital opening. The genital opening of the males appears as two small bumps, caudal of the eighth abdominal spiracle.

SB adults are plump, medium sized moths colored gray brown to chocolate brown near the center of the wings. The wings are traversed by 2 or more indistinct pale white lines. The hairs on the thorax form a distant crest or tuft at the posterior end pointing upward. There are two distinct morphological forms. The nebris variety has a series of three white spots on the basal portion of the forewing, followed by a second series of spots on the apical portion of the forewing. This second series of spots consists large yellowish spot surrounded by 3 to 5 smaller white spots. The variety *netila* entirely lacks these spots, or has them only indistinctly represented. The variety *netila* represented 71 percent of the SB reared in our laboratory colony over three years.

### 1.3.3 Life history

The eggs of the SB are laid on vegetation usually in masse, between mid-August and early October in Virginia. Hatching occurs in late April or May of the following year (Fig. 1). The date of egg deposition has been reported as in no way affecting the date of egg hatch (Decker 1931). The date of hatching is largely influenced by temperatures and egg development proceeds rapidly after mean daily temperatures reach 10° C (Levine 1986, Decker 1931).

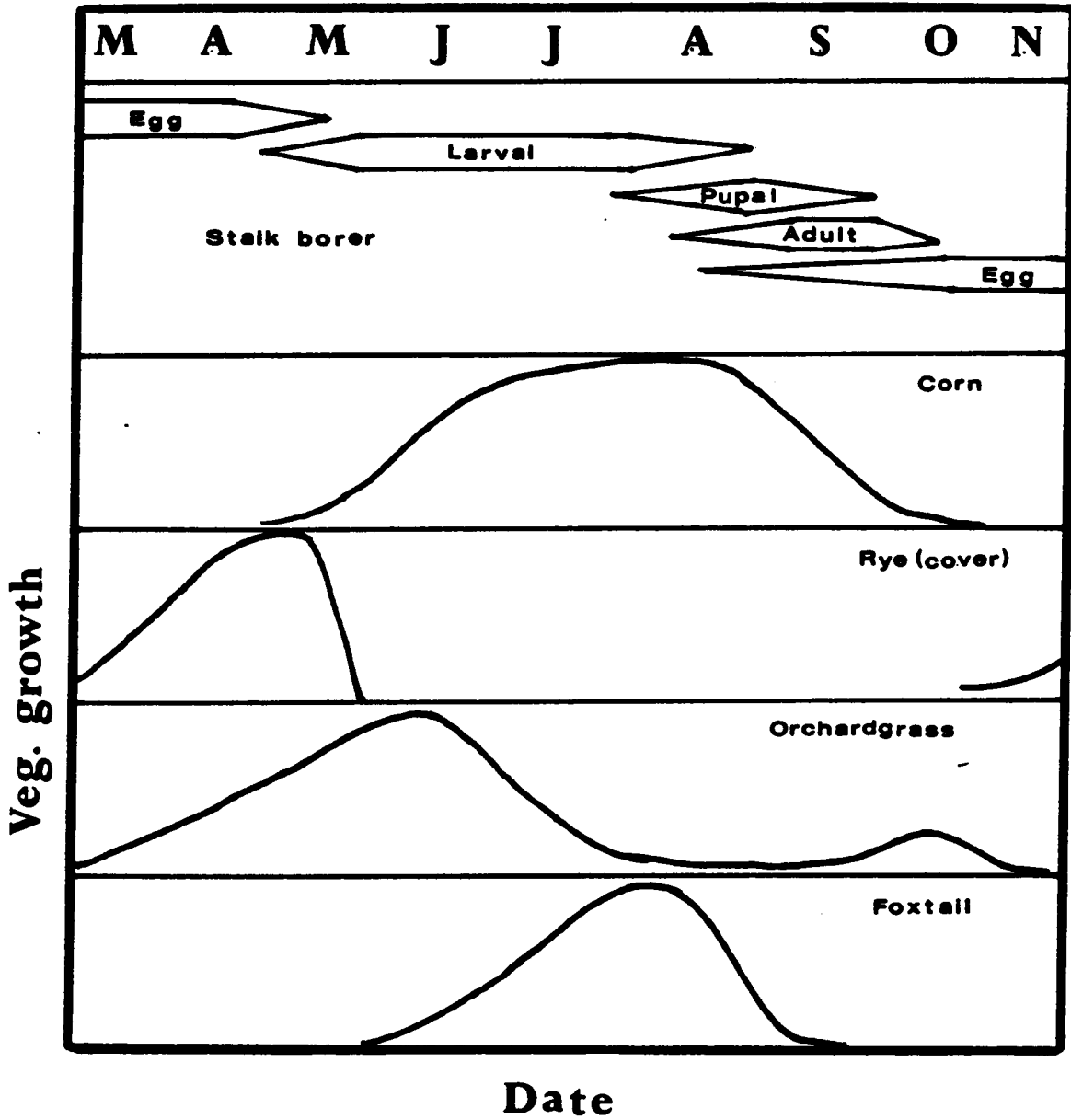


Fig. 1 Seasonal history of the stalk borer and associated host plants in Virginia



Newly hatched larvae begin feeding on surrounding vegetation, either as miners in the leaves of plants, as stalk or stem borers, or as foliage feeders (Levine 1983, Levine et al., 1984, Decker 1931). Destruction of a host plant will cause the larvae to migrate in search of more suitable hosts, and development is completed in large stemmed plants (Decker 1931).

The duration of the stadia and length of the larval life is primarily dependent on temperature, with food being of secondary importance (Decker 1931). Most SB reared in screened laboratories experience 7 or 8 instars, but as many as 16 have been observed (Decker 1931, Lowry 1927). The larval period extends for from 60 to 130 days. Females are believed to have a longer larval period than males (Decker 1931).

Pupation begins in Ohio in July and continues through August (Levine 1982). The duration of the pupal stage varies from 16 to 40 days, and is believed to be most heavily influenced by temperature (Decker 1931). Pupation occurs either in galleries constructed in the stalks of host plants, or in the soil just below the surface (Decker 1931).

Adult emergence lasts for two months, beginning early in August and continuing into October. The moths live from 6 to 32 days, depending on the temperature and availability of water or nectar.

Mating occurs at night within 2 days of adult emergence, and polygamy is common. The females will lay eggs for from one to seven days, and egg output usually decreases with time. The numbers of eggs

produced per adult have been reported as varying from 75 to 2,199 with an average of 879, (Decker 1931) or from 80 to 895, with an average of 352 (Lowry 1927).

#### 1.3.4 Damage syndrome

The SB is believed to develop first on weeds adjacent to or in corn when these weeds are mowed, killed with herbicides, or become too small for the developing larvae (Stinner 1983, Levine 1982). Cover crops preceding no-till corn, such as rye, could also serve as primary hosts for young SB. These insects can act as leaf miners, bore directly into the cotyledons of young plants, feed on young foliage, or bore directly into the stem (Decker 1931). Young larvae usually enter the plant at or just above the soil surface, but as they grow older they can enter the plant by boring into the stem anywhere from the base to the tip. Dried frass is often observed at entrance holes.

SB infestation in field corn usually occurs when the insect bores into the stem directly at or just above the soil line, the tunneling proceeding upward from the point of entry. Larvae, especially early instars, may feed in the whorl of the corn seedling much like an armyworm before boring directly down into the stalk. Attached leaves will at first show signs of epidermal scarification, followed by smaller but progressively larger holes in the young leaves and finally acquire a generally ragged appearance. The growing whorl of the corn plant will often be cut off at the base, similar to damage caused by a climbing cutworm.

Young, infested corn seedlings show what has been referred to as the "dead heart" symptom. This is characterized by entrance holes with frass at the base of the plant, and a stunted appearance, with brown and shriveled whorls (Rubirk and McCartney). Adventitious shoots often develop after SB feeding. Older (> 8 true leaves) corn often show no outward signs of SB attack, with the exception of the entrance holes, and appear to be only slightly affected (Levine et al., 1984).

#### 1.3.5 Association with weeds and crop plants in the agroecosystem

The SB is an extremely polyphagous species, unlike most other members of Papaipema which are monophagous or oligophagous. The SB has been reported as feeding on 176 different species of plants in 44 families (Table 1). Early larval stages have been reported feeding most often feeding on grasses. Later instars have been reported as requiring thick stemmed plants for their development (Decker 1931).

SB feed grasses when larvae are younger, but switches to thicker stemmed plants as the larvae mature (Decker 1931). In and around no-till corn in Virginia, cool season perennial grasses, such as orchard-orchardgrass, are the predominant vegetation in the early spring at SB egg eclosion. The annual, warmer season grasses become more predominant as the season progresses (Fig. 1). Lowery (1927) reared SB on timothy, orchardgrass, corn, curly dock, ragweed, burdock and lambsquarters. He also reported that young larvae prefer to feed on bluegrass, timothy, and orchardgrass.

Moths have been reported as ovipositing on many plants, including ragweed, pigweed, corn, dock, or golden rod, but grasses have been

Table 1. List of some identified host plants of the SB recorded in Iowa (Decker, 1931).

<u>Family</u>	<u>Species</u>	<u>Common Name</u>
Gramineae	<u>Zea mays</u> L.	Corn
	<u>Panicum scriberianum</u> Nash.	Panic Grass
	<u>Setaria viridis</u> (L.) Beauv.	Green Foxtail
	<u>Avena sativa</u> L.	Oat
	<u>Dactylis glomerata</u> L.	Orchard Grass
	<u>Poa pratensis</u> L.	Kentucky Bluegrass
	<u>Elymus canadensis</u> L.	Wild rye
Salicaceae	<u>Salix nigra</u> Marsh.	Willow
Urticaceae	<u>Urtica gracilis</u> Ait	Nettle
Polygonaceae	<u>Rumex crispus</u> L.	Curly Dock
Chenopodiaceae	<u>Chenopodium album</u> L.	Lamb's Quarters
Amaranthaceae	<u>Amaranthus retroflexus</u> L.	Green Pigweed
Leguminosae	<u>Melilotus officinalis</u> (L.)	Sweet Clover
	<u>Trifolium pratense</u> L.	Red Clover
Solanaceae	<u>Solanum tuberosum</u> L.	Potato
	<u>Nicotiana tabacum</u> L.	Tobacco
Compositae	<u>Solidago canadensis</u> L.	Golden-rod
	<u>Aster multiflorus</u> Alt.	Aster
	<u>Ambrosia trifida</u> L.	Ragweed
	<u>Ambrosia artemisiifolia</u> L.	Lesser Ragweed
	<u>Rudbeckia hirta</u> L.	Black-eyed Susan
	<u>Calendula officinalis</u> L.	Marigold
	<u>Cirsium arvense</u>	Canada thistle
	<u>Cirsium</u> sp.	Thistle
Asclepiadaceae	<u>Asclepias</u> sp.	Milkweed

identified as preferred for oviposition (Levine 1985, Stinner et al., 1984). Decker (1931) also reported that SB would oviposit on folded paper, cotton, pieces of bark, and the bodies of dead moths if leaf material was not available.

#### 1.4. Objectives of this study.

Our knowledge of the biology, ecology and behavior of the SB is not vast. Yet, this insect continues to increase its pest status in many parts of the United States where no-till corn is grown. Only recently has increased research energy been turned toward this insect pest. The biology and habits of this insect have never been studied in the state of Virginia. Any pest management program devised for the SB in no-till corn must have as its foundation structured biological research designed to answer basic questions relating to the SB and its relationships in nature.

The objectives of my research were to explore the ecological relationships of the SB in no-till corn. I examined the relationships of the SB with its various host plants, including feeding preferences by the larvae and ovipositional preferences of adults. The within field distribution of SB larvae in no-till field corn, as well as the association of temporal development of the SB with no-till corn, were examined. Finally, this information was summarized and an integrated SB control program proposed based on these research results.

**II. Feeding preferences and consumption rates  
of stalk borer larvae using plants found in no-till corn**

## 2.1 Introduction

Many theories have been presented to describe host-plant selection by phytophagous insects (Brues 1920, Fraenkel 1953 and 1959, Kennedy 1958, Thorsteinson 1960). The most generally accepted theory was presented by Dethier as the "total gestalt" hypothesis (Dethier 1982, Miller and Stricker 1984). This theory promotes the idea that determination of feeding choice by phytophagous insects is mediated by the total summation of external stimuli emanated by plants, and the total internal stimuli of the insect depending on its physiological state. This "total gestalt" theory takes into account not only secondary plant chemicals, but also plant nutrients as mediators of host plant selection.

Lepidopterous larvae have been shown to respond to various stimuli for host-plant selection. Heliothis zea Boddie, Heliothis virescens (Fabricius), and Spodoptera frugiperda Smith have been shown to respond to some plant extracts over others, and plant extracts other than sugars would elicit feeding response in these Noctuid larvae (McMillan et. al. 1966). While testing corn earworm larval feeding response to corn silk and kernal extracts, it was found that the primary feeding stimulant/arrestant was not related to sugars (Stals et. al. 1965). In other tests using the polyphagous fall armyworm, it was found that this insect

was able to discriminate in feeding preference tests between corn and Tripsacum dactyloides L., a species closely related to Zea mays (Wiseman et. al. 1967).

The stalk borer (SB), Papaipema nebris (Gn.), is a pest in no-till field corn, and has been described as extremely polyphagous in nature (Decker 1931). This insect has been reported as feeding on 176 host plants in 44 different families, including grasses, pigweeds, composites, legumes, Solanaceae, and even various trees and shrubs (Table 1). The SB has been observed feeding on a variety of weeds in or bordering no-till corn fields prior to movement to field corn (Decker 1931, Levine 1982, Stinner 1984). It is apparent that the SB is well adapted to the biotic environment exemplified in no-till agricultural systems.

Reasons for studying plant feeding preference of SB larvae are as follows. If a particular SB will feed only a short period of time on a particular host plant, the chances of it moving and being redistributed among the available host plant resources, and ending up in field corn, are greater than if it is content to remain feeding on a particular plant for a longer period of time. Also, the longer a particular SB will feed on an alternate host, the lower the degree of damage caused by the individual when it moves to field corn. Younger, smaller corn seedlings will sustain greater loss in stand and yield than older corn seedlings (Levine et al. 1984).



The objectives of this study were first to determine the feeding preferences of SB larvae testing field corn, rye, and various weeds found in no-till corn fields in Southwestern Virginia, and second, to determine feeding consumption rates of SB larvae comparing various host plants.

## **2.2 Materials and Methods**

Feeding preferences of first instar stalk borer larvae, lab study.

Stalk borer eggs were collected in 1984 cage studies from individuals reared to maturity on a meridic pinto bean based diet (Levine et. al. 1982). The laboratory colony was two generations removed from the field, where they were collected from infested field corn near Blacksburg, Virginia. Eggs were held outside in a covered, screened cage in plastic .75 oz. Solo Serve plastic souffle cups with lids until egg eclosion. Egg eclosion occurred between 5 and 11 May, 1985, when the feeding preference tests were conducted.

Feeding preference arenas contained either leaf disks 13mm in diameter, or stem sections .63 cm in length. Stem sections were selected either at or below 4 cm from ground level. Preference tests were conducted using pairs of plants being tested in all possible combinations. Two leaf disks or stem sections of each plant in the pair to be tested were placed in 10 cm square petri dishes on moist filter paper.

Plants used in this series of tests were collected from the field on the day of the test and included field corn, Zea mays L., rye, Secale cereale L., tall fescue, Fescuta arundinacea Schreb., orchardgrass, Dactylus glomerata L., red clover, Trifolium pratense L., and dandelion, Taraxacum officinale L. All plants were in bloom, except field corn and rye, which was in head formation. The youngest leaves from all plants were selected for use in leaf disk preference tests, and the youngest shoots or tillers were used for stem section tests.

Five newly hatched first instar larvae were placed in each feeding arena along with pairs of leaf disks or stem sections on moist filter paper using a squirrel's hair brush. Ambient temperature was  $22 \pm 2$  C for the duration of the test. Larvae hatched approximately 12 hours prior to feeding preference tests. Tests were ended after 2 hours and the number of larvae settling on the two hosts presented were counted and recorded. Each plant combination was replicated 8 times. Data from these tests was analyzed using ANOVA and LSD comparing pairs of plants tested, and ANOVA using Duncan's new multiple range test separating means combining all tests together by plant species. All percents were transformed using arcsine prior to analysis (Little and Hills 1978).

Development of first instar SB larvae on various plants, lab study.

Plants were grown in the greenhouse or transplanted from the field into metal trays , and watered twice weekly for the duration of the test. Tall fescue, cv. KY31, orchardgrass, cv. Hallmark, and giant foxtail, Setaria faberii Herrm. seeds were planted 3 April 1984, and field corn was planted on 1 May 1984. Dandelion and rye were recovered from a no-till corn field near Blacksburg, and transplanted to the metal flats on 3 May 1984.

First instar SB hatching in a screen covered outdoor cage were transferred using a squirrel's hair brush to test plants. One SB was placed on each individual plant at its base, and 50 replications were performed per plant species tested.

Fourteen days after artificially infesting the test plants, observations were made as to the number of plants showing feeding damage, the presence or absence of larvae in the plant stalks or feeding on the foliage, and the head capsule widths of recovered larvae. Measurements were also made of plant height and stem diameters 3 cm from the soil surface. Data was analyzed using ANOVA and Duncan's new multiple range test for mean separation.

Development of third or fourth instar SB larvae on various plants, field study.

Field corn ,cul. SS1021, rye, cul. Winter King, cheat, Bromus secalinus L., yellow rocket, Barbarea vulgaris R.Br., red clover, and orchardgrass plants were transplanted from the field to 1 X 1 X .62 m covered screened cages in the field on 18 May 1984. Each cage contained twenty-five individual plants of one plant species, and the plants were arranged in a grid with app. 15 cm separating individuals. Plants were watered after transferring to field cages.

Third or fourth instar larvae reared from egg eclosion on a meridic pinto bean based diet (Levine et. al. 1982) at  $22 \pm 2$  C constant temperature were transferred to test plants in field cages using forceps on 22 May 1984. Twenty-five larvae were placed in each field cage at the base of test plants, one larva per plant. A screened lid was securely fastened to prevent larval escape. Prior to test initiation, 30 larvae were randomly selected and their head capsule widths measured using an ocular micrometer.

Ten plants per plant species being tested were randomly selected on 5 June 1984, and again on 12 June 1984, and returned to the lab. Plants were inspected for feeding damage and entrance holes of tunnelling SB larvae. Plant stalks were opened and stalk borers removed. Head capsule widths of recovered stalk borers were recorded using an ocular micrometer.

Feeding consumption rates of SB larvae using stem sections of corn, sorghum, orchardgrass, and alfalfa.

Stalk borer larvae were collected from infested corn seedlings on 17 July 1983, and immediately placed in feeding consumption arenas with stem sections of corn and orchardgrass, corn and sweet sorghum, cv. WS20 sweet sorghum, or corn and alfalfa, Medicago sativa L. Two stem sections of each plant measuring 1.27 cm in length and .5 cm in diameter were placed in petri dishes with moist filter paper. Lids were placed on the petri dishes and attached with Parafilm M to prevent moisture loss. Larvae to be used in tests, along with stem sections, were weighed using a Mettler balance to .0001 gms prior to the test. Larvae were placed in the consumption arenas for 24 hours. Larvae and stem sections were removed and weighed separately to measure percent weight loss for the plants, and percent weight gain for the larvae. There were 10 replications per plant combination. Data were analyzed using ANOVA and LSD for mean separation of percent weight loss of plants.

### 2.3 Results and Discussion

Feeding preferences of first instar SB larvae, lab study.

Newly hatched SB larvae fed to a lesser or greater degree on leaf disks and stem sections of all test plant species (Table 2). Feeding scarification was observed on leaf disks of all plant species. Using analysis of variance

Table 2. Percentages of first instar SB feeding on selected host plants, 1985.

Leaf disks, mean seraration pooling tests by plant.						
Plant:	OG <sup>a</sup> ,	R,	F,	RC,	C,	D
Percent:	50a	40ab	38abc	34bcd	26cd	19d
	R	F	RC	C	D	
OG	17/30 <sup>b</sup>	30/22	25/17*	12/27*	10/27 <sup>*c</sup>	
R		10/17	15/20	10/30	25/15*	
F			10/17	5/15	0/22*	
RC				17/17	2/18	
C					10/20	

Stem sections, mean separation pooling tests by plant.						
Plant:	F,	R,	OG,	C,	D,	RC
Percent:	63a	63a	62a	61a	30b	26b
	R	F	RC	C	D	
OG	30/25	30/30	10/36*	15/28	20/30*	
R		27/30	11/46*	13/28	7/27*	
F			15/36*	26/28	10/27*	
RC				29/9	26/18*	
C					6/30	

<sup>a</sup> OG=orchardgrass, R=rye, F=tall fescue, RC=red clover  
C=field corn, D=dandelion

Percentages transformed using Arcsine ( Percent ) and analyzed using ANOVA at the .05 level of significance and Duncan's new multiple range test of significance for mean seperation.

<sup>b</sup> The numerator represents the mean percent of larvae settling on the host plant in the top row, the denominator represents the mean percent of larvae settling on the host plant in the left column.

<sup>c</sup> Asterisks designate significance at the P=.05 level using LSD after ANOVA for each paired comparison.

and mean separation combining tests by plant species for leaf disks, the higher number of stalk borers feeding on orchardgrass was not significantly different from the number of stalk borers feeding on either rye or fescue. Preference for orchardgrass leaf disks was found to be significantly higher than for leaf disks of red clover, dandelion, or corn. A preference for leaf disks of rye was shown when compared to corn or dandelion. Significant preferences exhibited when analyzing pairwise comparisons were for orchardgrass, rye, fescue, and red clover over dandelion, and for orchardgrass over red clover and corn.

Stalk borers were observed tunnelling into the stem sections of all plant species presented. Analyzing grouped data by plant species showed two distinct preference groups using stem sections, with the grasses (orchardgrass, fescue, rye and corn), being preferred over the broadleaf plants, (dandelion and red clover). Using LSD for paired comparisons, orchardgrass, rye, fescue and corn were preferred over dandelion, and corn, orchardgrass rye, and fescue were preferred over red clover.

First instar SB larvae prefer to feed on grasses as compared to the broadleaf plants used in this test. Stalk borer infestations in field corn have most often been associated with grassy areas in and around fields, and SB adult females prefer grasses as ovipositional substrates (Levine 1985, Stinner et. al. 1984). Cool season perennial

grasses, such as orchardgrass and fescue, are often the dominant vegetation during spring months when overwintering eggs hatch. Preferences for feeding on these grasses by larvae, coupled with ovipositional preferences of SB adults, enable this pest insect to make the temporal transition from growing season to growing season, and contribute to its pest status.

Many of the stalk borers tested did not settle on the plant parts presented. These "wandering" larvae comprised 65% of the individuals used in the leaf disk tests, and 48% of the individuals used in the stem section test. It is not known if the larvae exhibit dispersal behavior just after hatching, but this behavior could be important in the pattern of spread of this pest in infested fields. A tendency for the SB to settle and feed on stem sections as opposed to leaf disks is mirrored in field observations, where stalk borers exhibit a preference for stem boring, as opposed to feeding on leaf surfaces. Stalk borers exhibit negative phototaxis, preferring to feed on the underside of leaf disks, or to bore into stem sections. First instar larvae were often seen congregating on or in one plant part in feeding arenas. Findings of multiple stalk borers in single corn stalks is rare in the field, and the aggressive behavior of more mature stalk borer larvae has been observed (Decker 1931). First instar larvae, however, tend to respond to one another in a less aggressive fashion.



Development of first instar larvae on various plants, lab study.

The percent surface damaged (ie. feeding scarification) plants follows the percent infestation (ie. stalk tunnelling) in most cases, showing the tendency of this insect to tunnel into the plants it accepts as hosts (Fig. 2). Rye sustained the greatest amount of surface damage (74%), and had the highest percentage tunnelling (27%). Dandelion had the lowest mean surface damage rate (2%), and tunnelling rate (2%). Plant stem diameter was not correlated with percent tunnelling using linear regression analysis,  $P=.05$ .

Development of third or fourth instar SB larvae on various plants, field cage study.

The degree of tunnelling observed for the field cage study was slightly different than observed in the lab study, reflecting the different host plants tested, their maturity, and the stage of development of larvae. Surface damage levels were highest for red clover, orchardgrass, and corn, and tunnelling levels were greatest for orchardgrass and rye (Fig. 3). Damage levels were lowest for red clover and cheat. Tunnelling levels were lowest for red clover and yellow rocket. At 14 days post infestation, 40% of rye and orchardgrass plants showed tunnelling damage, and at 21 days

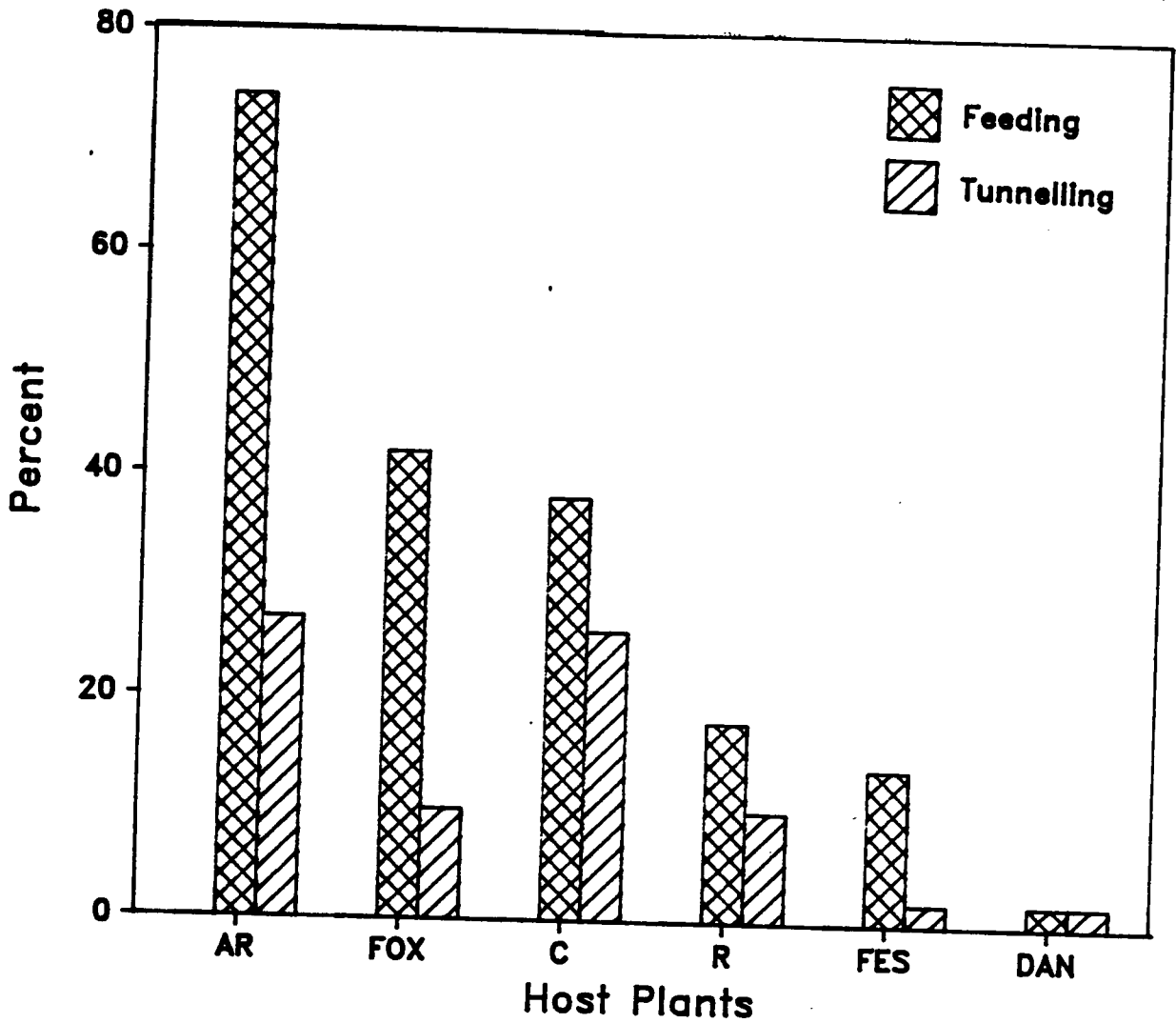
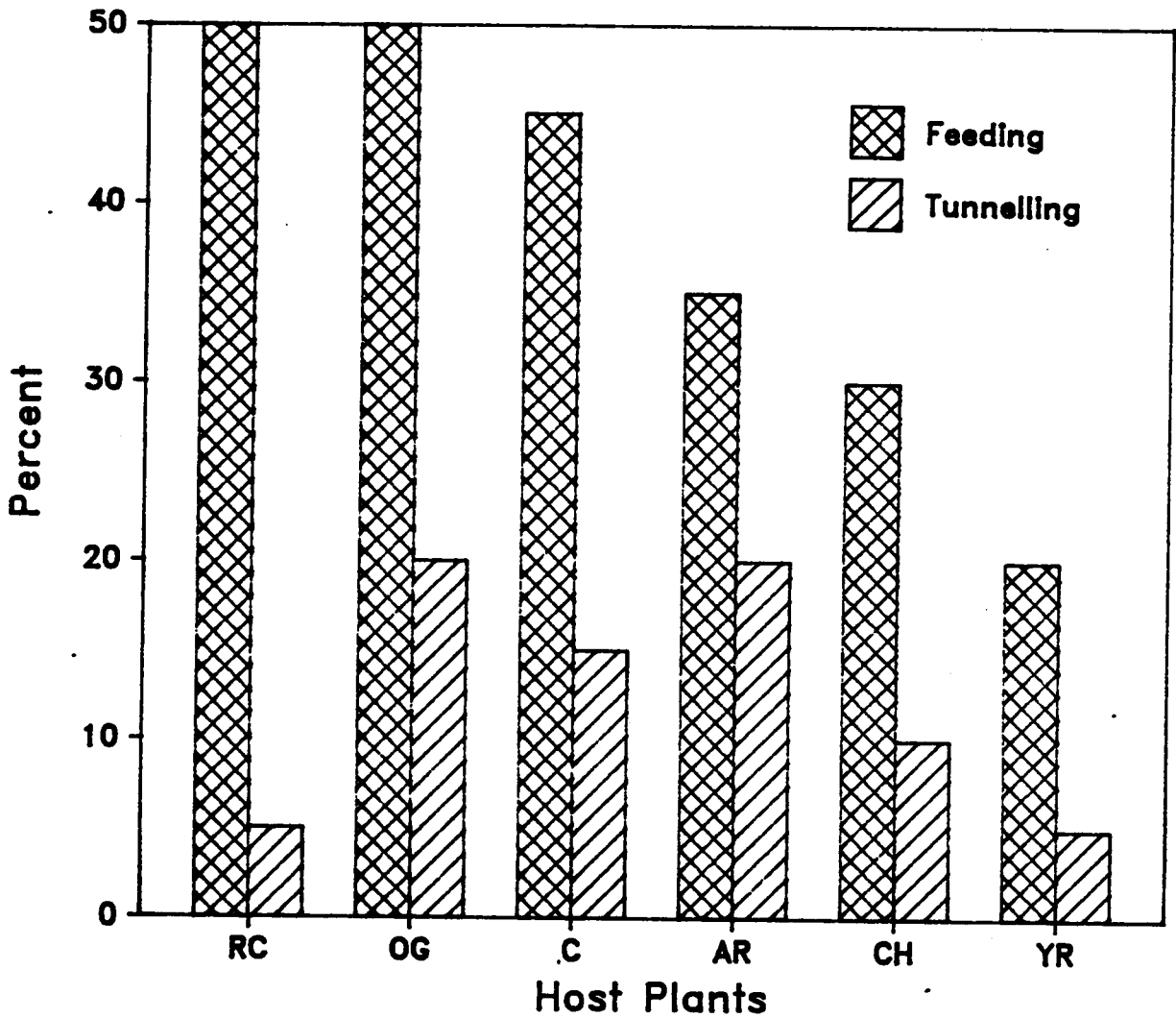


Fig.2 Percent plants showing surface damage and tunnel damage by first instar SB larvae, lab test, 1984.

	Mean stem length (cm)	Mean stem diameter (cm)
AR = rye	28.6	3.42
FOX = giant foxtail	1.8	1.11
C = corn	13.3	5.77
R = per. ryegrass	1.65	.72
DAN = dandelion	16.3	2.62



**Fig.3** Percent plants showing surface damage and tunnel damage by third and fourth instar SB larvae, field cage test, 1984.

	Mean stem length (cm)	Mean stem diameter (cm)
RC = red clover	29.5	3.54
OG = orchardgrass	50.1	3.37
C = corn	6.3	6.55
AR = rye	59.5	2.91
CH = cheat	35.5	2.7
YR = yellow rocket	28	4.72

post infestation, no larvae could be found in any plants sampled.

The larvae used in the lab and field cage studies fed to varying degrees on all plants presented, exemplifying a graded continuum of acceptance typical of many polyphagous insects when presented a series of "host" and "non-host" plants. Generally feeding was highest on grasses and lower on broadleaves. Feeding initiation resulted more frequently in tunnel formation, indicating that a decision to infest a certain potential host plant is made prior to tunnel formation. Chemical cues most probably mediate this behavior together with internal cues depending on the physiological state of the insect. In these "no choice" tests, factors other than stem diameter must account for the observed results.

Feeding by all stages of SB larvae, on either younger or more mature rye, readily occurs. This is the most common cover crop preceding no-till field corn in western Virginia. Infestations of this insect away from weedy borders or weeds in fields may be attributable to feeding by early larval stages on rye, prior to corn infestation. When rye is then killed using herbicides, these stalk borers seek alternate hosts, often choosing field corn. The practice of corn planting during rye treatment with herbicides leads to a perfectly timed situation of corn seedling emergence and SB movement, leading to increased damage to field corn.

Feeding consumption rates of SB larvae using stem sections of corn, sorghum, orchardgrass, and alfalfa.

Larvae collected from infested corn and placed in feeding consumption arenas showed clear preferences for corn over orchardgrass, and for corn over sorghum, an annual grass even more closely related to corn than orchardgrass (Table 3). Mean percent weight gain of larvae over the 24 hour period ranged from 1.06 to 1.26 percent, and these means were not significantly different using LSD at the .05 level of significance.

Table 3. Consumption of stem sections of corn, sorghum, orchardgrass and alfalfa by SB larvae recovered from no-till corn, 1983.

Plant	Mean percent wt. loss of plants	Mean % wt. gain of larvae
C <sup>a</sup> OG	17.8 a 0 b	1.26
C S	33 a 0 b	1.06
C A	23.4 a 0 b	1.11

<sup>a</sup>Means followed by the same letter are not statistically different using ANOVA with LSD at the .05 of significance. Plant combinations, C=field corn, OG=orchardgrass, S=sweet sorghum, A=alfalfa.

**III. Ovipositional preferences of the  
stalk borer among various plants,  
and for plants at varying growth conditions.**

### 3.1 Introduction

Lepidopterous females have been shown to exhibit decided preferences for plants used for oviposition. Some, like the imported cabbageworm, Artogeia rapae (L.) and the diamondback moth, Plutella xylostella (L.), prefer to oviposit on cruciferous plants. They are attracted to these plants and induced to oviposit by characteristic isothiocyanate or glycoside chemical cues. (Gupta and Thorsteinson 1960, Renwick and Radke 1983).

Chemical cues have been shown to be the most important criteria for host plant selection by ovipositing Lepidoptera, but height and denseness of vegetation, flowering of host plants, plant age, color, moisture level, and tactile characteristics have all been factors proposed to explain observed ovipositional preferences. The black cutworm, Agrotis ipsilon (Hufnagel), was shown to prefer curled dock, Rumex crispus L., and yellow rocket, Barbarea vulgaris R.Br. for oviposition over 14 crop and weed species, including corn and soybean (Bushing and Turpin 1976). Attractiveness was thought to be associated with low growth form. Using the cabbage looper, Trichoplusia ni (Hubner), workers found that this insect preferred 21 week old broccoli and cauliflower plants for oviposition to younger, 15 week old plants (Boling and Petrie 1971). Heliothis spp. laid 60 percent fewer eggs on varieties with glabrous rather than hirsute leaves (Lukefahr 1965), while



Platynota scabia layed 20 times more eggs on pubescent soybean leaves than on glabrous ones (Pedigo 1971).

Increases in the pest status of the stalk borer (SB) have been associated with changing weed populations, which act as alternate hosts associated with reduced tillage systems (Stinner et. al. 1984). Perennial and annual grasses have been identified as weeds whose development and reproduction is favored in no-till (Elliott 1974, Donaghy and Stabbe 1972, Williams and Ross 1970). Annual and perennial grasses, such as orchardgrass, Dactylis glomerata L., wheat, Triticum aestivum L., and quackgrass, Agropyron repens L., have been identified as preferred species for oviposition by SB females, and may account for the increased pest status of this insect in areas where no-till is practiced (Stinner et al. 1984, Levine 1985). This insect has also been reported as delaying its oviposition until a suitable plant substrate is provided, contributing to the belief that the SB is relatively selective when ovipositing (Decker 1931).

The objectives of my study were to determine what species of plants common to Virginia no-till corn fields would be preferred for oviposition by the SB, to determine common characteristics of preferred plants, and to define the implications of these ovipositional preferences by the SB in regard to its pest status in no-till corn.

### 3.2 Materials and Methods

Stalk borers were lab reared on a meridic pinto bean based diet till maturity (Levine 1983, Reese et al. 1972). Individuals were one generation removed from a wild population in 1984, and two generations removed in 1985. Pupae were sexed and held until adult emergence. Pupae were observed three times weekly, and all emerged adults were immediately placed in ovipositional cages so that adults used in tests were between 1-48 hours old at test initiation.

All tests were conducted in 60cm X 56cm X 70cm wooden organandy and glass cages with wooden floors. Cages were glassed on top, but tops were covered for the duration of tests to reduce temperature. Cages were placed in a well ventilated greenhouse during tests, where temperatures fluctuated, and ambient light-dark hours were observed. All tests took place between August 15 and October 1, 1984-85. Plants in all tests were carefully inspected for SB eggs at test termination. Eggs were counted in 1984 and 1985 tests, and the number of egg masses were counted in 1985.

Ovipositional preference among various plants presented either cut or standing, 1984.

Plants used in tests were selected on the basis of their relative prevalence and apparency in and bordering no-till corn fields in Southwestern Virginia. Foxtail, Setaria

spp., tall fescue, Festuca arundinacea Schreb., orchardgrass, Dactylis glomerata L., smooth pigweed, Amaranthus hybridus L., and rye stubble from the previous years corn cover crop were recovered from a no-till corn field near Blacksburg, Virginia. When plants were collected from the field, measurements were taken of leaf length, width, and fresh weight plus dry weight to measure percent moisture. Corn was grown in the greenhouse, and was at the 6-8 true leaf stage at the time of test initiation. All plants were inspected for SB egg masses, then transferred to .5 l plastic pots with potting soil. Plants used in tests were watered weekly. Plants were either presented to SB adults upright in pots in ovipositional cages, or cut and presented laying on cage floors. One pot, or cut plant bunch, comprised a replication for that plant species. Position of plants was randomized for each replication.

Eight pairs of adults within 48 hrs of adult emergence were released per cage for tests of plants in pots, and for cut bunches presented on cage floors (Tests 1 and 2, Table 4). Four pairs of adults within 48 hours of adult emergence were used in tests using plants of the same species presented in pots, and cut and presented on the cage floors (Table 4, Test 3). All cages were supplied with an open dish with 10% sugar water. Eight replications were performed in test 1 and 2, and four replications were performed in test

3. Replications were continued for either 21 days, or until the death of all moths, whichever came first.

Ovipositional preference for plants varying plant height, moisture level, and surface texture, 1985.

Foxtail, fescue, orchardgrass, fall panicum (Panicum dichotomiflorum Michaux.), common milkweed (Asclepias syriaca L.), smooth pigweed, bitter nightshade (Solanum dulcamora L.), and horsenettle (Solanum carolinense L.), were collected from the border of a no-till corn field in Montgomery County Virginia. Each plant was closely inspected for SB eggs prior to test initiation. Corn was grown in the greenhouse, and was in the 6-8 true leaf stage at the time of test initiation. All plants were transferred to .5 l plastic pots with potting soil.

In test 1, two plants of one species at two different heights were placed in ovipositional cages. Plants were clipped to either 20 or 40 cm in height (Table 6, Test 1). In test 2, two plants of one species under two different watering regimes were placed in ovipositional cages. Plants were either not watered, or were watered three times weekly during the duration of the test (Table 6, Test 2). Samples of each plant species under each water regime were weighed prior to and following the test to measure percent moisture at test conclusion. In test 3, fescue plants were either sprayed or not sprayed with 2 or 5 percent solutions of

Ortho X-77 spreader/sticker, and placed in ovipositional cages (Table 6, Test 3). The principle functioning agents of this chemical included alkylaryl polyoxyethylene, glycols, free fatty acids, and isopropanol. The X-77 was applied using a hand held mist blower, and plants were sprayed to runoff. In test 4 (results not shown in Table 6), single pots of common broadleaf weeds, including common milkweed, smooth pigweed, bitter nightshade, and horsenettle, were placed in ovipositional cages.

Four pairs of SB adults were released per cage in all tests. All cages were supplied with 10 percent sugar water. Four replications were performed for each test and tests were continued for 21 days, or until death of all moths.

Separate statistical analyses were performed for each test in each year. Data on ovipositional preference was analyzed using analysis of variance in a randomized complete block design. Differences between means were determined using Duncan's new multiple range test for 1984 data, and t-tests (least significant difference) for 1985 data, after all data were transformed using arcsine (percentage/100) (Little and Hills 1978). Data relating mean number of eggs laid, leaf moisture, leaf length, and leaf width were analyzed using simple linear regression of number of eggs laid per plant versus plant characteristic.

### 3.3 Results

Ovipositional preferences among various plants, presented either cut or standing, 1984.

In experiments testing the attractiveness among plants cut and presented to ovipositing SB females laying on cage floors, the greatest number of eggs were found deposited on foxtail, followed by orchardgrass (Table 4, Test 1). No eggs were found laid on pigweed, or on the rye stubble. When different plants are presented to ovipositing stalk borers upright in pots, fescue was the most highly preferred plant, followed by orchardgrass. Pigweed was the least desirable plant for oviposition in this series of tests (Table 4, Test 2).

#### Characteristics of plants chosen for oviposition.

Significantly higher numbers of eggs were laid in tests where plants were presented upright in pots, compared to the numbers of eggs laid in tests where plants are cut, and presented to the SB lying on cage floors. Using orchardgrass, fescue or foxtail, and presenting plants either cut or standing, moths preferred to lay eggs on standing, uncut plants in all tests. No eggs were laid on cut orchardgrass in 4 replications (Table 4, Test 3).

One characteristic of plants preferred for oviposition by the SB are narrow leaves. The two species most preferred for oviposition by the stalk borer in this series of tests, fescue and orchardgrass, were also the plants with the

Table 4. Ovipositional preferences of the SB for various plants, either upright or cut laboratory tests, 1984.

Test1 <sup>a</sup> -Plants cut and presented to the SB on cage floors.		
Plant	Mean no. of eggs $\pm$ SD	Range
Foxtail	69 $\pm$ 93 a <sup>b</sup>	0 - 272
Orchardgrass	47 $\pm$ 98 ab	0 - 279
Corn	34 $\pm$ 61 ab	0 - 170
Fescue	22 $\pm$ 29 ab	0 - 78
Pigweed	0 b	-
Rye (stubble)	0 b	-
Test2-Plants presented to the SB upright in pots.		
Fescue	974 $\pm$ 544 a	204 - 1512
Orchardgrass	622 $\pm$ 777 b	12 - 2068
Foxtail	234 $\pm$ 414 bc	0 - 7158
Corn	116 $\pm$ 157 bc	0 - 440
Pigweed	0 $\pm$ c	-
Test3-Plants of the same species are presented to the SB both cut, and upright in pots.		
Orchardgrass (uncut)	490 $\pm$ 467 a	26 - 1168
Orchardgrass (cut)	0 b	-
Fescue (uncut)	332 $\pm$ 204 a	212 - 638
Fescue (cut)	37 $\pm$ 36 b	0 - 76
Foxtail (uncut)	275 $\pm$ 375 a	4 - 820
Foxtail (cut)	24 $\pm$ 36 b	0 - 78

<sup>a</sup> Eight replications in tests 1 and 2, four replications in test 3 per plant species tested.

<sup>b</sup> Means followed by the same letter are not significantly different at the .05 level using Duncan's new multiple range test, data transformed to arcsine (Percent eggs laid/100).

narrowest leaves. (Table 5). Plants with relatively wide leaves, and high plant moisture, (corn and pigweed), were not among the plants most preferred by the SB for oviposition. Using regression analysis, no relationship was seen between mean number of eggs laid and either leaf moisture ( $y = 425.7 - 2.6x$ ,  $P < .77$ ,  $r^2 = .02$ ), or leaf length ( $y = 107.8 + 7.46x$ ,  $P < .42$ ,  $r^2 = .15$ ). A significant relationship was seen between mean number of eggs laid and leaf width ( $y = 817.8 - 201x$ ,  $P < .05$ ,  $r^2 = .76$ ).

When one plant species, either fescue, foxtail, fall panicum or orchardgrass, is presented to SB females at two different heights, adults lay higher numbers of eggs on the taller plants. Fescue was the only plant tested in which there were significantly higher numbers of eggs and masses laid on the taller plants (Table 6, Test 1). When individual plants of one plant species were presented to stalk borers either watered three times weekly, or not watered and allowed to desiccate, more eggs were laid on desiccating plants, regardless of the species used (Table 6, Test 2). The number of egg masses laid on desiccating plants is significantly higher using fescue, foxtail and orchardgrass, and the number of eggs laid on desiccating plants is significantly higher for corn, fescue and orchardgrass. Plants that were lowest in percent moisture were not necessarily preferred for oviposition. Rye stubble from the previous years crop had the lowest percent moisture, yet no



Table 5. Percent moisture, length and width of leaves from plants used in SB ovipositional preference tests, 1984.

Plant	Mean no. eggs laid	Mean percent moisture	Mean leaf length(cm)	Mean leaf width(cm)
Corn	116 bc <sup>a</sup>	76.5 a	57.8 a	4.3 a
Pigweed	0 c	51.6 a	5.3 d	3.6 b
Orchardgrass	622 b	35.0 ab	53.0 a	.67d
Foxtail	234 bc	30.6 ab	32.5 c	1.7 c
Fescue	974 a	32.0 bc	40.0 b	.39d
Rye stubble	0 c	8.2 c	--	--

<sup>a</sup> Means in variable grouping followed by the same letter are not different at the .05 level using ANOVA and Duncan's new multiple range test for mean separation.

Table 6. Ovipositional preference of the SB for various plants varying plant height, moisture level, and surface characteristics, laboratory tests, 1985.

Test1<sup>a</sup>-Plants cut to varying heights and presented to SB for oviposition.

Plant	Ht. (cm)	Mean no. of masses $\pm$ SD	Range	Mean no. of eggs $\pm$ SD	Range
Fescue	20	2.5 $\pm$ 3.3a <sup>b</sup>	0- 7	108 $\pm$ 182a	0-380
Fescue	40	12.5 $\pm$ 8.1b	1-19	543 $\pm$ 406b	20-898
Foxtail	20	2.25 $\pm$ 1.3a	1- 4	118 $\pm$ 76a	60-226
Foxtail	40	6.25 $\pm$ 5.1a	1-12	182 $\pm$ 155a	10-368
Fall panicum	20	1.5 $\pm$ 2.3a	0- 5	64 $\pm$ 110a	0-228
Fall panicum	40	4.2 $\pm$ 3.4a	0- 7	160 $\pm$ 131a	0-286
Orchardgrass	20	2.5 $\pm$ 2.4a	0- 5	103 $\pm$ 169a	0-356
Orchardgrass	40	5.5 $\pm$ 5.8a	0-13	228 $\pm$ 257a	0-556

Test2-Plants watered, or not watered and presented to SB for oviposition.

Plant	Water	Mean no. of masses $\pm$ SD	Range	Mean no. of eggs $\pm$ SD	Range
Corn	+	1.25 $\pm$ 2.5 a	0- 5	61 $\pm$ 123 a	0- 246
	-	5.75 $\pm$ 6.0 a	0-14	412 $\pm$ 531 b	0-1192
Fescue	+	2.0 $\pm$ 2.5 a	0- 5	79 $\pm$ 106 a	0- 224
	-	4.25 $\pm$ 4.0 b	1-10	199 $\pm$ 201 b	4- 410
Foxtail	+	.75 $\pm$ .95a	0- 2	47 $\pm$ 55 a	0- 98
	-	4.60 $\pm$ 2.60b	1- 7	165 $\pm$ 135 a	18- 308
Orchardgrass	+	1.0 $\pm$ 2.0 a	0- 4	64 $\pm$ 129 a	0- 258
	-	6.75 $\pm$ 3.1 b	4-11	359 $\pm$ 207 b	188- 646

Test3-Plants sprayed, or not sprayed with Ortho X-77 spreader sticker, and presented to SB for oviposition.

Plant	Spray solution (percent X-99)	Treat.	Mean no. egg masses $\pm$ SD	Min.	Max.	Mean no. of eggs $\pm$ SD	Min.	Max.
Fescue	2	+	2.0 $\pm$ 2.5a	0	6	49 $\pm$ 62a	0	290
		-	2.4 $\pm$ 4.3a	0	10	70 $\pm$ 125a	0	148
Fescue	5	+	2.4 $\pm$ 1.8a	0	4	40 $\pm$ 33a	0	142
		-	1.2 $\pm$ 1.8a	0	4	39 $\pm$ 62a	0	82

<sup>a</sup> Four replications were performed for each plant x factor interaction.

<sup>b</sup> Means followed by the same letter are not significantly different using LSD for each plant X factor interaction for number of egg masses or number of eggs. Level of significance was .05 for tests 1 and 3 and .1 for test 2. Data transformed to arcsine (percent/100).

eggs were oviposited on rye in any replication. Other characteristics of desiccating plants, such as leaf curl, color, or chemical changes related to desiccation, may serve as ovipositional cues for the SB. Spraying plants with X-77 spreader/sticker did not inhibit egg laying at the concentrations (2 and 5 percent) tested (Table 6, Test 3). No eggs were recovered from any replication using only broadleaf weeds as oviposition substrates.

### 3.4 Discussion

Perennial cool season grasses preferred by the SB for oviposition are very common plants in and around no-till corn in Virginia. Many fields have a history of continuous corn cultivation, and these grasses are used on field borders and in waterways. Replacement of these plants would be difficult, and the elimination of these plants is not a viable control alternative. Conversely, grass clumps inside SB infested fields can be targeted for control using herbicides prior to corn planting. This close relationship of the SB with perennial cool season grasses contributes to the cycle of the damage syndrome of the SB in no-till corn.

Increased SB infestations in certain fields, and in weedy areas in fields, has been observed from season to season, and could be explained by ovipositional preferences of the SB for existing weeds. Perennial cool season grasses are the predominant growing plants in early and mid spring

during SB egg hatch. Preference for oviposition by the SB for these grasses will increase the survival of newly emerged SB larvae by assuring eclosion near available food resources. Movement of SB females is believed to be limited (Bailey et. al. 1985), and could also contribute to the clumped distribution of many perennial infestations.

The fact that significantly more eggs were laid on upright plants could be an important behavioral factor of the SB to consider in following a manipulative cultural control practice. Plants in borders of infested fields could be cut prior to moth emergence, thus effectively moving ovipositing SB away from fields in search of more highly preferred oviposition sites.

Taller plants received higher numbers of eggs. One possible explanation for this may be that taller plants have more leaf and stem area. Higher leaf and stem area would increase the probability of SB oviposition, taking all other factors into account. Taller plants would also contain a greater number of preferred oviposition sites than shorter plants. I observed, however, that there was an abundance of unused ovipositional sites, even on plants on which oviposition was heavy. It is possible, however, that on a surface area basis, the number of eggs laid on shorter plants was not significantly less than the number laid on taller plants.

Reasons for the preference of the SB to oviposit on desiccating or dryer plants are unknown. One factor which could account for this behavior is the habit of the SB of using narrow leaves which fold at the midrib for oviposition. I would estimate that 90% of eggs in my tests in 1984 and 1985 were laid on the midrib of folding leaves. This natural folding of the leaves is accentuated when dessication occurs. Females laying eggs in the leaf crease often used spumaline to glue the fold together, forming a protective packet surrounding egg masses. This could serve to increase protection from adverse environmental factors during winter months, such as low temperature or moisture loss, and to protect eggs from parasites and predators. In preliminary tests using one pair of SB moths in smaller (45 X 50 cm) cages in a controlled environment ( $20 \pm 2$  C, 25 replications), moths laid an average of 128 eggs per female. Twenty-eight percent of the pairs of moths tested did not mate successfully and lay eggs. The uncontrolled, relatively high temperatures in the greenhouse during subsequent cage tests accelerated mortality of SB adults, contributing to the observed variability in egg numbers.

**IV. Variability in the distribution  
of infestations of the stalk borer in no-till field  
corn.**

#### 4.1 Introduction

Studies of the patterns of aggregation of insect populations have often been undertaken to gain an understanding concerning the underlying causes of variation seen in field populations. Basic models of aggregation in insect populations have been proposed (Anscombe 1950, Bliss and Fischer 1953, Waters 1959). Dispersion patterns not only affect the means of sampling, but also the method of analysis of field data (Southwood 1978). Density may be used to estimate population size, and can have an important bearing on control tactics employed for insect pests.

The pattern and degree of aggregation of insects has been shown to have a direct bearing on reproduction and survival. Factors such as interspecific competition for food resources, and the effectiveness of predators and parasites in regulating an insect pest population are directly affected by the spatial pattern of the population.

A single expression used to describe the amount of insect aggregation,  $k$ , is a quantitative expression which may signify a true biological aggregation, or it may be a simple statistical artifact (Waters 1959, Southwood 1968, Harcourt 1961). Dispersion indices are influenced by the number of samples taken, the total number of individual samples, the size of the sampling unit, and their actual density (Harcourt 1961, Kuehle and Frye 1972, Pielou 1977,

Southwood, 1961). More recently, indicators such as Green's coefficient of dispersion have been proposed that are not correlated to the mean density of a population. Such indices are proposed as the best candidates to use in analyzing actual changes in distribution of organisms with changing density (Myers 1978, Green 1966, Elliot 1979, Despins and Roberts 1986).

In many cases, the distribution of egg masses by insects is random, while the distribution of individual eggs and young larvae is clumped. The distribution of larvae often approaches randomness in later instars (Chiang and Hobson 1959, Guppy and Harcourt 1960, Harcourt 1961, Kono 1953, Keuhle and Fry 1972, Gomez and Bernardo 1974).

Insects showing a negative binomial distribution include cabbage loopers, pine sawflies, oribated mites, and oak leaf rollers (Harcourt 1965, Ibarra et al. 1965, Lyons 1964, Ellenberger and Cameron 1977).

The stalk borer, (SB), is a pest that has become predominant in many areas where no-till corn production is increasing (Gregory and Musick 1982, Rubink and McCartney 1982, Levine et. al. 1984). Adults lay egg masses predominantly on grasses (Decker 1931, Levine 1985, Stinner et. al. 1984). Larvae begin feeding on available weeds in the agroecosystem, moving to thicker stemmed plants as the larvae become larger, or if these weeds are mowed or killed using herbicides (Stinner et al. 1984). Corn becomes a



primary host in Virginia when rye Secale cereale L. used as a cover crop, along with weeds in the fields, is killed using herbicides. Eggs may be laid primarily on field edges, or throughout fields if weed infestations are predominant (Levine 1982). Stinner (1984) has observed that SB infestations are positively correlated with orchardgrass Dactylis glomerata L. infestations in fields. He also observed that the SB moved only a few meters from herbicide treated orchardgrass clumps to field corn.

Reports of the distribution of SB infesting no-till corn fields are varied. Observers have reported "locally heavy" SB infestations ranging from 1-2 acres in size within fields (Rubink and McCartney 1982). In contrast, workers have reported "serious" infestations throughout entire fields (Levine 1982). In Virginia, casual observations have indicated infestations confined predominantly to field edges.

The objectives of the present study were to determine the degree of SB infestation in no-till corn comparing areas adjacent to and away from field margins, and to assess the distribution of SB infestations in areas of fields away from field margins. Observations were made as to predominant weeds associated with SB infestations. An analysis of SB distribution in infested fields was made in relation to its biology, behavior, and pest status.

#### 4.2 Materials and Methods

SB infestations in areas adjacent to and away from field margins.

Infestations of SB in no-till corn fields in Montgomery and Floyd Counties, Virginia, were rated between 6 June and 26 June in 1984, and 10 June and 14 June 1985. Ten fields were evaluated in 1984, and 16 in 1985. Infestations were assessed in two areas of each field, either within 3.7 m of a field margin, or at least 30 m away from field margins. Ten 30.5 meter-row samples were selected at random within each area per field, and the number of SB infested seedlings were counted. A corn seedling was considered SB infested if it showed either SB larvae in the whorls, flagging, dead heart, or any combination of these symptoms. Preliminary sampling indicated 90-95% accuracy in determining SB infested seedlings using these visual symptoms. The primary border weeds were determined by visual examination of one 61 meter-row sample along each field border. Predominant weeds along borders were listed and ranked as to prevalence, number, and apparency.

Statistical analysis consisted of analysis of variance of the mean number of SB infested corn seedlings per area in each field. Mean separation was conducted by least significant difference at the .05 level.

SB distribution in infested areas away from field margins.

Within field (> 4 m from field margin) SB infestations were rated during 3 successive years, 1983-85, at the VPI & SU Agronomy Farm, Montgomery County, Virginia. These fields had been in continuous no-till corn for 8 years, and had a history of SB infestation. Rye used as a winter cover crop was treated 8 May 1983, 22 May 1984, and 1 May 1985 with atrazine 1.5 qt./A., paraquat 1pt./1A., simazine 1.5 qt./1A., and various insecticides tank mixed with liquid nitrogen and applied at the rate of 50 gallons/A.

Treated areas were subdivided into plots 3.9 m wide and 15.2 m in length. The center two rows of the 4 or 6 row plots were inspected for SB infested seedlings as described above. Data from the two rows was combined for analysis. Inspections for SB infestation took place at the 2-3 true leaf stage of development on 31 May 1983, 6 June 1984, and 31 May 1985.

Relief and contour maps of SB infestations were created using a computer program called Surface II, based on a grid procedure. Smoothing of contour lines was produced by piecewise Bessel interpolation within a grid cell. The point at which a contour line intersected the side of a grid cell was determined by simple linear interpolation (Sampson 1978).

Calculation of the value of  $k$ , the dispersion parameter of the SB population, was computed by several methods (Anscombe 1949, 1950), where

$$(1) k = \frac{\bar{x}^2}{s^2 - \bar{x}}$$

where  $\bar{x}$  = estimate of the mean of the population

$s^2$  = estimate of the variance of the population.

$$(2) \log \frac{N}{no} = k \log \left[ \left( 1 + \frac{\bar{x}}{k} \right) \right]$$

where N = number of samples

no = number of samples with no SB present

Solution of method 2 was conducted by iteration.

The test for the fit of the negative binomial distribution was based on calculation of the second moment statistic (U), which is the difference between the actual variance and the expected variance given by:

$$U = s^2 - \left[ \bar{x} + \frac{\bar{x}^2}{k} \right] \quad (\text{Evans 1953}).$$

Analysis of the inverse of k values to the means of counts for the four fields over the three year period indicated no trends in relationship between these statistics (Southwood 1978). Calculation of a common k is therefore justified. Calculation of kc for the SB over the three years was approximated as:

$$\frac{1}{kc} = \frac{\sum v_i}{\sum x_i}$$

$$\text{where } x_1 = \bar{X}^2 - \frac{s^2}{N}$$

$$\text{and } y_1 = s^2 - \bar{X} \quad (\text{Bliss and Owen 1958; Bliss 1958})$$

Green's coefficient of dispersion was calculated as:

$$G_x = \frac{(s^2/\bar{X}) - 1}{(x-1)}$$

where  $G_x$  = Green's coefficient of dispersion

and  $x$  = a variate, or one sample (Green 1966).

Economic analysis of SB damage.

Yield reduction estimations caused by SB infestations were calculated by placing wooden stakes adjacent to infested and non-infested corn seedlings in the 3-4 leaf stage, and harvesting whole plants for silage yield at the end of the growing season. One hundred infested, and one hundred non-infested plants were staked on 5 June 1984. All plants had been treated with carbofuran granules at the rate of 1 lb. ai per acre at planting applied in the furrow, and toxaphene at the rate of .2 lbs. ai per acre applied tank mixed with herbicides as a spray to the rye cover at corn planting. Plants were harvested on 11 October 1984, and weighed as a group. Four, five-plant subsamples were chosen at random, weighed, dried, and reweighed to calculate percent moisture at harvest date. Estimations of silage yield reduction by SB attack were based on a plant

population of 54340 plants per hectare, 45 percent moisture content, and a price of 25 dollars per ton (G.E. Groover, per. comm.).

Estimations of economic damage of the SB were calculated for 26 entire fields, (excluding areas within 2 rows of field margins), scouted in 1984 and 1985, and for identified infestation areas within fields for 4 fields from 1983 to 1985. Calculations were based on mean numbers of SB infested corn seedlings per unit area.

#### **4.3 Results**

Higher numbers of SB infested corn seedlings were found within 4 m of the field margins compared to those found at least 30 m away from field margins (Tables 7,8). Significantly higher numbers of SB infested seedlings were found in 3 of 10 fields with SB in 1984, and 10 of 16 fields with SB in 1985 (Tables 7,8). The SB infestations were generally higher in 1984, compared to 1985. Higher numbers of SB infested seedlings were found in 1984 compared to the number found in the same fields (6 of 7) in 1985. Only one field in the two year study showed significantly higher numbers of SB infested seedlings in area 2, at least 30 m away from a field margin (Table 7).

Primary border plants around infested fields varied, but orchardgrass and fescue were predominant. Casual observations did not support a connection between weed

Table 7. SB infestations in no-till corn fields, Montgomery and Floyd Counties, Virginia, 1984.

Field	Area <sup>a</sup>	Mean no. SB	±SD	Range	Est. loss (doll./hec.)	Primary border weeds
K1	1	21.5	7.1	8- 33		Fes, Rye <sup>b</sup>
	2	135.9*	47.7	68-197	764.2	
K2	1	11.7	10.0	0- 31		Fes, OG
	2	5.8	2.7	2- 10	32.6	
K3	1	1.69*	1.2	0- 4		Fes, OG
	2	0.29	0.28	0- 2	1.6	
SM1	1	24.9*	10.7	6- 39		OG, Fes
	2	4.1	4.1	0- 14	23	
SM2	1	7.6	12.0	0- 38		OG, Fes
	2	0	0	0- 0	0	
SB	1	4.0	4.65	0- 14		Fes, Rye
	2	1.0	1.7	0- 4	5.6	
CS	1	2.6*	2.1	0- 6		Fes, OG
	2	0.3	0.7	0- 2	1.7	
F1	1	2.0	2.0	0- 6		Fes, OG
	2	1.1	1.1	0- 4	2.1	
PS	1	0.94	0.95	0- 3		Fes, OG
	2	0.38	0.32	0- 1	1.7	
RR1	1	9.7	8.1	0- 22		Fes, OG
	2	4.3	3.1	0- 10	25.5	

<sup>a</sup>Area 1 is within 3.7 m. of a field border, and Area 2 is at least 30 m. away from a field border. Asterisks (\*) indicate significantly different means using ANOVA and LSD at the .05 level.

<sup>b</sup>Fes = fescue, OG = orchardgrass, Rye = rye

Table 8. SB infestations in no-till corn fields, Montgomery and Floyd Counties, Virginia, 1985.

Field	Area <sup>a</sup>	Mean no. SB	±SD	Range	Est. loss (dol./hec.)	Primary border weeds
CS	1	1.7*	0	0- 6	0	Fes, OG <sup>b</sup>
	2	0	2.1	0- 0		
FOX	1	2.6*	2.8	0- 9	0	Fes, OG
	2	0.1	0.3	0- 1		
G	1	11.3	2.3	10-14	110.8	OG, P
	2	19.7	9.5	10-29		
HS	1	3.0*	1.0	1- 5	6.7	Fes, B
	2	1.2	1.5	0- 3		
IF2	1	1.4	2.5	0- 8	0	OG, P
	2	0	0	0- 0		
K1	1	6.6*	1.6	2-15	112.5	Fes, OG
	2	2.0	4.5	0- 4		
K2	1	7.7*	3.0	4-13	2.8	Fes, OG
	2	0.5	1.0	0- 3		
K3	1	4.9*	3.3	0-10	3.2	Fes, P
	2	0.6	1.1	0-		
RF	1	2.0	1.5	0- 4	6.1	Rye, Fox
	2	1.1	2.1	0- 4		
RR1	1	6.3*	5.8	1-19	3.2	OG, Fes
	2	0.6	0.96	0- 3		
RR2	1	16.5*	9.8	0-28	48.9	OG, Fes
	2	8.7	6.0	2-18		
RR3	1	2.5*	2.5	0- 6	3.4	OG, B
	2	0.6	0.7	0- 2		
R1	1	6.6	6.5	0-18	11.0	Fes, Alf.
	2	2.3	3.2	0-10		
SM1	1	4.1*	4.3	0-14	2.2	P, OG
	2	0.4	1.0	0- 3		
SM2	1	0.2	0.42	0- 1	0	OG, Fes
	2	0	0	0		

<sup>a</sup>Area 1 is within 3.7 m. of a field border, and Area 2 is at least 30 m. away from a field border. Asterisks (\*) indicate significantly different means using ANOVA and LSD at the .05 level.

<sup>b</sup>OG = orchardgrass, Fes = fescue, Rye = rye, PI = poison ivy, B = assorted brambles, P = pigweeds, Fox = foxtails, Alf = alfalfa.



infestation levels and SB infestation levels within infested fields.

Contour and transect maps of the distribution of SB within infested fields in 1983, 84, and 85 show considerable clumping in all 3 years (Figures 4-11). General infestation levels were lower in 1984 compared to 1983 and 1985. Contour maps show "peaks" and "valleys" indicating areas of high and low SB infestation, respectively. The apparent clumped distribution of the SB within fields in 1983, '84 and '85 exhibited by the contour and transect maps is confirmed by the high variance to mean ratios (Table 9). This is also expressed in the calculated k values. The larger the k value, the closer the distribution to true randomness, while the smaller the k value ( $<8$ ), the closer the distribution to the negative binomial (Southwood 1978). It is apparent that the distribution of the SB within fields over the 3 years is most closely described by the negative binomial model. Chi-square tests at the 5% level showed the statistic U is less than its standard error for every field examined. This further confirms my conclusion that the observed distribution is the negative binomial, and that my k values are justified. Combining data for the three years, the kc for the SB was calculated as 1.953.

Plants showing SB damage in the 3-4 leaf stage had a reduction of 75.4 percent in silage yield compared to plants escaping SB damage. Maximum economic damage from SB attack

Table 9. Mean numbers of SB infested corn seedlings per plot, with respective k values, the efficiencies of these estimates, and Green's coefficient of dispersion, VPI and SU Agronomy Farm, 1983-1985.

Year (field)	Mean (X)	Variance (s <sup>2</sup> )	No. of samples (N)	Method 1		Method 2		Green's coe. (Gx)
				k	Effic. of est. (%)	k	Effic. of est. (%)	
1983(K1)	18.5	135.0	64	2.93	75	1.67	<50	.0069
1984(K1)	8.5	49.6	40	1.74	65	2.49	<50	.0220
1985(K1)	16.1	199.5	28	1.42	58	1.27	50	.0312
1985(K2)	16.0	150.6	44	1.90	58	1.56	<50	.0127

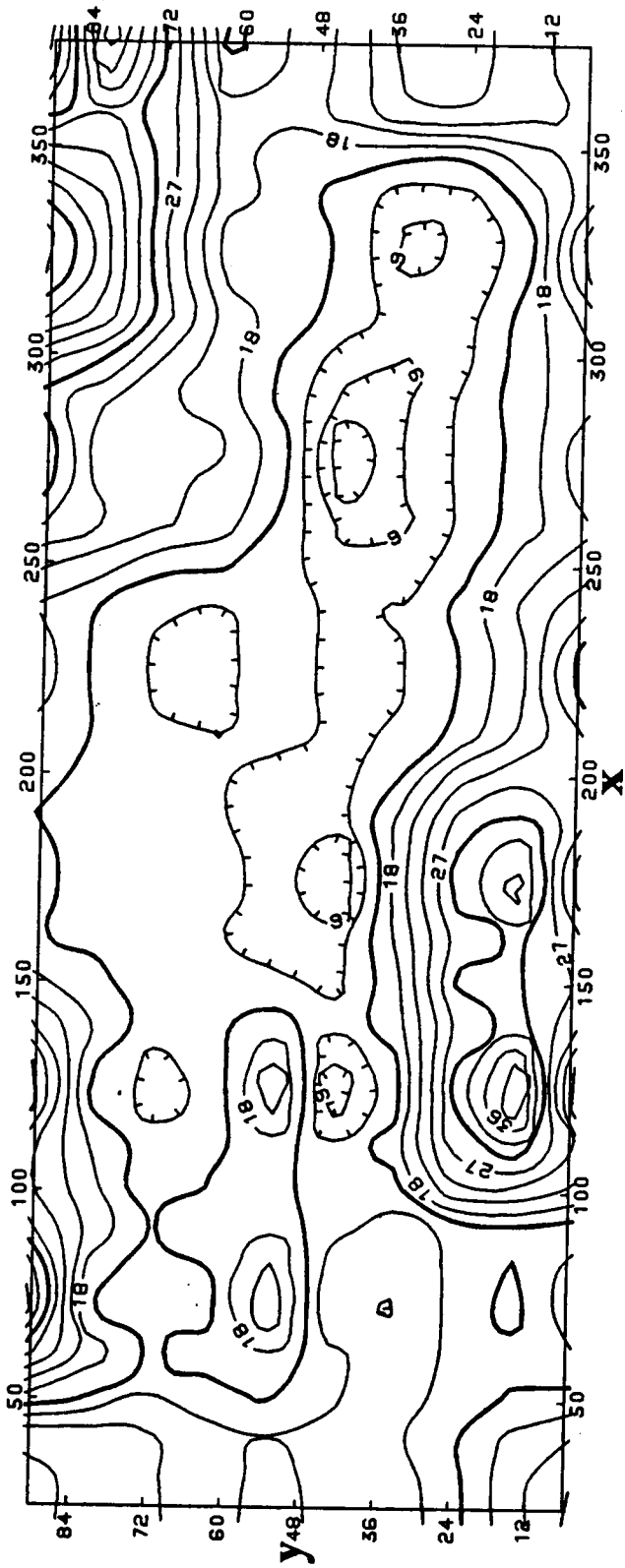


Fig.4 Contour map of SB infestation, VPI & SU Agronomy Farm, 1983.

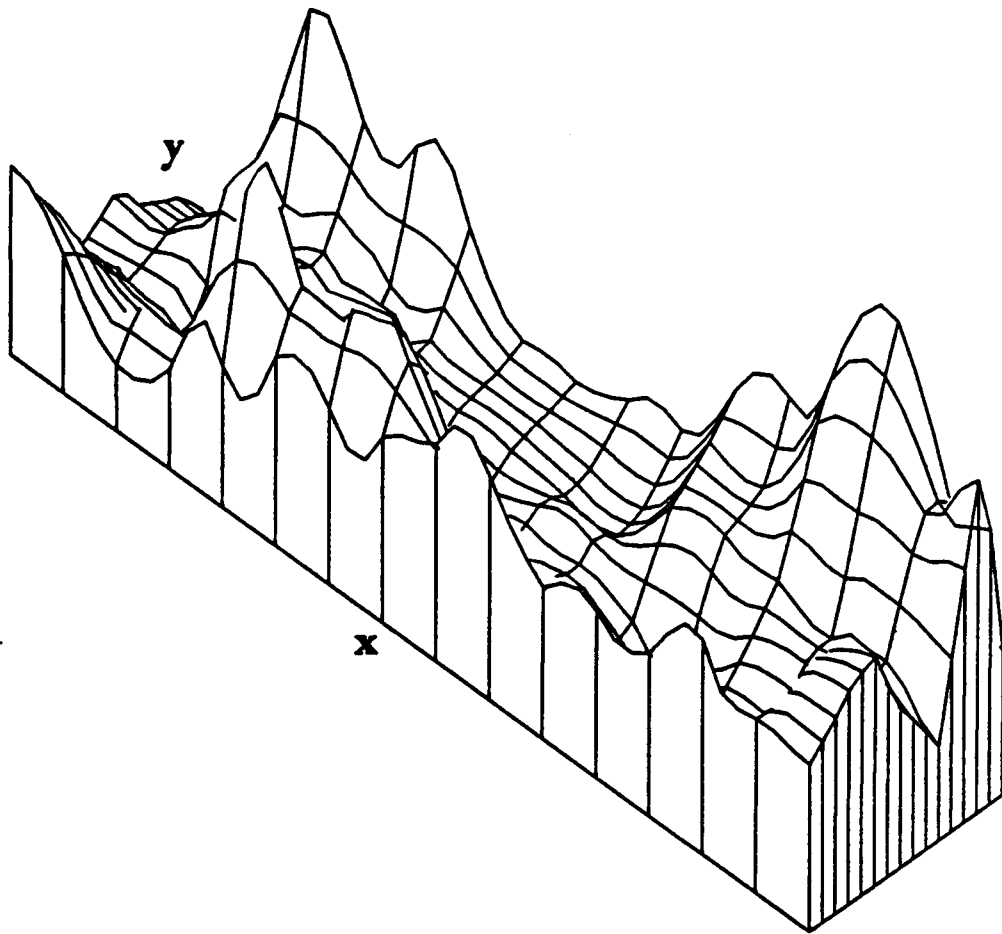


Fig. 5 Transect map of SB infestation, VPI & SU Agronomy Farm, 1983.

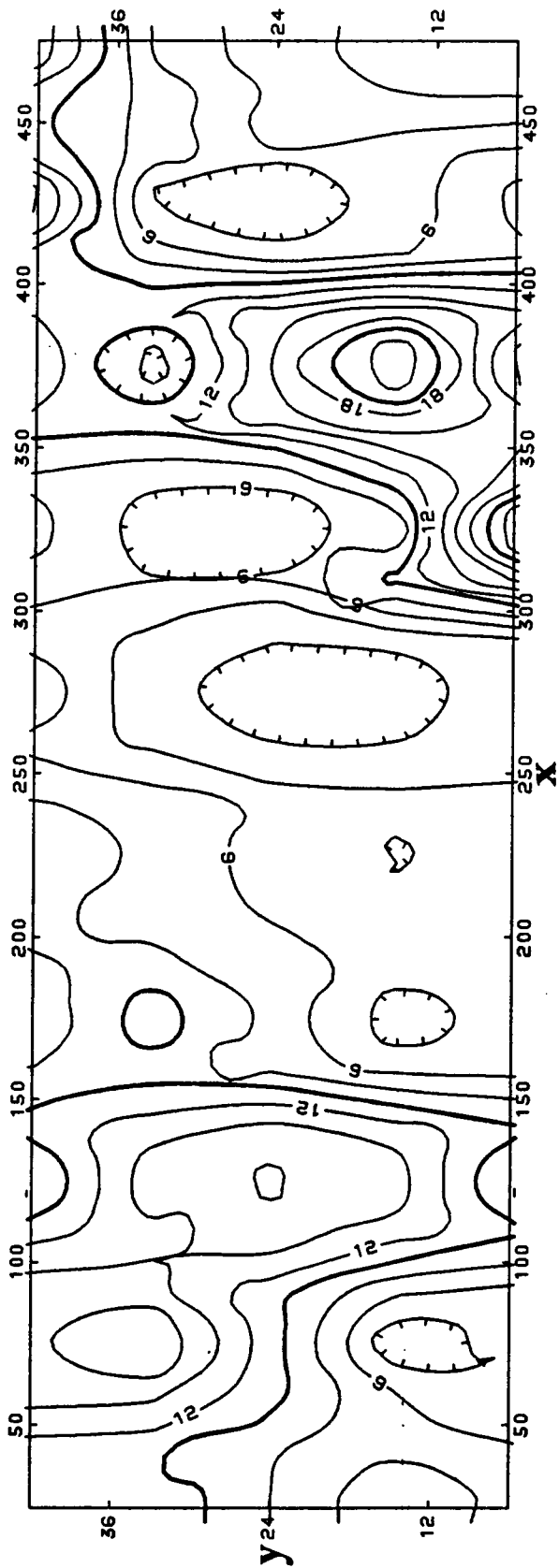
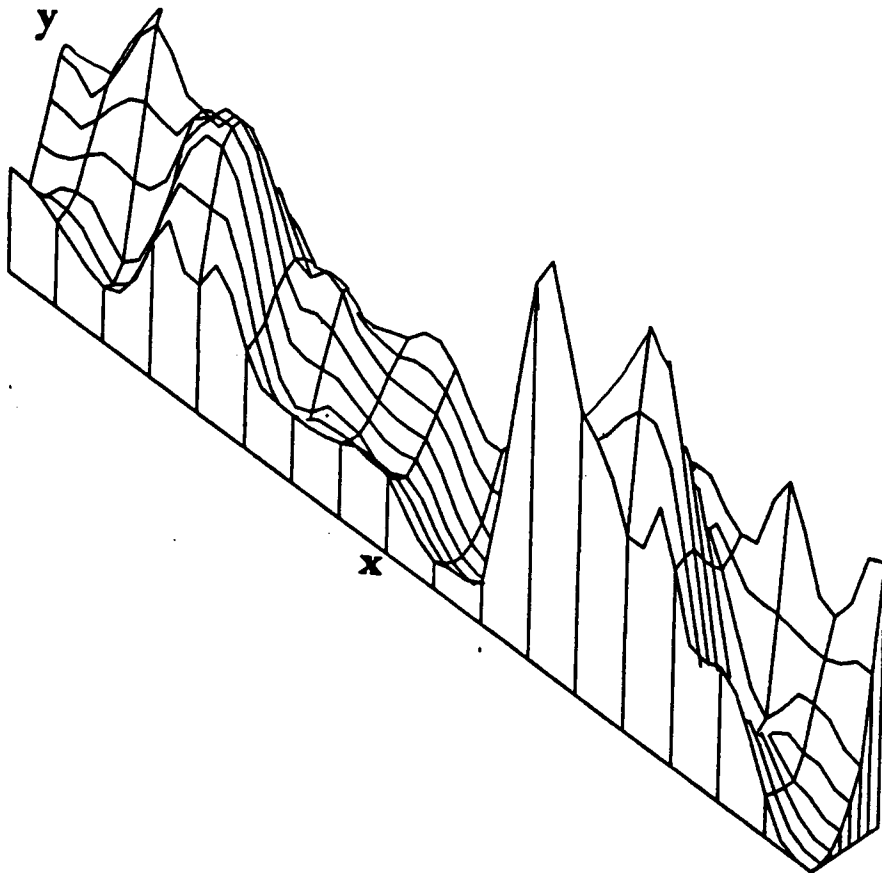


Fig. 6 Contour map of BB infestation, VFI & SU Agronomy Farm, 1984.



**Fig. 7** Transect map of SB infestation, VPI & SU Agronomy Farm, 1984.

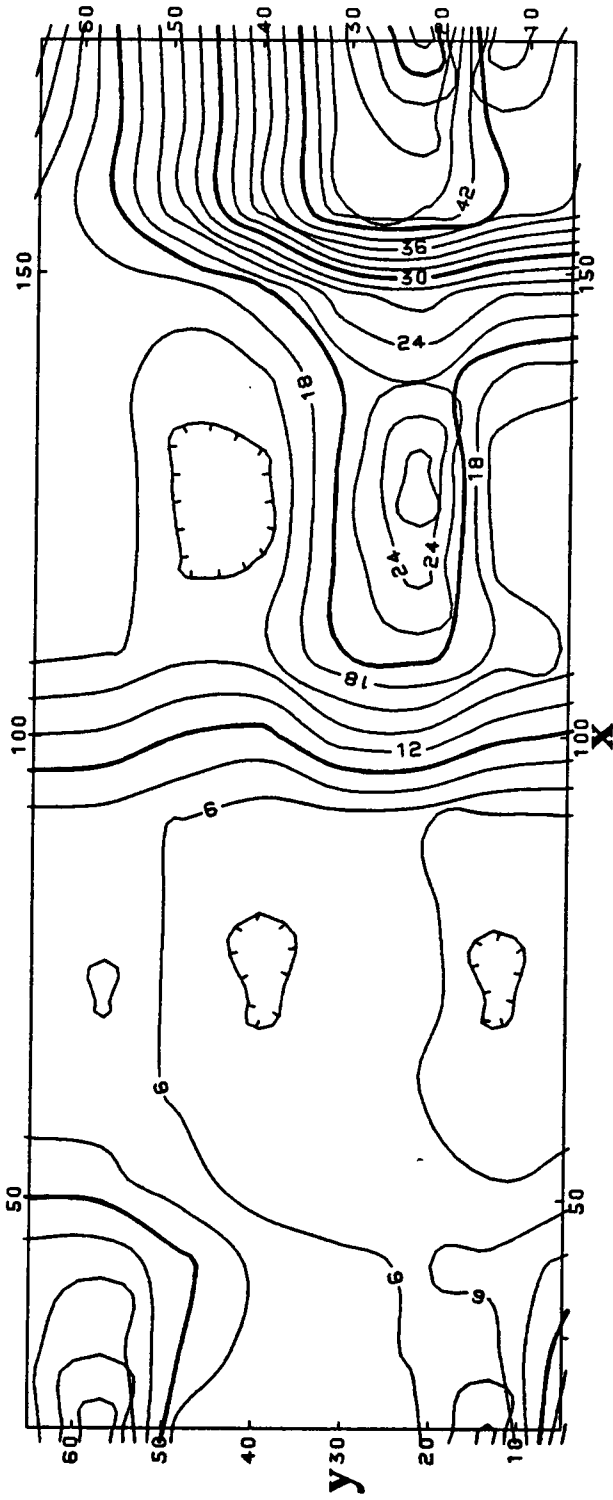
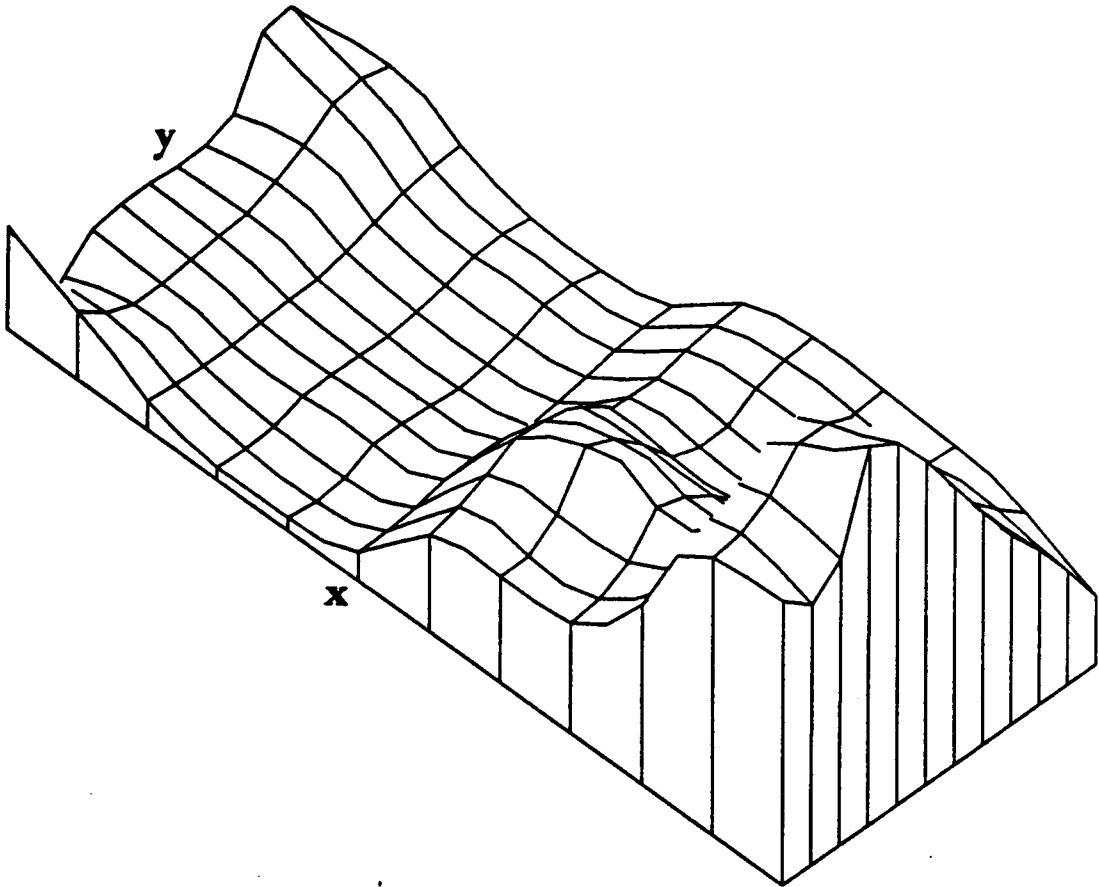


Fig. 8 Contour map of SB infestation, VPI & SU Agronomy Farm, 1985-a.



**Fig. 9** Transect map of SB infestation, VPI & SU Agronomy Farm, 1985-a.



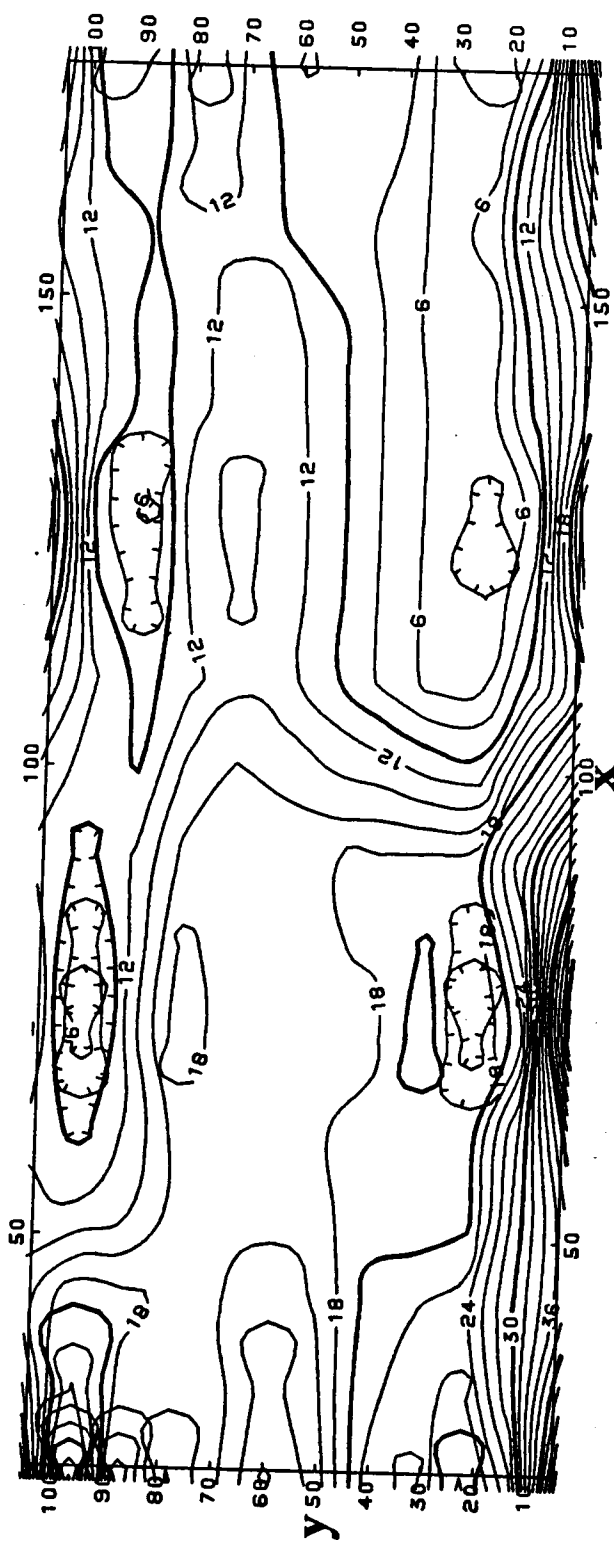


Fig. 10 Contour map of SB infestation, VPI & SU Agronomy Farm, 1985-b.

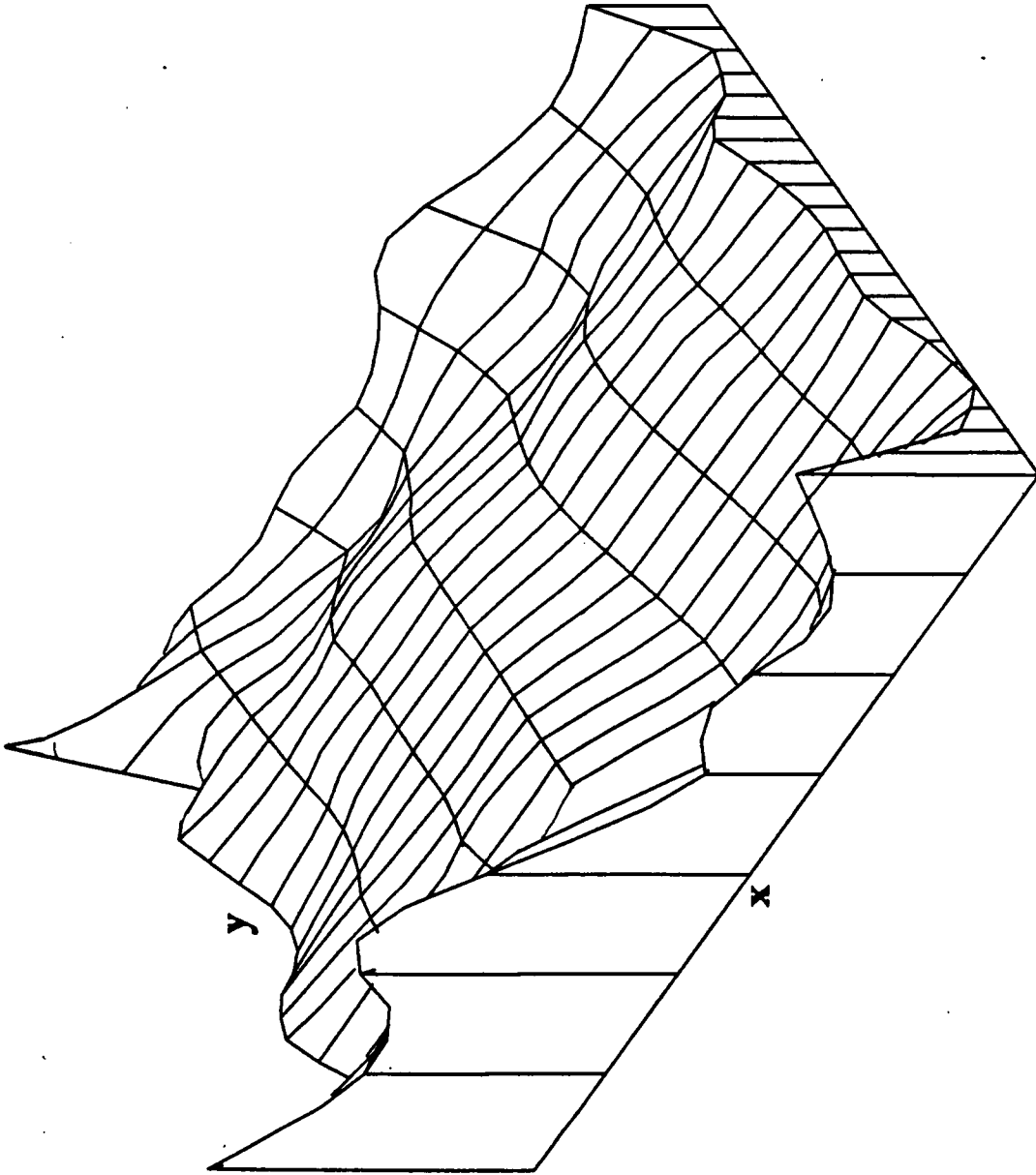


Fig. 11 Transect map of SB infestation, VPI & SU Agronomy Farm, 1985-b.

was a reduction of 30.57 tons silage per hectare, valued at 764.2 dollars, over the 26 fields scouted over 2 years (Tables 7-8). Economic damage was generally below 20 dollars per hectare in these fields.

Analyzing identified within-field infestations showed economic damage of 104 dollars per hectare (4.16 tons per hectare) in 1983, 47 dollars per hectare (1.91 tons per hectare) in 1984, 90.5 dollars per hectare (3.6 tons per hectare) in 1985(K1), and 89.9 dollars per hectare (3.6 tons per hectare) in 1985(K2). Losses from SB infestations were viewed as significant within these infested areas. However, areas used for distribution analysis in these fields were selected on the basis of SB prevalence. Actual density within these fields may have been lower than indicated using counts based on these infested areas.

#### **4.4 Discussion**

Higher numbers of SB were found on field margins compared to numbers found within infested fields. This could be related to the presence of certain plants, especially perennial grasses, preferred by the SB for oviposition in no-till field margins. Generally, grass weed populations within fields in our study were quite low. In two fields where corn was planted for the first time into grass sod, and perennial grasses were predominant within the field, I observed no corresponding increase in SB infestation levels.

In contrast in another field in continuous corn cultivation and with heavy grass infestation within the field, I observed intense SB infestation and total destruction to the first planting of corn.

It appears as if adult SB's actively seek plant material preferred for oviposition. If the SB deposited eggs indiscriminantly on corn in the fall, I would expect many of these eggs to survive corn grain harvesting procedures. Subsequent field infestations would be random in distribution. Newly hatched SB larvae from eggs laid on field corn within fields away from weedy field margins could feed on rye prior to corn emergence. If corn was harvested for silage, where the entire corn plant was removed, I would not expect SB infestations from eggs deposited on field corn to be as severe the following year as in grain harvested fields. This aspect of SB infestation in no-till field corn has not been investigated.

The reasons why higher numbers of SB were found in scouted fields in 1984 compared to those found in 1985 could be due to fall conditions during oviposition, condition of the previous years crop, winter temperatures causing egg mortality, the timing of SB egg hatch and corn seedling emergence, or the effectiveness of insecticide applications. The exact insecticides applied to scouted fields was not known, however, carbofuran 10G granules (1lb. ai./A.) applied in the row at planting, and/or toxaphene 6EC (.2

lbs. ai/A.) applied as a spray tank mixed with herbicides just prior to planting, are two common control strategies in Southwestern Virginia. Variable timing of sprayed insecticides, and residual activity of granular insecticides will vary from year to year depending on field conditions, and could account for variable populations. Stalk borer resistance to these insecticides could have developed in fields under no-till production, after exposure to these insecticides continuously from year to year. It is more probable, however, given the area-wide differences seen in SB populations from 1984 to 1985, that environmental conditions were the most significant population control factors.

Reasons for the clumped distribution associated with within-field SB infestations are not known. Distributions could be dependent on SB egg laying behavior in which certain plants are preferred for oviposition, and eggs are laid in clutches in concentrated areas. Weed distributions preferred for oviposition in fields could greatly influence SB infestation.

Clumped distributions of SB are a primary reason for the phenomenon of the SB damage "syndrome". Aggregations of SB in infested fields destroy field corn in concentrated areas in fields, and on field borders. This opens the vegetative canopy, contributing to the establishment of weed populations in these areas. Proliferation of weeds in these

areas attracts adults resulting in increased oviposition. This in turn results in greater corn damage from the SB the following year, completing the cycle of the SB "syndrome".

A possible control strategy would be treatment of infested field margins and identified SB high density areas in fields with sprayable insecticides timed to SB egg hatch in the early spring. Since SB infestations are primarily confined to field margins and clumped aggregations in fields, such a strategy would decrease insecticide use, and at the same time provide adequate control.

**V. Temporal aspects of early stages of the SB  
with growth and development of no-till field  
corn using accumulated heat units in  
Southwestern Virginia**

## 5.1 Introduction

The prediction of the seasonal occurrence of insect pests, plus their synchronization with development of host plants, is essential for accurate scheduling of sampling and control efforts. Thermal requirements for growth and development are often used as a basis for predictions.

Typically, data on insect development used in prediction is gathered from controlled environments. A shallow sigmoid (S-shaped) curve will result if reciprocals of insect developmental times are plotted as rates versus temperature. At lower temperatures, the limit of developmental rate asymptotically approaches zero development. A linear response occurs in mid range temperatures. Developmental rate slows at higher temperatures above an optimum, falling off rapidly as more individuals die from high temperatures (Wagner et al. 1984).

Different models have been proposed to describe the temperature dependency of insect growth (Sharpe and De Michele 1977, Stinner et al. 1974). Fitting these models to developmental data is often mathematically cumbersome, requiring nonlinear regression techniques, and a maximum amount of data for formulation. The averaging method of estimating degree-days uses the linear portion of the development curve only. This approach is widely accepted because it requires a minimum amount of data for formulation, is easy to calculate, and often results in very close approximations



of correct values (Arnold 1960, Baskerville and Emin 1969, Sevacherin et al. 1977, Aliniazee 1976, Butts and McEwen 1981, Obrycki and Tauber 1981). Disadvantages to this approach are that it is only valid over the intermediate temperature range, and the developmental threshold temperature is determined empirically by extrapolation of the straight line to the temperature axis (Allen 1976, Arnold 1959). This can result in degree-day accumulations that are too low at the lower temperatures, and too high at the upper temperatures. Sine wave methods have been devised that more accurately calculate degree-day accumulations by simulating the actual temperature profile occurring in the field (Baskerville and Emin 1969, Allen 1976). Computer models are available that greatly reduce computational time requirements (Allen 1976).

Degree-day based approaches to insect and plant development have been developed for a variety of components in agroecosystems, though coupling of models has seldom been attempted (Gutierrez et al. 1975, Giese et al. 1975, Arnold 1974, Duncan et al. 1972, Gilbert and Gutierrez 1973, Miles et al. 1974, Eckenrode and Chapman 1972, Tummala et al. 1975, Ives 1973). Modelling black cutworm Agrotis ipsilon L. development, workers found that growth was generally faster than predicted by model simulation. It was hypothesised that variable developmental times within a population, the use of constant as opposed to fluctuating temperatures, and soil moisture could all affect simulated versus actual developmental rates (Kaster and Showers 1984).

Corn plant development models have been developed over the years based on increasing the number of environmental inputs (Curry and Chen 1971, Childs et al. 1977, Baker and Horrocks 1976, Duncan 1975). Hanway's (1963) model of field corn development was based primarily on calendar days. Blacklow (1973) proposed a model predicting the germination and emergence of corn in fluctuating temperatures. In a separate model, a curvilinear relationship was proposed for the rate of leaf tip appearance and temperature (Tollenar et al. 1979).

CORNF, a dynamic growth and development model for corn, was created from data already generated in the literature, and refined through field experiments conducted in Texas (Stapper and Arkin 1980). This model was calibrated by testing five different corn genotypes in six different latitudes across North America. Factors such as seedling emergence, tassel initiation, dry matter production, and grain yield were generally simulated well with CORNF.

The stalk borer (SB) is an early season pest of no-till corn. Movement of this pest to corn occurs early in the season, when ensuing damage to newly emerging corn seedlings is most severe. The amount of damage observed is largely dependent on the relative maturity of corn plants during SB attack. In one study, no new SB damage was observed in plants beyond the 8-leaf stage. In this same study, reduction in grain yield and number of ears produced by attacked plants decreased as plant age increased with SB injury (Levine et al. 1984).

The objectives of my study were to compare development of

SB larvae collected from infested no-till corn over a three year period. Heat unit accumulations were used to predict SB field development. Predictions were also made on SB field development and no-till corn development based on planting dates and heat unit accumulations in Southwestern Virginia.

## 5.2 Materials and Methods

### SB field development data

Corn was planted no-till in winter rye on 8 May 1983, 22 May 1984, and 1 May 1985 at the V.P.I. & S.U. Agronomy farm. Suspected SB infested seedlings were removed from the field, starting within 7 days of seedling emergence, and dissected for the presence of SB larvae. The head capsule widths of recovered larvae were measured as described in Chap. 7.1. Twenty to forty larvae were collected per week until no larvae could be found infesting the corn. Dates of SB collection began and ended on 8 June to 16 August 1983, 9 June to August 1984, and 15 May to 16 August 1985.

### Corn development data

Measurements were taken at 14 day intervals in 1984 and 1985 starting from seedling emergence. The number of leaves present, height of the stalk from ground to the youngest emerging leaf, and stem diameter 2 cm from ground level were the plant characteristics recorded. Ten plants were inspected on each sampling date.

### Environmental data

Maximum and minimum soil temperatures were recorded at the V.P.I. & S.U. Turfgrass Research Farm app. 2 mi. SE of the Agronomy Farm using a YSI 700 series thermister 10 cm in bare soil. Data was recorded using a Campbell Scientific CR21 data logger recording every 30 minutes, starting from corn planting dates in 1984, and 1985.

Maximum and minimum air temperatures were recorded by the National Oceanic and Atmospheric Administration, Blacksburg station, app. 6 km SE of the city.

### Data analysis

Head capsule widths of SB larvae collected from infested corn were grouped by year, and statistics calculated using means analysis. The date of predicted egg hatch was calculated by accumulating heat units using Allen's modified sine wave algorithm (Allen 1976). Total egg degree-days (EDD) required for egg eclosion were assumed as 256 at a lower developmental threshold temperature of 8.4 C (Levine 1983).

Larval degree-days were calculated using Allen's modified sine wave algorithm starting from the date of predicted egg hatch. The lower developmental threshold temperature was assumed as 3.7 C (Levine 1983).

Head capsule widths of field collected larvae were regressed on cumulative LDD from predicted egg hatch using simple linear regression, for data collected in 1983, 1984, and 1985. Regression lines derived from data taken from the three

years were compared using analysis of covariance after a general linear model.

The time period from corn planting to seedling emergence is linearly related to soil temperature and seed depth at planting, after an initial restriction on the start of the emergence process. Accordingly, days to seedling emergence were calculated as:

$$1/DE = .0134 ((S_{\text{Min}}+S_{\text{Max}})/2 - 8.7)$$

where DE = days from planting to emergence

S<sub>Min</sub> = minimum soil temperature

S<sub>Max</sub> = maximum soil temperature (Stapper and Arkin 1980).

Leaf tip appearance is a function of accumulated growing degree-days (CDD), which were accumulated using air temperatures and Allen's modified sine wave algorithm. Accumulations were started on the date of predicted corn emergence, with a lower developmental threshold of 10 C, and an upper developmental threshold of 30 C (Stapper and Arkin 1980). CDD is estimated as 40 between appearances of consecutive leaves in the linear phase (mean temperature between 12-26 C) of the corn plant growth curve (Stapper and Arkin 1980).

### 5.3 Results and Discussion

Coefficients of variation of head capsule sizes decrease with julian date, indicating less variation in the range of developmental stages as time progresses (Table 10). Head capsule size ranges indicated that instars 2, 3, or 4, were sampled from the youngest, newly emerging corn

Table 10. Mean head capsule widths of SB larvae collected from infested no-till corn, VPI & SU Agronomy farm, 1983-1985.

Julian date	Accum. LDD	N	Mean HCW $\pm$ SD	Range	Coeff. of variation
1983					
159	259	40	.90 $\pm$ .29	.47-1.54	32
164	321	40	1.11 $\pm$ .35	.47-1.94	31
175	493	32	1.46 $\pm$ .33	.94-2.14	22
189	738	25	2.03 $\pm$ .40	1.34-2.75	20
194	812	24	2.24 $\pm$ .48	1.54-2.95	21
202	970	23	2.44 $\pm$ .47	1.54-3.08	19
209	1105	26	2.85 $\pm$ .21	2.34-3.15	7
214	1189	30	2.68 $\pm$ .22	2.01-3.01	8
228	1434	25	2.85 $\pm$ .17	2.48-3.15	6
1984					
160	922	20	1.33 $\pm$ .21	1.02-1.70	16
170	1286	15	1.01 $\pm$ .24	.68-1.43	24
173	1393	15	1.23 $\pm$ .19	.95-1.49	15
181	1690	20	1.50 $\pm$ .25	1.00-1.89	17
191	2064	20	2.16 $\pm$ .33	1.36-2.86	15
194	2182	20	2.27 $\pm$ .22	1.84-2.72	10
205	2615	20	2.59 $\pm$ .37	1.97-3.19	14
208	2730	21	2.74 $\pm$ .38	1.63-3.06	15
217	3080	6	2.89 $\pm$ .14	2.72-3.06	5
221	3232	7	2.88 $\pm$ .13	2.72-3.06	5
1985					
135	274	25	.67 $\pm$ .13	.44- .92	20
144	390	25	.78 $\pm$ .17	.60-1.20	22
152	491	25	.99 $\pm$ .23	.60-1.40	24
159	611	25	1.28 $\pm$ .21	1.00-1.96	16
168	747	23	1.55 $\pm$ .37	.82-2.92	24
178	900	23	2.26 $\pm$ .27	1.63-2.92	12
184	983	18	2.31 $\pm$ .29	1.97-2.92	13
193	1130	25	2.43 $\pm$ .46	1.36-3.12	19
200	1257	25	2.63 $\pm$ .37	1.70-3.13	14
218	1556	25	2.87 $\pm$ .20	2.45-3.40	7
228	1729	15	3.00 $\pm$ .28	2.72-3.74	9

<sup>a</sup>Accumulated larval degree-days begun at predicted egg hatch (256 LDD) from julian date 1, dev. temp. thresh. eggs = 8.4 C ;dev. thresh. larvae = 2.41 C (Levine 1984).

seedlings. Degree-day accumulations varied considerably at comparable calendar dates between the three years. Degree-day accumulations on dates 159 and 160 varied from 259 in 1983, to 611 in 1985, to 922 in 1984. Ranges of head capsule widths varied at sampling dates, especially early in the season. This would indicate an extended egg hatch period, despite the fact that samples were taken from the same field.

There appears to be serious discrepancies between LDD accumulations and head capsule widths seen in 1985, and those noted in 1983 and 1984 (Table 10). This shift in larval development is exemplified when comparing head capsule sizes between the three years.

These discrepancies could be due to improper predictions of egg eclosion dates based solely on heat unit accumulation. Generally, the winter and spring was warmer in 1985 when compared to 1983 or 1984. Egg eclosion, however, could also be dependent on day length, solar radiation, humidity, and cold stress during winter diapause. However, in preliminary egg eclosion tests, 50 percent egg eclosion occurred at julian dates 124 in 1984, and 107 in 1985, indicating a connection between temperature and egg maturity.

Bailey (1984) and his co-workers have reported actual SB moth flights which did not agree with predicted moth flights using accumulated degree-day units. They indicated an apparent uniformity in SB adult emergence dates from year to year, regardless of accumulated degree-day units. This data, coupled with our own, strengthens our hypothesis that factors

other than temperature could account for SB stage development in the natural environment.

The log head capsule widths of field collected larvae regressed against log LDD agreed with a linear model in 1983, 1984, and 1985 (Fig. 12, Table 11). Covariance analysis indicated that slopes and intercepts from regressed lines were different between the three years. The results of this analysis indicate that variation exists between larval development seen in the field from year to year. Temperature thresholds and heat unit accumulations were based on work by Levine (1983) from a laboratory reared population from Illinois. His experiment was conducted at constant temperatures, and larvae were reared on a meridic diet. Developmental rates could differ between Levine's population reared on a meridic pinto bean based diet at constant temperatures, and wild populations collected by me from the field developing at fluctuating temperatures and feeding on a variety of different plants. The variation in heat unit accumulation and larval development cannot be explained by accumulated heat units. Other factors such as egg eclosion dates, host plant condition, moisture level, humidity level, differences in temperatures recorded at weather stations and experienced by SB in corn stalks, or natural variation could affect wild larval development.

The CORNF model was accurate in predicting corn seedling emergence and leaf appearance in Southwestern Virginia no-till corn (Table 12). Predictions of seedling emergence varied by one day to actual emergence in 1984, and predicted the



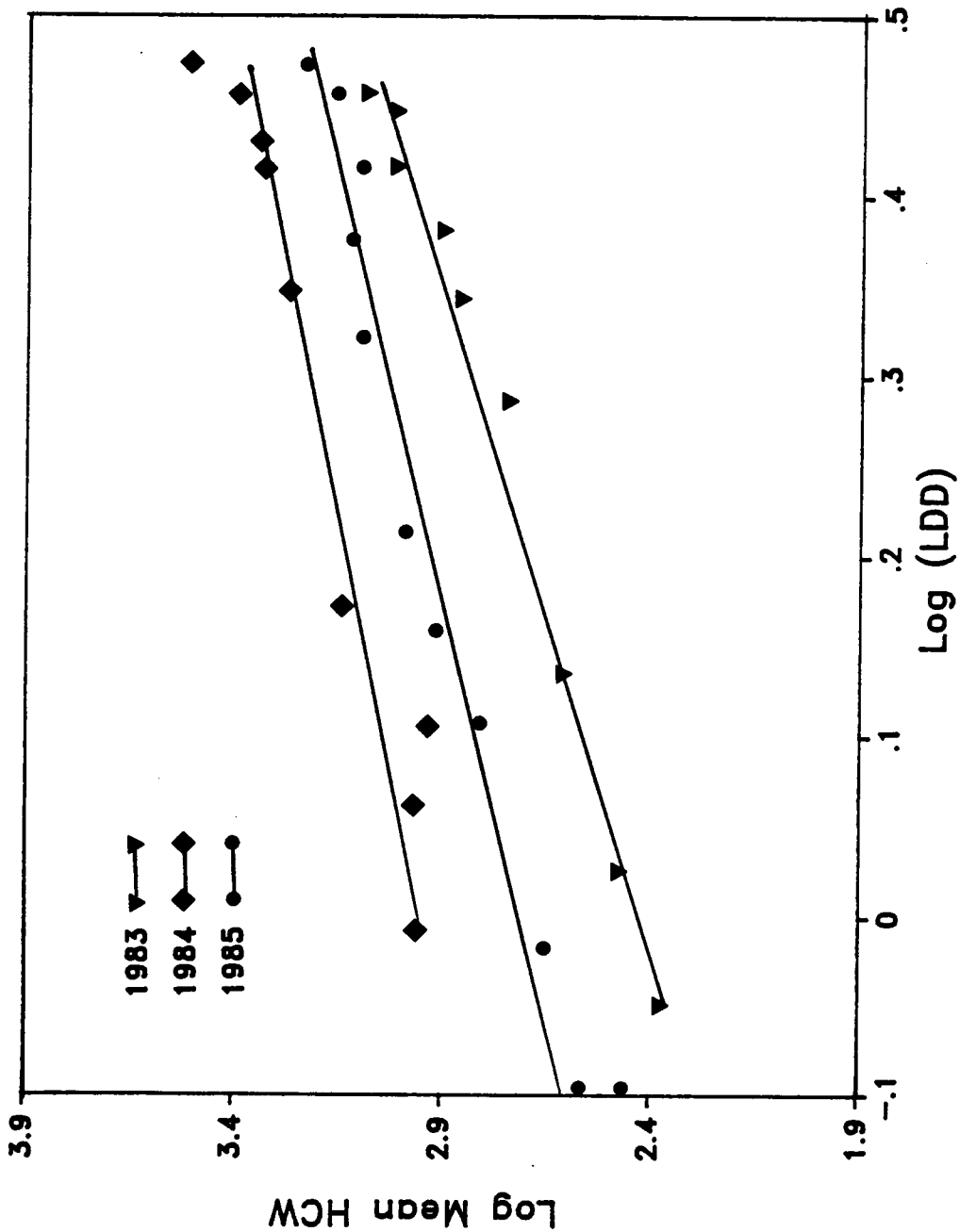


Fig. 12 Regression of log SB accumulated LDD with log mean head capsule widths, 1983-1985.

Table 11. Linear regression equations of field collected SB larval head capsule widths with associated degree-day accumulations, 1983-1985.

<u>Year</u>	<u>Equation</u>	<u>r-square</u>
1983	$y = .7430 - 4.2489x$	.78
1984	$y = .8547 - 5.8236x$	.70
1985	$y = .9352 - 5.7419x$	.87

<sup>a</sup>P>F at .0001 for all equations.

Table 12. No-till corn development predicted using calendar days and a degree-day model, compared with actual field observations, VPI & SU Agronomy farm, 1984-1985.

Year	Jdate	CDD	Mean no. leaves		Actual
			Predicted Hanway	CORNF	
1984	148	7	0	0	(emergence)
	156	55	2	1.45	3
	163	146	4	3.65	5.6
	194	483	13	12.0	10
	205	660	16	15.0	10.6
1985	129	9	0	0	(emergence)
	135	62	2	1.55	3.5
	144	126	4	3.15	4.5
	152	180	6	4.5	5.5
	159	258	8	6.45	8
	168	340	11	8.5	8.5
	184	479	16	11.97	10
	200	656	16	16.4	12.5

<sup>a</sup> Hanway (1963) leaf emergence based on calendar days. CORNF leaf appearance at the rate of 40 ADD per leaf (Stapper and Arkin 1980). Regression equation of CDD versus actual leaf emergence  $y = 1.86 + .0169x$ , r-square = .96, data from 1984 and 1985 pooled.

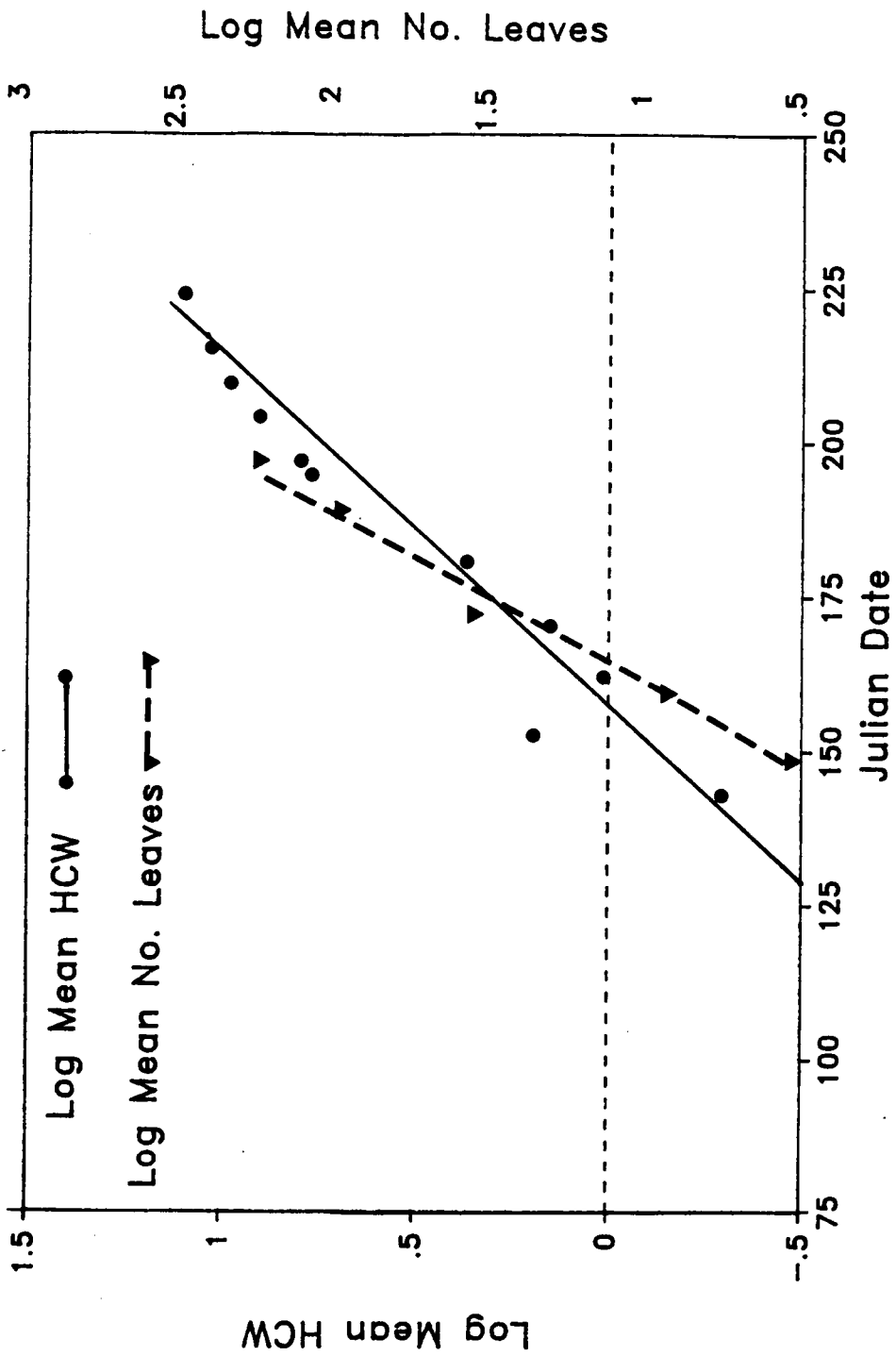


Fig. 13 Log mean SB head capsule width to log mean number of leaves in no-till corn, VPI & SU Agronomy farm, 1984.

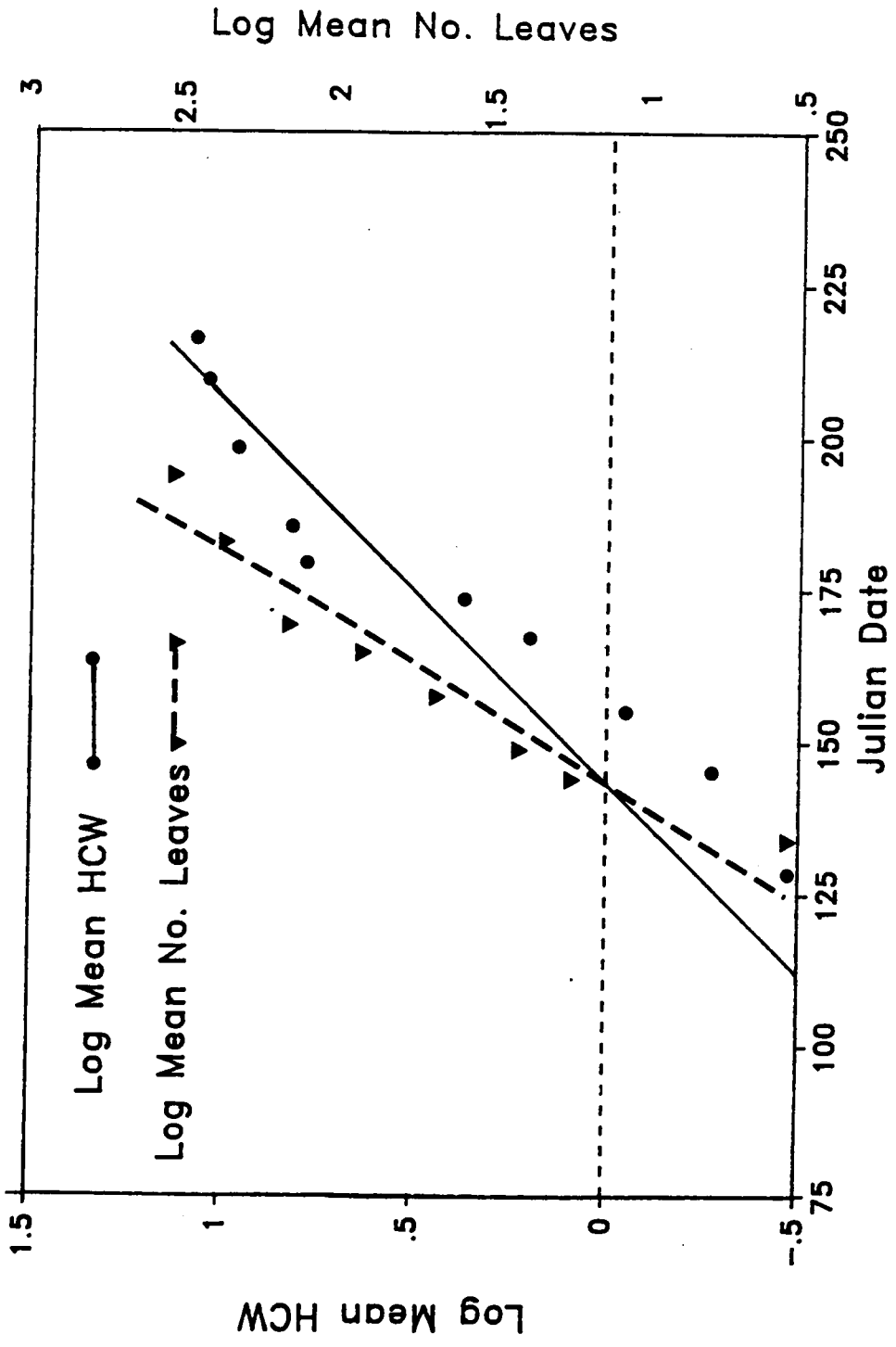


Fig. 14 Log mean SB head capsule width to log mean number of leaves in no-till corn, VPI & SU Agronomy farm, 1985.

exact day of emergence in 1985. CORNF predicted leaf emergence slightly slower than actual leaf emergence early in the growing season, and slightly faster than actual leaf emergence late in the growing season.

Mean head capsule widths of field collected larvae plotted against corn stage development indicated that SB egg eclosion occurs well before corn seedling emergence (Fig. 13-14). Equations for regressed lines of head capsule widths versus julian dates were  $y = -2.74 + 0.0177x$ ,  $P < .0001$ ,  $r^2 = .87$  for 1984, and  $y = -2.52 + 0.017x$ ,  $P < .0001$ ,  $r^2 = .89$  for 1985. Equations for regressed lines for leaf number versus julian dates were  $y = -2.32 + 0.0233x$ ,  $P < .06$ ,  $r^2 = .88$  for 1984, and  $y = -1.2028 + 0.0192x$ ,  $P < .0007$ ,  $r^2 = .92$  for 1985. Planting date has been proposed as a possible control strategy for this insect, however, corn planting must occur within soil temperature and moisture limits. There are also certain time constraints associated with corn planting that are virtually unmanageable for many growers. For these reasons, planting date alone would not adequately reduce damage from SB attack.

Head capsule widths of larvae collected from corn between the 0 and 8 leaf stage were between 1.3 and 1.85 mm in 1984, and between .9 and 1.9 mm in 1985 (Fig. 13-14). From this data we would predict that SB damage would be greater in 1984, because the larvae attacking the young corn seedlings would be larger, and therefore, would cause more damage to the plants. We have no evidence from this two year study, however, to support this hypothesis.

## **VI. SUMMARY**

## 6.1. Research results

Although the SB is known as a very polyphagous feeder in the larval stage, young larvae show preferences for feeding on some plants over others. Perennial cool season grasses, often the predominant vegetation in spring during SB egg eclosion, are also the most preferred host plant of neonate SB larvae (See II). Rye, the predominant cover crop for no-till corn in Virginia, is readily fed on by the SB, and could act as an important early season host. This insect will readily bore into the stalks of many different host plants, which makes timing of control measures critical (See II). The causes of host plant switching by feeding SB larvae are unknown, and more research on host plant preference and field behavior will be necessary to answer this important question.

One common observation concerning SB infestations in no-till corn has been the close relationship between weed infestations and SB attack. The primary reason for this is ovipositional preferences exhibited by SB adults. In caged studies, adults laid significantly higher numbers of eggs on perennial grasses when compared to other plant types, including field corn. Taller and dryer grasses were preferred for oviposition as opposed to shorter, more succulent plants (See III). This phenomenon could be a result of adults distinguishing plants resulting in higher offspring survival. This results in oviposition on more mature (i.e., taller, dryer) plants. These more mature plants would conversely be the



first species of plants to emerge in the early spring, a critical period for early instar larval survival.

Surveys of infested field corn for SB indicted that higher densities of SB were found on field edges compared to numbers found within fields (See IV). This association is related to ovipositional and feeding preferences for border weeds, especially perennial cool season grasses. Infestations within fields tended towards clumpiness (See IV). Aggregations of SB within fields could be due to weed infestations, high local moisture levels, or soil conditions.

The degree of damage caused by the SB is a matter of location, density, and timing. Higher SB density on field edges are in reality not as damaging economically as most infestations within fields. This damage, however, is very apparent to a grower, and may promote control measures out of proportion to the actual damage caused. On the other hand, high density SB areas within fields may go unnoticed, gradually enlarging with time in continuous corn fields.

SB larvae were collected from infested corn over a three year period (See V). Using degree-day accumulations to predict SB size through time was not always successful. Variation in dates of egg eclosion, larval development or field populations could account for these discrepancies. Egg eclosion occurs well in advance of corn emergence, and feeding occurs on alternate hosts before movement to corn. However, size of SB at the early stages of corn attack vary from year to year, and size of the SB at corn emergence, as well as the movement pattern exhibited by the larvae, will have a direct bearing on the observed level of damage.

## 6.2. An integrated pest management program for the SB in no-till corn.

Weed control must be a primary concern for growers with SB problems in no-till corn. Weeds, especially grasses, attract SB adults for oviposition, and are primary food sources for young SB larvae. Since SB female moth movement is not extensive (Bailey et al. 1985) crop rotation is another viable cultural control alternative. In the Virginia no-till areas, however, crop land and alternate crops are limited, and thus crop rotation is not a viable alternative for many growers. Early corn planting, already advocated for reduction of damage from European corn borer Ostrinia nubilalis (Hubner), can also be advocated for reducing SB damage. Border weeds, especially grasses, should be cut prior to SB adult emergence in the early fall. This would force egg laying adults away from border areas, decreasing SB damage the following year.

SB control efforts should begin with identification of particular fields, and areas within fields, of heavy SB concentration. Control efforts can be concentrated in these areas the following year. Treatment of field borders along infested edges with sprayable insecticides at or just after egg eclosion could give good control results. Coupling this strategy with the mowing of border weeds could be especially effective.

Treatment of infested fields would involve approved sprayable insecticides tank mixed with herbicides applied to kill the rye cover crop. Larvae would move out of desiccating rye and into treated areas.

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## **VII APPENDIX**

### **7.1 Head capsule measurements of the stalk borer reared in the laboratory.**

### 7.1.1 Introduction

The pest status of the stalk borer (SB), Papaipema nebris Gn., has increased markedly in no-till field corn throughout the Midwestern and Northeastern United States in recent years (Kuhlman 1982, Rubink and McCartney 1982). Recent studies on its basic biology have concentrated on the temperature requirements for stage-specific development of this pest reared on a meridic diet (Levine 1983).

In an examination of Dyar's rule (1935), it was found that an application of this rule by the method of least squares does not corroborate the number of observed instars in the case of Heliothis obsoleta (Fab.) (Gaines and Cambell 1935). Examining case studies from past publications, Gaines and Cambell found that rather than constant growth ratios as proposed by Dyar, the usual for lepidopterous larvae was constantly diminishing growth ratios. Examination of larval head capsules (HC) of the Nantucket pine tip moth showed 5 distinct groups representing 5 instars with successively greater HC sizes. The estimated range of each instar overlapped the range of each adjacent instar, forming a continuum (Fox et al. 1971). Examinations of elm spanworm, Ennomos subsignarius

(Hubner), head widths reared on different host plants showed changes in instar numbers with changes in host plants, and a significant correlation was derived for HC dependent on sex (Drooz 1965). Developmental polymorphism exhibited by Choristoneura viridis Freeman reared on an artificial medium showed a total of from 6-8 instars prior to pupation and no apparent difference in HC widths between HC of individuals passing through instar 6, 7 or 8 (Schmidt et al. 1977). These studies do not adhere to Dyar's principle, and they cast doubt on the use of measurements of body parts to predict developmental stages in insects. This is especially true for insects with variable developmental rates and variable numbers of instars depending on sex, food quality, or environmental factors (Decker 1931, Bellinger 1985, Raske 1976).

The SB has been described as having from 7 to 16 instars, but normally either 7 or 8 instars (Decker 1931). The males have been reported as completing development in one less molt than do the females. Poor food quality has been shown to influence the number of molts to pupation. Generally, as food quality decreases, the number of instars to pupation increases (Decker 1931, Lowry 1927). Given the variability of SB larval development, the use of HC measurements to identify immature growth stages is questionable. On the

other hand, the determination of accurate stage specific frequency distributions is essential in the formulation of age specific predictive population models. Such predictive models would be very beneficial in measuring population and adult ratios through time in order to target control measures. .

The objectives of my study were to examine the appropriateness of using HC width measurements to determine stadium number, and the use of these measurements to predict nearness to pupation of SB using a laboratory reared population.

#### **7.1.2 Materials and Methods**

SB eggs were laid on plant material in screened ovipositional cages from 16 to 24 September 1984, and from 9 to 12 October in 1985. Eggs were transferred to open plastic bags for overwintering on 29 October 1984, and 19 October 1985. Individuals were one generation removed from the field in 1984, and two generations removed from the field in 1985. SB eggs hatched on 28 May 1984, and on 17 May 1985, and the larvae were individually transferred using a squirrel's hair brush to 21 ml diet cups containing Reese's modified pinto bean diet (Reese 1972). Larvae were reared at 18-20 C with a photoperiod of LD 12:12, and humidity maintained



between 65-80%. Diet was added to all larval cups every third week of the study until pupation.

Head capsule sizes of all larvae were recorded using an ocular micrometer, following the technique of McGugan (1954) weekly until pupation during 1984, and twice weekly from egg hatch until 3 July, and weekly from 3 July to pupation, during 1985. Head capsule width is the widest distance on the larval head capsule seen from a frontal view. Specimens with head capsules measuring .34 to 1.054 mm were examined at magnification X 25 or X 30, while specimens with head capsules measuring greater than 1.054 mm were examined at magnification X 15. The result of this procedure was greater accuracy in measuring the smaller specimens.

Caste head capsules and exoskeletons were counted and removed from larval cups with each observation. Dates of pupation were recorded and the pupae sexed. Males were easily separated from females by the presence of gonadal pads on segment 8, and the position of the gonadal pore, which was located on segment 8 in the females, and on segment 9 in the males (Decker 1931). Larvae used in 1984 were one generation removed from the field, and larvae used in 1985 were two generations removed from the field. Data was analyzed by grouping HC sizes into a frequency distribution plot

resulting in multimodal curves. Mean HC width, range, and ratio of increase was calculated per instar. Data was grouped according to sex and the data from 1984 and 1985 was grouped before analysis.

Means were derived according to the method of Taylor (1931) where the mean ratio of increase (MRI) was the average ratio of increase from instar to instar or

$$\text{MRI} = \frac{\bar{X}_n}{\bar{X}_{n-1}}$$

where  $\bar{X}$  = mean HC width

n = instar number

### 7.1.3 Results and Discussion

Frequency distributions were generated using the combined mean HC width data, and are presented in Fig.15. Observations of changes in HC size, cast HC, and frequency distribution peaks indicated 7, 8, or 9 instar larvae for this laboratory reared population. Five percent of the females and 0% of the males went through 7 instars before pupation, 56% of the females and 67% of the males went through 8 instars before pupation, and 39% of the females and 33% of the males

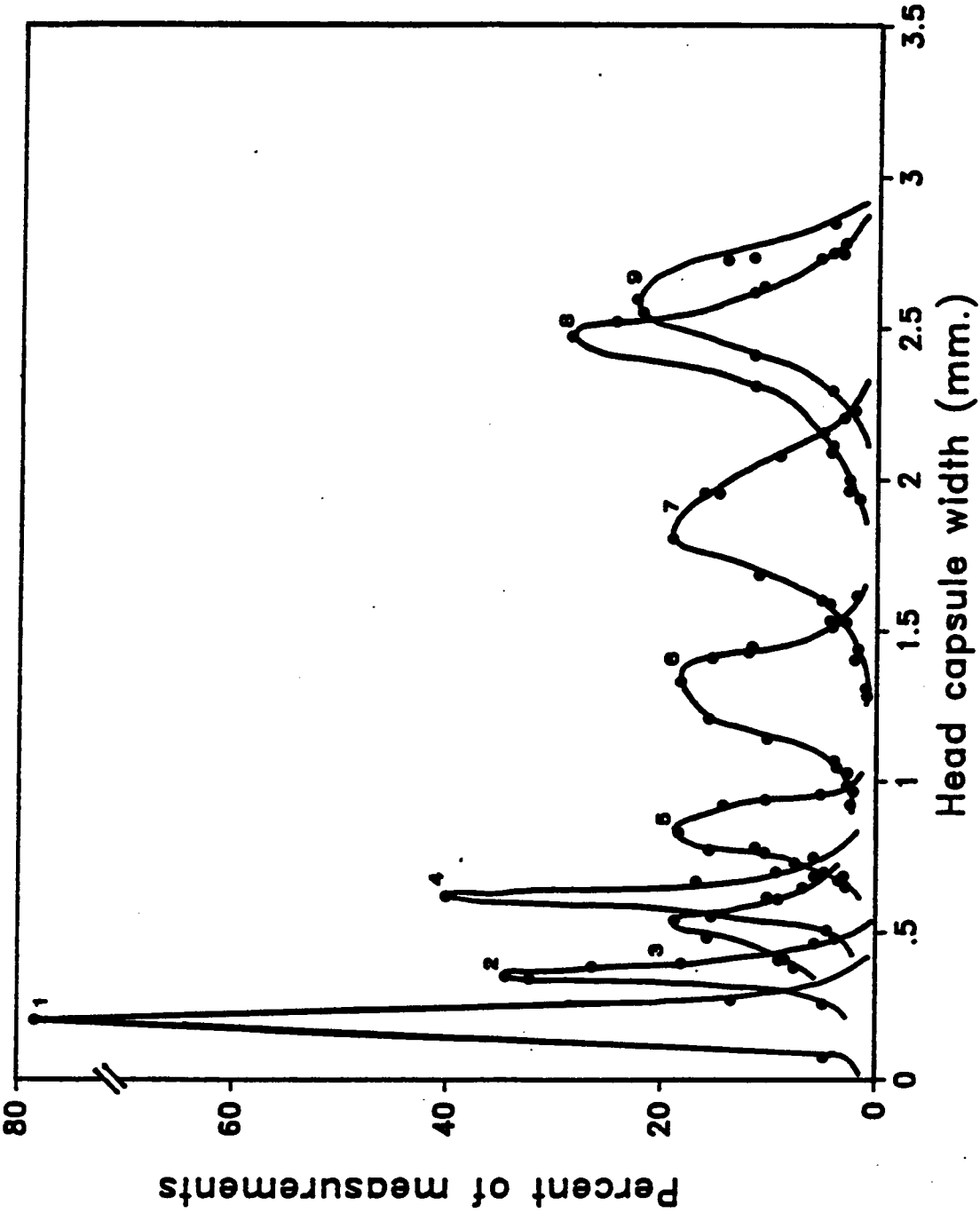


Fig. 15 Range of SB head capsule width measurements by instar, laboratory reared, 1984-1985.

went through 9 instars before pupation. These data do not support Decker's (1931) observation that SB females always go through an "additional" instar.

The HC width ranged from .24 to 3.13 mm (Table 13). This HC range does not form discrete HC sets, but rather a continuum through the range, with overlap occurring between adjacent instars (Fig. 15). The range of instar 3 covers the mean HC width of instar 4. Consequently, it would be difficult to accurately assign SB larvae collected in the field to their respective instar numbers based on HC size.

Ninth instar larvae showed the lowest CV and therefore the least variability in HC size, while the sixth instar larvae showed the highest CV, therefore the greatest variability in HC sizes.

The rate of increase of mean HC sizes fits Dyar's rule closely, as indicated by the mean values in Table 13. The log of the mean HC width increased with instar number in a linear fashion, as indicated through regression analysis. For 1984-85 data combined,  $Y = -.7128 + .1399X$ ,  $r^2 = .99$ ,  $P < .05$ , where  $Y$  = instar number, and  $X$  = HC width (mm).

Separating HC widths according to sex when possible, both female and male HC measurements indicated close fits to Dyar's rule, and regression analysis of instar number by log mean HC sizes of

Table 13. Head capsule widths of 70 laboratory reared SB larvae,  
1984-1985.

Instar	No.	Range (mm)	Mean HCW $\pm$ SD (mm)	Calc. mean <sup>a</sup>	Ratio of increase	Coef. of variation
I	36	0.24-0.28	0.25 $\pm$ 0.01	0.26	-	6.14
II	47	0.34-0.51	0.38 $\pm$ 0.03	0.36	1.52	8.57
III	19	0.41-0.68	0.54 $\pm$ 0.07	0.49	1.42	13.49
IV	22	0.52-0.76	0.65 $\pm$ 0.06	0.70	1.20	9.70
V	57	0.72-1.05	0.91 $\pm$ 0.08	0.98	1.40	8.84
VI	66	1.02-2.04	1.46 $\pm$ 0.20	1.40	1.60	13.63
VII	110	1.36-2.58	2.14 $\pm$ 0.23	2.01	1.47	10.95
VIII	136	2.04-3.13	2.78 $\pm$ 0.20	2.52	1.30	7.31
IX	48	2.72-3.13	2.90 $\pm$ 0.11	3.33	1.04	3.89
AVG.					1.37	

<sup>a</sup>Calculated mean as described by Taylor, 1931.

females and males resulted in linear relationships (Table 14). For females,  $y = -0.17 + 0.32x$ ,  $r^2 = 0.93$  and for males,  $y = -0.48 + 0.36x$ ,  $r^2 = 0.96$ . The CV for females was generally lower than for males, indicating less variability in HC sizes of females.

Due to the overlap of frequency distribution curves between adjacent instars, and because larvae go through variable numbers of instars, determination of correct instar number using HC widths is difficult if it is unknown whether the specimen examined was male or female, and how many instars it would go through before the onset of pupation. The range of HC widths for the last larval instar before pupation was from 2.18 to 3.13 mm. Since approximately 60% of the larvae go through 8 instars, we would be correct in predicting a following pupation after the eighth instar only 60% of the time.

Larvae that went through 8 or 9 instars often had extended ultimate stadial lengths. It was not uncommon for both 8 and 9 instar larvae to remain in their respective ultimate instars for 5 weeks prior to pupation. Other factors besides larval instar number, such as body size, may play a decisive role in controlling the onset of metamorphosis (Nijhout 1975). We have observed great variation in the weights of SB larvae throughout development even when media and

Table 14. Head capsule widths of laboratory reared SB larvae separated by sex, 1984-85.

Instar	No.	Range (mm)	Mean HCW $\pm$ SD (mm)	Calc. mean <sup>a</sup>	Ratio of increase	Coef. of variation
<b>Female</b>						
I	10	0.22- 0.28	0.24 $\pm$ 0.01	0.25	-	5.2
II	20	0.34- 0.51	0.37 $\pm$ 0.05	0.35	1.48	7.0
III	8	0.41- 0.68	0.53 $\pm$ 0.10	0.49	1.46	18.5
IV	7	0.56- 0.68	0.65 $\pm$ 0.04	0.72	1.20	6.8
V	18	0.75- 1.02	0.97 $\pm$ 0.08	0.97	1.39	8.4
VI	21	1.05- 1.70	1.46 $\pm$ 0.18	1.48	1.55	12.7
VII	44	1.70- 2.58	2.24 $\pm$ 0.18	2.02	1.45	8.17
VIII	59	2.38- 3.13	2.79 $\pm$ 0.18	2.60	1.36	6.64
IX	21	2.72- 3.06	2.90 $\pm$ 0.11	3.38	1.05	3.65
AVG.					1.37	
<b>Male</b>						
I	5	0.24- 0.28	0.25 $\pm$ 0.02	0.26	-	7.2
II	11	0.34- 0.65	0.37 $\pm$ 0.05	0.37	1.48	13.3
III	4.	0.48- 0.65	0.54 $\pm$ 0.07	0.49	1.46	13.8
IV	3	0.60- 0.68	0.65 $\pm$ 0.05	0.70	1.20	7.0
V	15	0.82- 1.02	0.90 $\pm$ 0.07	0.96	1.39	8.3
VI	8	1.16- 1.70	1.40 $\pm$ 0.18	1.36	1.55	12.7
VII	23	1.63- 2.38	2.03 $\pm$ 0.19	1.96	1.45	9.4
VIII	34	2.18- 3.06	2.75 $\pm$ 0.18	2.44	1.36	6.7
IX	16	2.72- 3.13	2.90 $\pm$ 0.13	3.31	1.05	4.4
AVG.					1.37	

<sup>a</sup>Calculated mean as described by Taylor, 1931.

temperature are controlled. It is possible that actual size of the larvae controls pupation, and that individuals add instars if this optimum body size has not been reached prior to pupation.



**7.2 Cold stress tolerance of eggs and first instar  
larvae of the stalk borer.**

### 7.2.1 Introduction

The stalk borer (SB) has been a pest of gardens and field crops since before the 1930's (Lowry 1927, Decker 1931). It has attracted attention more recently as a pest in no-till or reduced till field corn, and extensive damage has been reported across the Midwest from Iowa to Ohio, and in the Mid-Atlantic States from Pennsylvania south to Virginia (Rubink and McCartney 1982, Stinner et. al 1984). The SB has one generation per year and overwinters in the egg stage, hatching in the early spring and feeding on available weeds or emerging crops. Eggs are laid usually on grass leaves along the midrib. Desiccating blades are folded over and glued together forming a protective packet around the eggs. Eggs are usually laid in masses (Lowry 1927, Decker 1931), and development does not proceed until warming spring temperatures (Decker 1931).

Many overwintering insect eggs have been shown to be very cold hardy, especially if the cold shock periods occur before the onset of embryogenesis. Leptohylemyia coarctata (Schnabl and Dzedzicki) eggs have been shown to be able to withstand temperatures of as low as -24 C, with 50 percent survival at -20 C after 50 days, and 50 percent survival at -2 C after 150 days. Eggs of Acheta commodur L. in diapause were observed to be very cold hardy, while pre-diapause eggs

were cold sensitive (Howe 1967). Species indigenous to an area must have the ability to survive winter stress, and this natural selection process will produce populations with varying cold hardiness characteristics. The objectives of this research were to study the effects of temperature, moisture, and time of exposure to temperature on the survival of overwintering SB eggs, and to examine the effect of cold stress on newly emerged SB larvae, using a population from Southwestern Virginia. Knowledge about the ability of diapausing SB eggs and larvae to survive stressful conditions will aid research directed towards developing a temperature sensitive predictive model of SB population fluctuation. This in turn will aid pest management specialists and growers in predicting years of high SB density and damage.

### **7.2.2 Materials and Methods**

#### **Egg and larval cold shock, 1984-1985**

Eggs laid by SB females in 60 X 56 X 70 wooden, organandy and glass oviposition cages were transferred to .5 dram shell vials, and were held for 124 days in a 4 C refrigerator in 1984, and for 112 days outside in a covered, screened cage in 1985. Cold shock treatments were administered from 19-30 January in 1984, and from 12-17 February in 1985. Cold shock temperatures were 5,

-10, -20, and -30 C in 1984, and -15, -25, and -30 C in 1985. Twenty eggs were tested per treatment. Time periods for cold shocks were 3, 24 and 48 hours. Eggs were returned after cold shocks to a 4 C refrigerator until April 19 in 1984, when they were held at 18 C cold room until egg hatch, and to an outside screened cage until egg hatch in 1985. Eggs at the 5, -10, -15, -20 and -25 C treatment levels were placed in individual freezers which were monitored three times daily using glass mercury thermometers calibrated to  $\pm 2$  C accuracy. Eggs at the -30 C treatment level were placed in shell vials on a thermal cold plate. Cold plate temperature was monitored and adjusted three times daily.

First instar larvae were collected in 1985 within 12 hours of egg hatch at 22 C, transferred to 3 ml plastic Solo Serve cups with lids, and placed in refrigerators at -12, 0, and 27 C for varying time intervals. There were 5 larvae per replication and 6 replications per time/temperature combination. Larvae were observed 25 minutes after removal from temperature chambers, and the number dead was recorded. A larva was assumed dead if no movement was observed.

### Egg eclosion in overwintering temperature and moisture regimes, 1984

Groups of eggs were placed in Solo Serve cups with lids, and held at 5, 10, 17, and 20 C temperature chambers, outside in a screened cage, and in a heated greenhouse from 26 October, 1984 until 19 April, 1985. Half of the eggs were placed on filter paper and given 2 drops of water once weekly until egg hatch. Eggs were transferred to 18 C on 19 April, after which dates and rates of egg hatch were recorded.

#### 7.2.3 Results and Discussion

##### Egg and larval cold shock, 1984-1985.

Eggs held outside in a screened cage in 1984 and 1985 had significantly higher eclosion rates than those subjected to cold (-10 to -30 C) shocks (Table 15). Most eggs hatched within 4 to 10 days, and all cold shock treated eggs were delayed (3 to 3.5 days) in hatching as compared to "control" eggs held outside overwinter, and not given a cold shock (Fig.16). Eggs held outside during the winter and spring of 1985 showed higher survival rates than eggs held in a 4 C freezer over the same time period in 1984, even after administration of cold shock treatments. Cold shock temperatures of from -10 to -30 C significantly reduced

Table 15. Stalk borer egg eclosion rates after cold shock treatments, embryo undeveloped, 1984-1985.

Temp. (C)	Time period cold shock (hrs)	No. reps.	Mean percent hatch by time period	Standard error of mean	Mean percent hatch (total)
			1984		
0S	-	10	-	4.5	67.0a <sup>a</sup>
+5	3	4	22.5	10.9	
	24	3	15.0	8.7	23.1bc
	48	4	30.0	8.9	
-10	3	4	47.5	12.5	
	24	3	40.0	5.8	38 bc
	48	4	27.5	11.1	
-20	3	4	33.7	14.6	
	24	3	40.0	20.8	42 c
	48	3	56.7	15.9	
-30	3	4	23.7	14.5	
	24	4	12.5	4.3	18 d
	48	4	18.7	9.4	
			1985		
0S	-	10	-	4.6	76.5a
-15	3	7	41.4	28.1	45.0b
	24	5	51.0	17.1	
	48	8	45.0	7.1	
-25	3	7	46.0	11.3	46.4b
	24	6	41.7	13.0	
	48	8	58.7	8.6	
-30	3	6	59.2	12.4	54 b
	24	6	52.5	10.0	
	48	7	52.1	6.7	

<sup>a</sup> Means followed by the same letter are not significantly different at the .05 level using Duncan's multiple range test for mean separation after a general linear model.  
 0S = eggs held outside, no cold shock.

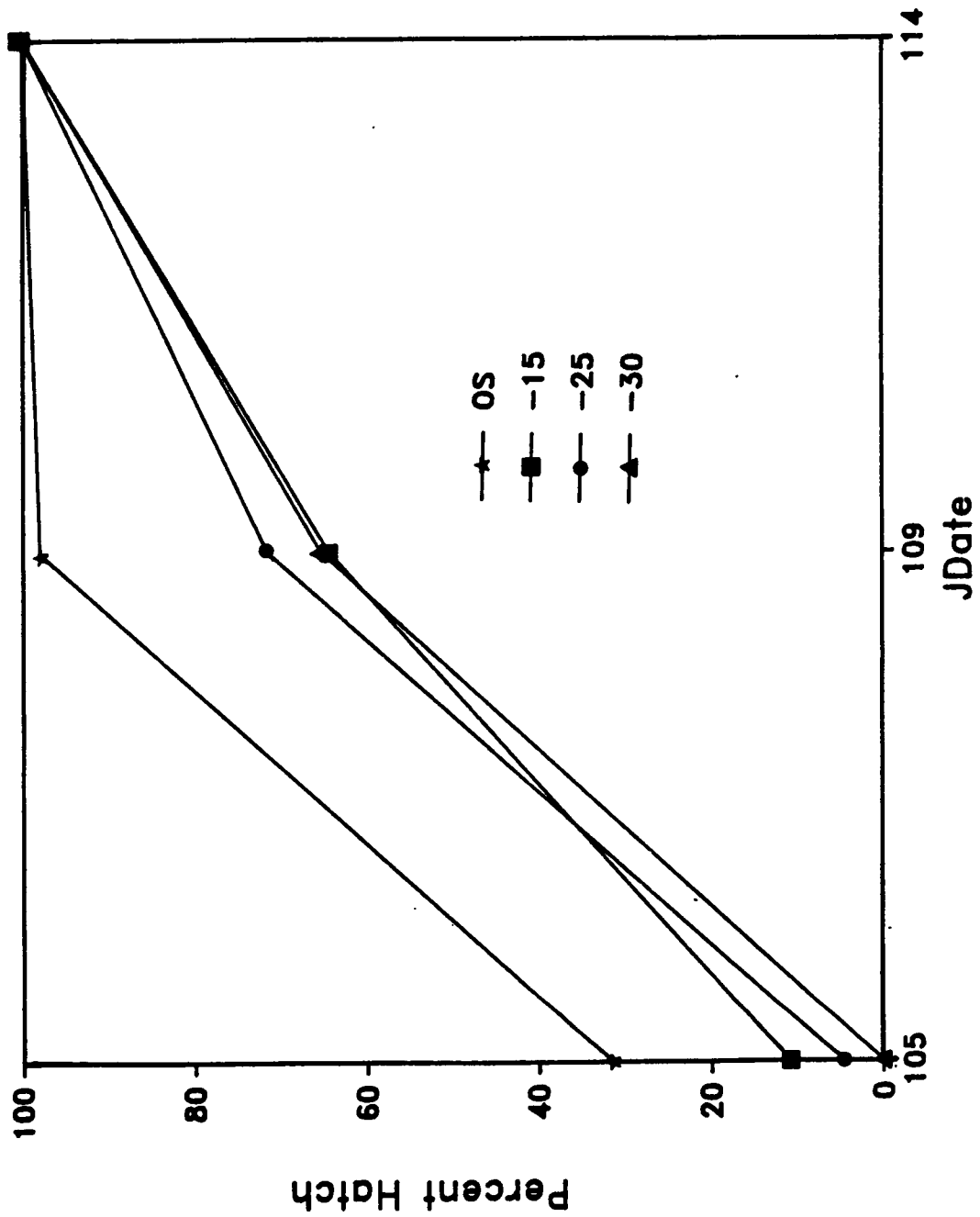


Fig. 16 Percent eclosion of SB eggs subjected to chilling temperatures, or held outside and not subjected to chilling temperatures, 1985.

SB egg survival during 1984 and 1985. However, in the 1985 tests, over 50 percent of eggs survived after cold shocks of -30 C for 24 and 48 hour time periods. No differences in survival were noted between groups of eggs given a particular cold shock temperature, but varying the time limit of treatment. In 1984 and 1985, 42 and 46 percent respectively of eggs survived after cold shocks of -20 or -25 C.

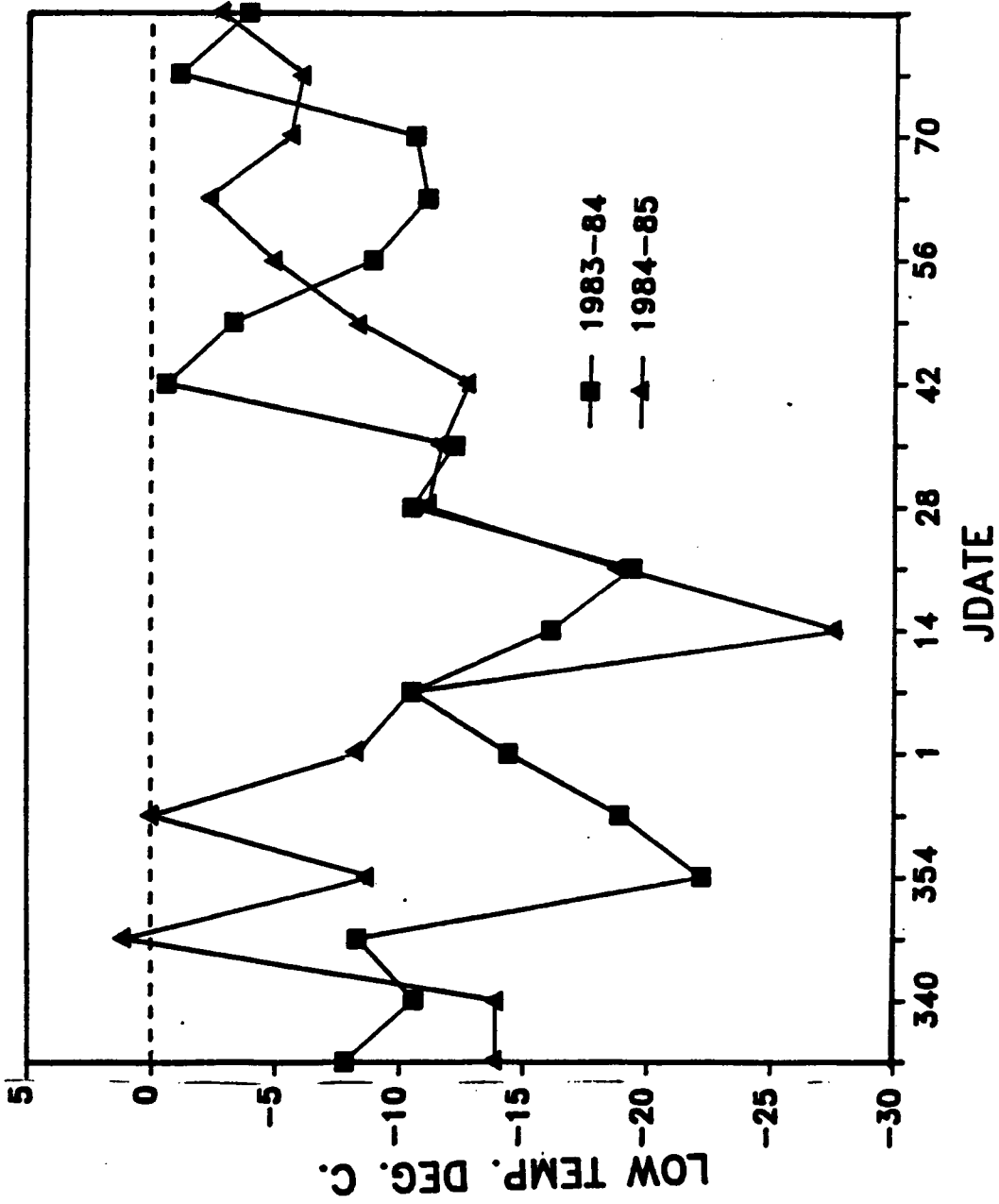
Temperature changes experienced by eggs in these tests were much more rapid than would be experienced by eggs in the field. The gradual cooling acclimation of eggs in the wild would probably contribute to survival by allowing increased time for concentrations of various solutes in the hemolymph following chilling (Salt 1961, Chino 1957). The eggs in these tests were removed from the grass leaves and placed in glass vials during cold shock. Eggs laid in the natural environment are glued to grass leaves, and the edges of the grass leaves usually folded and glued together forming a protective insulating packet around the eggs. The insulating ability of this spumaline/leaf packet is unknown, but presumably eggs overwintering in this condition would have higher survival rates than eggs removed from grass leaves.

Survival of cold shocked eggs was generally higher in 1985 compared to 1984. Eggs given cold shocks



overwintered in a 4 C refrigerator in 1984, where temperature was constant, was higher, and where moisture was lower, than for eggs given cold shocks and held outside overwinter in 1985. Any or all of these factors could have contributed to egg mortality. Eggs held outside in 1984 had comparable survival rates to eggs held outside in 1985. Temperatures fell below -10 C during 10 weeks in 1984, and 6 weeks in 1985. (Fig. 17). Temperatures fell below -15 C for 4 weeks during 1983-84, and only twice during 1984-85. Our results here show that the SB is able to adapt and survive such cold extremes.

Cold hardy insects have been described as either freeze tolerant, meaning that they have the ability to survive freezing of body fluids, or freeze susceptible, meaning that they can either produce antifreeze agents which lower freezing points, or select a thermally buffered overwintering site (Duman 1982, Salt 1961, Danks 1978). Various insects have been shown to be able to produce polyols, sugars, proteins, or ice nucleating agents as larvae or pupae in order to lower their supercooling point, or to prohibit damaging intercellular ice formation (Salt 1961). Information on the cold hardiness mechanisms of insect eggs is scarce, and the mode of action contributing to SB egg survival after cold stress is unknown at this time.



Fig

Survival of first instar SB larvae after cold stress was generally higher at 0 C and lower at -12 C, although over 50% of the larvae survived -12 C at the 2 and 4 hour treatment levels (Table 16). Early instar larvae are well adapted to freezing (0 C) temperatures for from 1 to 24 hours, but survival declines as the time subjected to this temperature increases above 24 hours. In addition, over 50 percent of larvae subjected to -12 C for 2 or 4 hours survived. Survival and development of these larvae was not recorded after the initial reading, however, this insect appears to be very freeze tolerant in the first instar. More studies need to be performed to elucidate the protective mechanisms involved.

Egg eclosion in overwintering temperature and moisture regimes.

Eggs held overwinter in chambers where temperature and moisture were controlled showed significant mortality at temperatures above 17 C (Table 17). If all temperature treatments are combined, those eggs given moisture showed significantly higher survival (50.1%) than eggs that were not given moisture (29.0%), using analysis of variance with LSD at the .05 level of significance. The SB overwinters in nature in the egg stage in obligatory diapause throughout the

Table 16. Survival of first instar stalk borer larvae after cold stress, 1985.

Temp. (C)	Time period (hrs)	Mean percent survival	Standard error of mean	Total mean survival (per temp)
-12 <sup>a</sup>	1	44.0 a <sup>b</sup>	8.3	52.0a
	2	57.0 a	6.7	
	4	55.0 a	17.0	
0	1	98.0 a	2.0	83.1b
	2	98.0 a	2.0	
	4	100.0 a	0	
	24	85.0 b	3.8	
	48	70.0 c	6.1	
	90	48.0 d	5.3	
27	1	96.0 a	2.6	65.3a
	2	90.0 a	5.4	
	24	10.0 b	4.5	

<sup>a</sup> Six replications at each temperature and time treatment level, five first instar larvae per replication.

<sup>b</sup> Means followed by the same letter are not significantly different at the .05 level using Duncan's multiple range test for mean separation after a general linear model.

Table 17. Stalk borer eclosion rates in different temperature and moisture regimes, 1984.

Temp. (C)	Moisture	Mean percent hatch	Standard error of mean	Mean percent hatch(total)
0S <sup>a</sup>	H <sup>b</sup>	75.0	7.5	63.2a <sup>c</sup>
	L	59.2	4.4	
5	H	55.8	2.7	34.6b
	L	13.3	2.1	
10	H	80.8	7.4	81.2a
	L	81.7	2.0	
17	H	0	-	0.8c
	L	1.6	-	
20	H	0	-	-
	L	0	-	
GH	H	0	-	-
	L	0	-	

<sup>a</sup> There were 6 reps. of 20 eggs each per temp./moisture regime. OS eggs were held outside in a screened cage, and GH eggs were held in a heated greenhouse.

<sup>b</sup> Two drops distilled water added weekly until egg hatch to high moisture containers. Low moisture containers had no extra water added.

<sup>c</sup> Means followed by the same letter are not significantly different at the .05 level using Duncan's multiple range test for mean separation after a general linear model.

northeastern and midwestern U.S. Consequently, prolonged, higher temperatures would not be the norm in the insects geographical range. I therefore would expect higher mortality at these higher temperatures. Additionally, dessication could be a major factor in egg mortality, and some of the higher mortality at the higher temperatures could be due to moisture deprivation.

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