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SEEDCORN MAGGOT IN CONVENTIONAL AND CONSERVATION
TILLAGE SOYBEANS AND DAMAGE EFFECTS ON SOYBEAN GROWTH
AND YIELD

Iowa State University

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Seedcorn maggot in conventional and conservation tillage soybeans
and damage effects on soybean growth and yield

by

Joseph E. Funderburk

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of the
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INTRODUCTION

The seedcorn maggot, Hylemya platura (Meigen), is believed to be of European origin, though the species is now cosmopolitan (Throne 1980). The common name is misleading, because the insect attacks many different crops, including corn, during germination. In the United States, the seedcorn maggot severely damages beans in the Northeast; beans, corn, and vegetables in the Southeast and Midsouth; beans and vegetables in the Far West; and soybeans and corn in the Midwest (Cooperative Plant Pest Report 1976-80). In most years, damage to soybeans and corn in the Midwest is sporadic, with occasional replanting of some fields necessary. However, the seedcorn maggot can be a major pest in the Midwest in some years, causing severe damage over wide geographic areas. For example, the insect was categorized as a "major" Iowa soybean pest in 1975. Damage was even more severe in 1976, with extensive replanting of soybean fields in at least 7 Iowa counties (Cooperative Plant Pest Report 1976).

The need to control insect pests associated with an agroecosystem often is related to agronomic practices, i.e., seedbed preparation, cultivation, etc. Therefore, basic to pest management approaches are studies on biology and ecology of insect pests. Many previous laboratory studies and field observations emphasized basic biology of the seedcorn maggot, especially ovipositional preferences. They demonstrated that seedcorn maggot oviposition was enhanced by forms of decaying organic matter, e.g., natural fertilizers and some crop residues. These evidences, albeit extremely circumstantial, led to the hypothesis that

crop residues left on the soil surface provide an ideal site for seedcorn maggot oviposition and development.

Because crop residues left on the surface reduce soil erosion, conservation-tillage production recently has increased in Iowa and other midwestern states. Yet, concern about stand establishment and insect pests has slowed grower acceptance of such systems (Kelly 1977, Owens and Patterson 1973). Because of its association with decaying crop residues, the seedcorn maggot is expected to become the most serious pest during germination in conservation-tillage soybean systems. Therefore, investigations conducted under field conditions are needed to determine the influences of tillage and other agronomic practices on seedcorn maggot oviposition and development. Elucidation of these relationships is necessary to determine potential seedcorn maggot damage, to develop control methods, and ultimately to ensure acceptance, if feasible, of each conservation-tillage system.

The quantification of a pest's numbers requires the development of a sampling procedure that accurately estimates population levels. Yet, sampling soil insects such as the seedcorn maggot presents many difficulties, because most methods are time consuming and suffer from mechanical and human error. These probably are the reasons that an absolute sampling procedure was never developed for the seedcorn maggot. The elaboration of such a sampling method would provide a way to determine and contrast its numbers in different soybean tillage systems. Further, an absolute sampling procedure would provide a means to identify factors that influence seedcorn maggot oviposition and development, but differ

by tillage system (e.g., crop residue, weed cover, and soil moisture).

Pest management attempts to maximize the benefits of pest-control activities and corrective measures. Therefore, knowledge of yield-loss relationships between a crop and its insect pests previously has been an emphasized aspect of pest-management programs. Knowledge of damage which affects plant growth other than yield has been less emphasized. Yet, such damage may interact with later-season stresses (e.g., weeds and hail) and contribute to yield reduction. Soybean injury from the seedcorn maggot potentially could interact with numerous other types of damage, because it occurs at the beginning of the growing season.

However, a lack of adequate experimental procedures often hampers elucidation of such crop-stress relationships. Previous investigators of Iowa soybean pests were concerned about this problem. Consequently, they developed adequate experimental methods to study soybean responses to insect defoliation (Stone and Pedigo 1972, Poston and Pedigo 1976, Poston et al. 1976). But, no procedures were developed to investigate and determine the effects of seedcorn maggot damage on soybean growth and yield.

Research reported in this dissertation was conducted to determine the potential for seedcorn maggot problems in reduced-tillage soybean systems and to ascertain soybean responses to seedcorn maggot injury. Specific objectives were the following:

1. To develop an absolute sampling method that accurately estimates seedcorn maggot population numbers (Part I);

2. To determine and contrast seedcorn maggot incidence during germination in conventional and reduced-tillage soybean systems (Part I);
3. To determine the influences of crop residue, weed cover, and soil moisture on seedcorn maggot oviposition and development (Part I);
4. To elucidate the effects of seedcorn maggot damage on soybean growth and yield (Part II); and
5. To develop a simulation method which accurately represents soybean responses to seedcorn maggot damage (Part II).

LITERATURE REVIEW

Early seedcorn maggot literature consisted mostly of biology and recommendations of control. Complete life-history discussions were given by Hawley (1922), Miles (1948), and Miller and McClanahan (1960). They described all stages of seedcorn maggot development, including information about overwintering, ovipositional behavior, etc. Throne (1980) compiled a complete bibliography of seedcorn maggot literature. It contains articles published since the original description of the species through 1979, excluding citations in the Cooperative Plant Pest Report and Canadian Insect Pest Review. Because of this published bibliography, the remainder of this literature review will deal with information concerning seedcorn maggot phenology, ovipositional preferences, and damage to legumes. Seedcorn maggot damage to soybeans results in stand loss, cotyledon damage, and plumule abscission. Therefore, a review of literature pertinent to the effects of such damage on soybean growth and yield also is presented. Finally, previous reports involving insects in reduced-tillage systems are summarized.

Seedcorn Maggot

Seedcorn maggot phenology has been investigated by numerous authors. These investigators often attempted to predict periods when seedcorn maggots were in nondamaging stages and advised planting during these periods. Harukawa et al. (1932, 1934) and Reid (1940) conducted studies on the relationship of temperature to the velocity and duration of seedcorn maggot development. They reported that velocity curves of

egg, larval, and pupal development were very slightly s-shaped over 10-30 °C. Velocity of development decreased sharply from 30-35 °C. Further, they concluded that the threshold temperature for development was lower than 10 °C, but actual values for egg, larval, and pupal development were not determined.

Strong and Apple (1958) determined a thermal-unit system to define the relationship between temperature and seedcorn maggot development, by using the method later described by Arnold (1959). They found that 318 centigrade day-degrees (threshold of development ca. 10 °C) were required for egg-to-adult development, with 26, 131, and 159 required for egg, larval, and pupal development, respectively. Recently, Sanborn et al. (1982) observed in Wisconsin that seedcorn maggot adults emerged in the spring before both onion maggots, Hylemya antiqua (Meigen), and cabbage maggots, H. brassicae (Bouché), whose threshold temperatures were known to be below 5 °C. Using x-intercept and least-variability methods, they estimated the threshold temperature at 3.9 °C, with 29.5, 204.0, and 142.1 thermal units necessary for egg, larval, and pupal stages, respectively.

Because of this rapid development, numerous seedcorn maggot generations have been reported in many areas. The seedcorn maggot was reported to overwinter in the pupal stage in all areas. Adults were most numerous usually from May through mid-July in northern latitudes. Hawley (1922) observed 3 complete generations per year in New York. A few generation-4 adults appeared in August and September, but he believed that most overwintered as puparia. Other investigators also reported results that suggested bimodal emergence for some seedcorn maggot

generations. Eckenrode et al. (1973), also in New York, attracted seedcorn maggot adults to meat and bonemeal placed under cone-screen traps. Peak adult numbers were collected before July. Hagel et al. (1981) observed 2 generations in Washington between May 1 and June 15 and noted that numbers decreased tremendously after that time. Adults were collected in Wisconsin from cone-screen traps in large numbers from May through mid-July, with 3 distinct generations during this period (Sanborn et al. 1982). Adults were less numerous from mid-July through September. In the southeastern United States, adults were reported common in the fall, early winter, and spring months, but few were observed in midsummer (Berisford and Tsao 1974, Reid 1936, Reid 1940).

Begg (1962) and Miller and McClanahan (1960) used 2 methods to study the number of generations and the emergence period for each generation in Ontario. From early April through October, emergence cages (each cage was an 8-l pail with a glass vial fitted into a hole at the upper end) were used to determine periods of seedcorn maggot emergence from the soil. Also, flour baits (whole-wheat flour and water kneaded into a ball) were covered by 5-cm soil and emergence cages placed over these baits after 14 days. In each year, 3 distinct adult peaks were recorded from April through mid-July. Another peak occurred later in the summer, but the authors did not report the size of this peak relative to the earlier ones. Strong and Apple (1958) attracted the adults to honey and yeast placed under cone-screen traps. As previous investigators in other areas, they observed 3 distinct peaks from May

through July and 2 smaller ones in August and September. They concluded that 4 complete and 2 partial generations occurred in Wisconsin.

To determine the causes of problem infestations, many investigators attempted to identify factors influencing seedcorn maggot oviposition and development. Numerous types of organic fertilizers were reported to enhance oviposition. Reid (1936) reported that seedcorn maggot infestations often were associated with the use of organic fertilizers and that severity of crop damage was in proportion to the amount used. He found that eggs were deposited on cottonseed meal, fish meal, fish scrap, animal tankage, and dried blood. Other investigators reported that oviposition was enhanced by fish meal (Starks and Lilly 1955) and dried meat and bonemeal (Eckenrode et al. 1973). Hawley (1922) noted that manure did not stimulate egg laying.

Decaying crop residues also were reported to be associated with seedcorn maggot infestations. Hawley (1922) identified several kinds of plant materials that enhanced seedcorn maggot oviposition. These included decaying bean pods, decaying bean vines, rotting cabbages, and plowed-under sod. Miller and McClanahan (1960) observed 2 severely infested fields in Ontario that they believed were associated with the presence of plant materials. The fields were planted just a few days after decaying crop residues had been disked under the soil surface. Likewise, plowed-under rye stalks were reported conducive to seedcorn maggot infestation (Begg 1962, Harris et al. 1966). Barlow (1965), after conducting laboratory studies, concluded that seedcorn maggot females did discriminate between oviposition sites on the basis of their organic

nature. He demonstrated that chopped rye seedlings strongly stimulated oviposition. Dindonis and Miller (1980) found that decomposing onion seedlings were attractive to ovipositing females. However, Miles (1948) found no direct association under field conditions between seedcorn maggot occurrence and the presence of decaying vegetation. Further, she reported that observed seedcorn maggot attacks of beans and cabbages were not associated with buried crop residues.

Germinating vegetable seeds were found to stimulate seedcorn maggot oviposition. For example, Barlow (1965) reported that after emergence rye and tobacco seedlings enhanced egg laying. Peas stimulated oviposition in that study, even when they were below the soil surface. Yu et al. (1975) investigated the ovipositional preferences of females for numerous kinds of vegetable seeds. They were found to oviposit readily beside germinating snap bean, squash, and cucumber seeds. Under field conditions, germinating snap beans attracted more females than did germinating lima beans or unplanted areas. Dindonis and Miller (1980) reported that healthy onion seedlings attracted ovipositing females. Ibrahim and Hower (1979) evaluated 5 stages of Amsoy 71 soybean growth (2-h soaked seed, germinating seed, emerging seedling, emerged seedling with cotyledons closed, and seedling with plumule fully opened) for ovipositional preferences by females (Table 1). Plain soil was used as a control. The females deposited significantly more eggs adjacent to newly emerged soybean seedlings than any other stage of growth. Lowest numbers were oviposited adjacent to the 2-h soaked seed and on the soil with no seeds.

Table 1. Ovipositional response of seedcorn maggots to various developmental stages of Amsoy 71 soybeans

Stage of Soybean Development	Mean No. Eggs/Replication ^a	SD	% of Total Eggs
Emerged seedling	24.5A	8.9	62.0
Germinating seed	7.3B	2.5	18.3
Emerged seedling with cotyledons closed	5.0B	1.9	12.7
Seedling with plumule fully opened	1.5B	1.1	3.8
Soil with no seed	0.8B	0.3	1.9
Seed soaked for 2h	0.5B	0.5	1.3

^aMeans followed by the same letter are not significantly different ($P < 0.05$) as determined by Duncan's Multiple Range Test.

Therefore, investigations identified organic fertilizers, decaying crop residues, and germinating seeds of various crops as factors influencing or enhancing seedcorn maggot oviposition. However, the actual causative agents for seedcorn maggot infestations under field conditions were not determined adequately in these previous investigations. Miles (1950) speculated that seedcorn maggot larvae were primarily scavengers feeding on organic matter in the soil and that attacks on crops were associated with a lack of adequate food. Miller and McClanahan (1960) tested this hypothesis. They placed seedcorn maggot eggs on moist soil surfaces taken at random from a fertile field. The maggots matured presumably feeding on the organic matter in the soil. They further concluded that there was no evidence to show that seedcorn maggot oviposition occurred after planting and as a direct result of the

presence of seeds or seedlings. Eckenrode et al. (1973) refuted this finding. They reported consistent variation in degree of seedcorn maggot injury between lima beans, kidney beans, peas, and sweet corn planted on the same date and in the same location. They suggested that this variation was because of seedcorn maggot ovipositional preferences for some seedlings or differences in crop susceptibility to maggot injury. For whatever reason, beans and soybeans usually were reported the most damaged of all seedcorn maggot hosts.

Hofmaster and Nugent (1956), Miles (1948), and Miller and McClanahan (1960) characterized seedcorn maggot damage to lima, kidney, and snap bean seedlings, and Vea et al. (1975) described damage to soybeans. These descriptions of damage to soybeans and other beans were very similar. It was observed that the maggots penetrated the cotyledons as soon as the testa split. They then fed on the cotyledons, burrowing into their interior or beneath the testa. These tunnels soon became full of a brownish, rotting matter. If the seedling survived and emerged, the tunnels later appeared as brown scars and deformities on the cotyledons. When several maggots were present on one seedling, the food reserves were seriously depleted, and it usually did not survive.

Miles (1948) probably was the first who reported that seedcorn maggot tunneling often destroyed the plumule or growing point. She called these plants, which were found to sometimes survive, "snakeheaded seedlings". Later investigators also noted that snakehead seedlings frequently were produced by seedcorn maggot damage (Hofmaster and Nugent

1956, Miller and McClanahan 1960, Ristich and Schwardt 1949, Veal et al. 1975, Veal and Eckenrode 1976a).

Because a method was never adequately developed to sample seedcorn maggot populations, measuring damage to germinating soybeans and other beans became a popular method of evaluating insecticide efficacy against the seedcorn maggot. Damage trials nearly always used stand loss as a criterion for rating seedcorn maggot damage (Hofmaster and Nugent 1956, Judge and McEwen 1970, Judge and Natti 1972, Ristich and Schwardt 1949, Starks and Lilly 1955, Veal and Eckenrode 1976a). In such experiments, evaluations occasionally were made of the number of surviving seedlings with scarred cotyledons and of those in which the plumule was abscised (Ristich and Schwardt 1949, Veal and Eckenrode 1976a, Veal et al. 1975).

Although many investigators noted that damaged soybeans and other beans frequently survived seedcorn maggot damage, few attempts were made to quantify the effects of such damage on subsequent growth and yield. Miles (1948) noted that the loss of the plumule greatly affected later growth of the bean plant. She reported that such plants survived by producing lateral branches, but no data were collected on their yield. Hofmaster and Nugent (1956) observed that snakehead seedlings were greatly deformed, producing few accessory buds, leaves, or pods. Miller and McClanahan (1960) reported that such seedlings had dwarfed pods, poor-quality seeds, and depressed yield.

Veal and Eckenrode (1976b) investigated yield components of seedcorn-maggot-damaged plants of lima, snap, and red kidney beans. After inducing

seedcorn maggot damage in experimental plots, injured seedlings with various levels of defoliation (25, 50, 75, and 100%) to the unifoliate leaves were selected. Although isolated plants were avoided, little attempt was made to quantify the plant population surrounding these damaged plants. Injury to plumules was not discussed in this study, but seedlings with 100% defoliation to the unifoliate leaves probably were snakehead plants. Yield components of the various levels of seedcorn maggot damage to the unifoliate leaves were compared to each other and to undamaged plants. Yields were reduced (11-48%) for snap beans when the unifoliate leaves were defoliated 25%. In all cases, snap bean seedlings with 100% defoliation produced less than 10% that of normal plants. Yield reductions in lima and kidney beans were observed only in seedlings with 100% loss of the unifoliate leaves. The yield losses of damaged plants were because of smaller pods and fewer pods per plant.

Seedcorn Maggot Injury to Soybeans

Germination is probably the developmental phase of any plant which is most subject to control by the environment (Mitchell 1970). Temperature stimulation for germination usually is restricted to a narrow range, and the seed requires ample water for rehydration. In soybeans, the cotyledons contain organic and inorganic substances needed for germination and early seedling growth. Before they are aborted (ca. 20 days after emergence under field conditions), 70% of their total weight is translocated to the seedling (McAlister and Krober 1951). Most of this translocation occurs before emergence.

Seedcorn maggot larvae feed on the cotyledons and/or the plumule of a soybean or other leguminous seedling during germination. This damage results in stand loss and injured seedlings. Most studies of legume damage by the seedcorn maggot emphasized stand loss, probably because it was the most recognized form of damage. Seedcorn maggot injury which results in stand loss relates directly to soybean plant population.

Stand reduction

A survey of the literature indicates that considerable research has investigated the effects of plant population on soybean yield components and other plant-growth characteristics. The literature on soybean plant population was reviewed by Cartter and Hartwig (1963), Eglie (1976), and Pendleton and Hartwig (1973).

The relationship between soybean plant density and yield has been investigated in all of the major soybean-producing areas of the United States. These studies have shown that the soybean plant has the ability to make wide adjustments to space and produce optimal yields over a wide range of plant density.

Because of the soybeans' compensatory ability, numerous studies found no differences in seed yield over the range of populations investigated. In Minnesota, populations of 13, 26, 52, and 78 plants per 1-m row (Blackhawk and Mandarin varieties) gave similar yields at row spacings of 50 and 100 cm (Lehman and Lambert 1960), and populations of 13, 26, and 39 plants per 1-m row (Corsoy, Wells, and Hodgson varieties) at a

76-cm row spacing yielded similarly in 2 of 3 years (Leuschen and Hicks 1977). No yield differences were found between 19, 38, and 57 plants per 1-m row at a 91-cm row spacing for Corsoy, Harosoy-63, L-63-1397, Hark, A-100, Rampage, and Lindarin-63 varieties in Wisconsin (Pandey and Torrie 1973). In Arkansas, McClelland (1940) was unable to find any large yield differences over a wide range of plant densities for Mammoth-yellow (populations ranged from 8-36 plants per 1-m row) and Laredo (populations ranged from 13-107 plants per 1-m row) varieties grown at a row spacing of 91 cm. In Arkansas, Caviness (1966) found yields similar for Lee soybeans grown at 3 plant densities and 4 row widths.

In many studies, soybeans yielded best at a population between the least and greatest plant density in the experiment. Mukden, Mandell, Dunfield, and Illini varieties in Indiana (76-cm row spacing) yielded best at 13 and 20 plants per 1-m row (Probst 1945). Yields were greatest at 28 plants per 1-m row for 9 soybean varieties (including Amsoy 71) in Illinois at a 75-cm row spacing (Cooper 1977). Similarly, yields were best at 26.2 plants per 1-m row for Hill, Lee, and Hardee varieties in Georgia at a 91-cm row spacing (Johnson and Harris 1967). The Bragg soybean variety was included in the Georgia study, but optimal yields were obtained at 6.6 plants per 1-m row. Weber et al. (1966) investigated the yield response of Hawkeye soybeans in Iowa to various plant populations and row widths. Yields were greatest at the plant density of 52,000 plants per 0.4 ha at all row widths.

Decreased yields at plant densities greater than 30 plants per 1-m row frequently were associated with increased lodging. Leffel and

Barber (1961) found that Dorman soybeans decreased in yield and increased in lodging as plant density increased. Other investigators reported similar results for other varieties and determined that varieties classified as lodging resistant will lodge at greater populations (Johnson and Harris 1967, Probst 1945, Weber et al. 1966). Cooper (1971) demonstrated that early lodging reduced yield as much as 23% when compared to plants that were artificially maintained in an upright position. He concluded that lodging was an important factor influencing the response of soybeans to plant population and row spacing. For densities greater than 30 plants per 1-m row, reports of lodging and subsequent yield reductions were commonly reported in the literature. However, these reductions usually were small and insignificant (Athow and Caldwell 1956, Cooper 1977, Hartwig 1957, Probst 1945, Weber et al. 1966, Wiggans 1939).

Soybeans at densities below 20 plants per 1-m row often yielded as well as the greater, more optimal populations. At typical row spacings (70-102 cm), plant densities between 10-20 plants per 1-m row yielded near optimal in many experiments (Borst 1929, Caviness 1966, Johnson and Harris 1967, Leffel and Barber 1961, Lehman and Lambert 1960, Leuschen and Hicks 1977, McClelland 1940, Pandey and Torrie 1973, Probst 1945). Populations less than 10 plants per 1-m row were reported in a few experiments to yield near optimal (Johnson and Harris 1967, Leffel and Barber 1961, McClelland 1940, Wiggans 1939). However, populations less than 20 plants per 1-m row often have resulted in reduced yields. Borst (1929) found yields less at 5 than at 12 and 39 plants per 1-m row (71-cm row spacing), and Probst (1945) reported reduced

yields at 8 and 10 compared to 13, 20, and 39 plants per 1-m row (76-cm row spacing). At the similar row width of 81 cm, Wiggans (1939) found differences by year. For 3 of 4 years, yields essentially were reduced only at the population of 9 plants per 1-m row (lowest population in experiment at that row width). In the other year, rather large yield reductions were demonstrated at populations equal to and less than 17 plants per 1-m row. Johnson and Harris (1967) found differences in each of 3 years (91-cm row spacing). In their study, populations between 6.6 and 26.2 plants per 1-m row yielded near optimal in some years and not in others. At a 91-cm row spacing, Athow and Caldwell (1956) found yields less at 10 than at 13, 20, and 39 plants per 1-m row. Cartter and Hartwig (1963), after surveying this literature, determined that populations below 20 plants per 1-m row often resulted in reduced yields.

The relationships between soybean plant population and other yield components were reported in numerous investigations. These studies revealed that the main soybean yield component affected by plant density was the number of pods per plant. As within-row plant density increased, the number of pods per plant decreased (Burlinson et al. 1940, BATTERY 1969, Caviness and Miner 1962, Leuschen and Hicks 1977, Molinyawe and Cao-Van-Nau 1966, Pandey and Torrie 1973, Weber et al. 1966). Pandey and Torrie (1973) found that pods per unit area remained constant over a wide range of plant density (18.2-54.5 plants per 1-m row) and concluded that pods per unit area was an important factor in determining seed yield. The other soybean yield components, seeds per pod and

weight per seed, usually remained constant according to plant density. The number of seeds per pod was not affected by plant density in any reports (Dominguez and Hume 1978, Lehman and Lambert 1960, Pandey and Torrie 1973). Likewise, most investigators found that weight per seed was not affected by plant population (Caviness and Miner 1962, Dominguez and Hume 1978, Lehman and Lambert 1960, Pandey and Torrie 1973, Probst 1945). However, the weight per seed for some soybean varieties was influenced by plant density. Lee (Johnson and Harris 1967), Improved Pelican (Molinyawe and Cao-Van-Nau 1966), and E. G. 5 (Molinyawe and Cao-Van-Nau 1966) varieties produced heavier seeds at low populations. Seed weight of Hawkeye soybeans decreased slightly at intermediate populations (Weber et al. 1966).

Studies have shown that plant population influenced pod numbers per plant and some other plant-growth parameters in much the same way. On a per-plant basis, flower number, pod number, and leaf area were inversely related to plant density. Flower number and leaf area also were influenced by plant density on a per-area basis. Buttery (1969) and Dominguez and Hume (1978) demonstrated that percentage flower abortion increased at greater plant densities. More flowers were produced at greater populations, but more flowers also were aborted. Weber et al. (1966) found that the rate of leaf area index (LAI) accumulation was directly related to plant population. However, they concluded that maximum seed yield occurred at less than maximum LAI.

Plant population affected height and node number of determinate and indeterminate soybean varieties differently. Most studies revealed

that height of indeterminate varieties remained constant over plant population (Hinson and Hanson 1962, Leffel and Barber 1961, Leuschen and Hicks 1977). Some indeterminate varieties showed a trend to decrease in height, although insignificantly, as plant density increased (Dominguez and Hume 1978, Probst 1945); however, the indeterminate variety, Hawkeye, tended to increase in height as plant density increased (Weber et al. 1966). Unlike most indeterminate varieties, determinate varieties increased in height as plant density increased (Dominguez and Hume 1978, Johnson and Harris 1967). The Johnson and Harris (1967) study revealed that the height of 4 determinate soybean varieties increased up to a certain density and then remained constant above that density. Plant height of Bragg, Hill, and Lee varieties increased as population increased through 26.2 plants per 1-m row, while the Hardee variety reached maximum height at 13.1 plants per 1-m row.

The number of nodes for indeterminate varieties decreased as plant population increased (Dominguez and Hume 1978, Pandey and Torrie 1973). Node number of determinate varieties remained stable over plant population (Dominguez and Hume 1978).

Therefore, studies revealed that seed yields usually were optimal at plant densities of 20-39 plants per 1-m row. Within this range of plant density, crop management considerations involving weed control and other later-season stresses dictated the actual recommended seeding rate. Because LAI accumulation directly was related to plant density, populations of ca. 30 plants per 1-m row and greater were reported more

competitive than soybeans grown with fewer plants. As a result, there were fewer weed problems (Borst 1929, Hartwig 1957, Johnson and Harris 1967, Leffel and Barber 1961).

Cotyledon and plumule damage

Seedcorn maggot feeding on soybean cotyledons during germination removes some of the food supply used for subsequent growth of the seedling. No investigations have been conducted to determine the effects of this cotyledon feeding on later development of the soybean plant. However, the effects of removing one or both cotyledons at emergence have been investigated. Results from these investigations suggested that, unless severe, seedcorn maggot feeding on the cotyledons would not substantially affect soybean growth and yield. McAlister and Krober (1951) found that plants with both cotyledons removed at emergence were shorter and showed a tendency toward a reduction in seed yield. In a study conducted by Weber and Caldwell (1966), removing a cotyledon at emergence did not influence yield, although removing both cotyledons reduced yields 8.5%.

The effects of plumule abscission during germination from seedcorn maggot damage on subsequent soybean growth have not been investigated. However, the effects of growing-point removal at later growth stages to simulate hail injury were studied. Weber and Caldwell (1966) found that clipping all plants below the unifoliate nodes at growth stage VI reduced seed yields 2.8% (only plant density in study was 33 plants per 1-m row). Weber (1955) reported that the effects of topping (removing the growing point) were greatest at early growth stages of soybean growth. During

the vegetative stages, seed yields were decreased less than 5% at 25 and 50% topping and less than 10% at 75 and 100% topping. They also found that height decreased as topping percentages increased and that seed size was not appreciably affected by topping.

Insect Pests and Reduced-tillage Systems

Considerable agronomic research recently has been conducted of reduced-tillage production schemes. For each system, comprehensive studies have involved yield potential, production economics, equipment development and improvement, and weed control (Musick and Collins 1971). Yet, research on insect problems in reduced-tillage systems has not kept pace with agronomic research (All and Gallaher 1976). As a result, most reports of insect pests in these systems were based almost completely on speculation (Musick and Beasley 1978). Generally, most investigators hypothesized that pest problems would be greater in reduced-tillage systems compared with conventional systems (All and Gallaher 1976, Gregory and Musick 1976, Musick and Beasley 1978, Phillips and Young 1973).

Surface crop residues in reduced-tillage systems were found to favor oviposition and development of numerous insect pests. Musick and Petty (1974) in Ohio reported that the black cutworm, Agrotis ipsilon (Hufnagel), attacked 15% of the seedlings in no-till cornfields, whereas only 1% of the seedlings from adjacent, conventionally plowed fields were attacked. They attributed the increased damage in the no-till system to ovipositional preference by the moth for surface trash and to increased larval survival. Later, corn and soybean debris were determined suitable

for oviposition, and damage in some fields was observed related to the availability of such oviposition sites (Busching and Turpin 1976).

Oviposition by the northern corn rootworm, Diabrotica longicornis Say, was directly related to the amount of surface trash (Musick and Collins 1971). Therefore, the numbers of eggs present in a reduced-tillage system were found dependent upon the amount of surface trash. Also, surface trash and decaying organic matter previously were thought to provide an ideal site for oviposition and development of the seedcorn maggot (All and Gallaher 1976, Gregory and Musick 1976).

Delayed germination in reduced-tillage systems was reported because of lower soil temperatures. Gregory and Musick (1976) and Musick and Beasley (1978) speculated that this delayed germination extended vulnerability of the seed to insect damage. They believed that seed pests such as the seedcorn beetle (Agonoderus lecontei Chaudoir), slender seedcorn beetle (Clivina impressifrons LeConte), and seedcorn maggot were important potential pests in reduced-tillage systems.

Also, greater weed problems associated with reduced-tillage fields were found to increase the damage by some insects. The armyworm, Pseudaletia unipuncta (Haworth), has been very damaging to no-till corn in the Midwest (Gregory and Musick 1976, Musick 1973, Musick and Beasley 1978). The larvae were found to prefer weeds to corn, but they transferred and fed on corn when the weeds were killed by herbicides. Corn damage by the stalk borer, Papaipema nebris (Guenee), was found associated with weedy and grassy areas. Damage in conventionally tilled corn was

restricted to field peripheries, but damage occurred over all areas in no-till fields (Anonymous 1968, Gregory and Musick 1976).

Because some insect pests overwinter in crop residues, Gregory and Musick (1976) hypothesized that these pests would be greatly affected by plowing and tillage practices. The European corn borer, Ostrinia nubilalis (Hübner), and the southwestern corn borer, Diatraea grandiosella (Dyar), therefore were expected to become series pests in reduced-tillage systems. However, All and Gallaher (1976) reported similar numbers of European corn borers in conventional and no-tillage plots.

Roach (1981) compared destructive and beneficial insect populations in conventional and reduced-tillage cotton and tobacco systems. In the cotton plots, destructive insect species were Heliothis zea (Boddie), H. virescens (F.), Spodoptera exigua (Hubner), S. frugiperda (J. E. Smith), and Anthonomus grandis grandis Boheman. No significant differences in infestation levels of these pests were found between the tillage systems, except in 1 of the 3 years. In that year, conventional plots suffered greater larval infestation of Heliothis spp. and greater percentage damaged squares than no-till plots. In tobacco, infestation levels of destructive insects were similar in the conventional and reduced-tillage plots. In both cotton and tobacco, disease and parasitization of the insect pests were very similar in the conventional and no-till plots.

PART I: SEEDCORN MAGGOT EMERGENCE IN CONVENTIONAL AND REDUCED-
TILLAGE SOYBEAN SYSTEMS

ABSTRACT

Absolute population estimates, based on emergence trapping, were made for the seedcorn maggot, Hylemya platura (Meigen) (Diptera: Anthomyiidae), during germination in 4 typical Iowa soybean tillage systems (fall moldboard plow, fall chisel plow, till-plant, and no-tillage). The emergence trapping method gave acceptable levels of precision for an intensive sampling program. Although significant differences in emergence were found between tillage systems, numbers of seedcorn maggots present were not a serious problem in any system. Emergence was greatest in the fall chisel-plow system, followed by the till-plant system. Emergence in the no-till and fall moldboard-plow systems was similar. Comparisons of emergence between within-row and between-row areas in these systems suggested that germinating soybeans were not attractive for oviposition under field conditions. Surface corn residue and soil moisture were not significant factors influencing oviposition and development.

INTRODUCTION

The seedcorn maggot (SCM), Hylemya platura (Meigen), is a pest of increasing importance to germinating soybeans in Iowa. The maggots tunnel through germinating seeds, feeding on the cotyledons and plumules. Injury results in poor plant stands and damaged plants. Seedlings, in which the plumule has been eaten, respond by producing a branch at each cotyledonary node. These plants ultimately yield less than healthy plants, with such damage usually going unnoticed by the grower.

Many past studies on SCM biology attempted to predict periods when developing SCM were in nondamaging stages and advised planting during these periods. Strong and Apple (1958) determined a thermal-constant system for SCM development. They found that 722 Fahrenheit day-degrees (threshold of development 50°F) were required for emergence of first-generation adults, with 46, 236, and 287 required for egg, larval, and pupal development, respectively. In Iowa, larvae of the first SCM generation, after oviposition by the overwintered generation, pose an early season problem from mid- to late May. The first-generation adults emerge in early to mid-June.

Other studies on SCM biology have emphasized ovipositional preferences. Barlow (1965) reported that females were most stimulated to oviposit on moist soil. Oviposition also was stimulated by moist peas, even when they were below the soil surface. Ibrahim and Hower (1979) showed that oviposition was stimulated by newly emerged soybean seedlings.

Reid (1936) reported that the most severe SCM infestations occurred in soils containing the greatest quantity of decaying vegetation. Miller and McClanahan (1960) noted that severe infestations of SCM in southwestern Ontario occurred in fields associated with decaying crop residue. Recently, these observations have led to the hypothesis that decaying organic matter from crop residues in reduced-tillage systems provide an ideal site for SCM oviposition (Gregory and Musick 1976).

In recent years, interest in reduced-tillage production has increased in Iowa. In 1970, there were 29,206 ha under chisel-plow systems, 85,874 ha under till-plant systems, and 20,976 ha under no-till systems. In 1980, there were 2,682,369 ha under chisel-plow systems, 107,453 ha under till-plant systems, and 45,178 ha under no-till systems (USDA, Soil Conservation Service, Des Moines, Iowa). This large increase in Iowa reduced-tillage production has generated considerable concern about insect control. Many growers are slow to adopt reduced-tillage practices because of this concern.

Therefore, the main objective of this study was to investigate the potential of SCM problems in reduced-tillage soybean systems. Specific objectives were two-fold. First, SCM emergence from 4 soybean tillage systems (fall chisel plow, fall moldboard plow, no-tillage, and till-plant) was investigated to determine and contrast SCM incidence during germination in these systems. Second, the relationships between residue cover, weed cover, soil moisture, and SCM emergence were determined to evaluate factors responsible for SCM oviposition.

MATERIALS AND METHODS

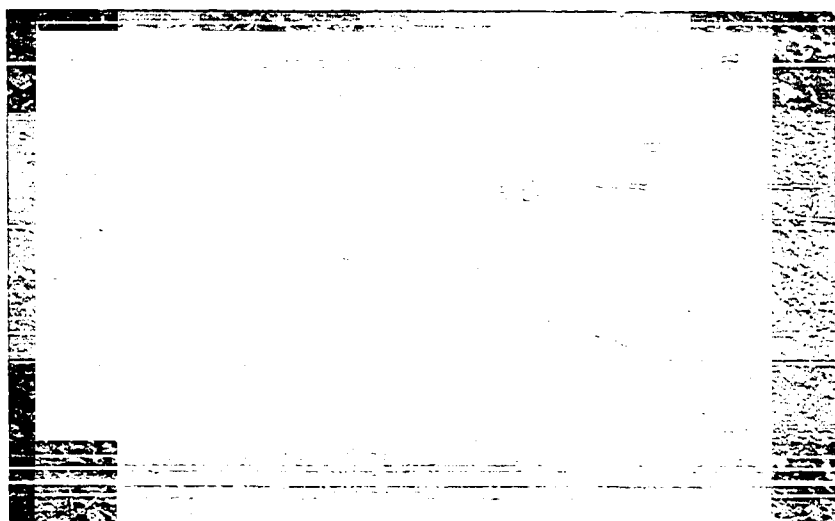
A sampling program was established to obtain absolute population estimates of the SCM in 0.405-ha soybean plots (var. Vickery) located at the Northeast Iowa Research Center near Nashua. Tillage treatments were fall moldboard plow, fall chisel plow, no-tillage, and till-plant. The plots were a corn/soybean rotation, which is the typical production practice for these crops in Iowa. Tillage operations for each of the systems were the following:

- (1) Fall moldboard plow. The land was moldboard-plowed in the fall. Spring seedbed preparations were made with a tandem disk harrow and a spike-tooth drag harrow.
- (2) Fall chisel plow. The land was chisel plowed in the fall. The seedbed was prepared with a tandem disk harrow.
- (3) No-tillage. Soybeans were planted by using a planter with rolling coulters in front of the disk openers.
- (4) Till-plant. Ridges were rebuilt during the previous year. Soybeans were planted with a Buffalo® till planter.

Each system was cultivated twice during the growing seasons because the till-plant system needed 2 cultivations to rebuild the ridges. The plots were arranged in a randomized complete block design and replicated 3 times. These tillage plots were established in 1977.

Sampling was conducted with traps designed to capture emerging adults (Figure 1). An emergence trap was designed and constructed, which gave absolute population estimates of the number of maggots present

Figure 1. Emergence trap for seedcorn maggot adults emerging from the soil



during soybean germination. For each trap, a galvanized, 30-gauge steel sheet (1.2 x 0.4 m) was bent and the sides riveted to make a rectangular, bottomless box with the following dimensions: length 1.0 m, width 0.2 m, and height 0.1 m. The interior was painted black. A 5-cm-diam hole was drilled 0.3 m from each end, and a Mason® jar band riveted flush to the top, directly over the hole. The trap was then placed over its selected area, and soil banked lightly against the exterior sides; 0.25-liter Mason jars with Tack Trap® applied to the inside bottom were screwed into the bands. This allowed for removal and replacement of jars for sampling the positively phototactic seedcorn maggot adults.

In 1979, 13 such traps were randomly placed over the soybean rows (covering 1 m) in each plot. In 1980 and 1981, 30 randomized locations were selected, 15 over soybean rows and 15 in between-row areas. The between-row traps were used to provide additional information on the biology and ovipositional preferences of the SCM. In all years, SCM emergence was determined by counting and removing flies from each trap every 3 days.

Emergence traps were placed in the plots 5 days after soybean planting in 1979 and 1980 (May 25 and 20, respectively) and 4 days after planting in 1981 (May 18). Because egg incubation ranges ca. 1-3 days (Strong and Apple 1958), SCM developing from eggs laid up to the time traps were placed in the plots were potentially damaging to the emerging soybeans (emergence period 8-10 days). Subsequently, any adult SCM emerging in the traps 287 day-degrees (ca. 12-15 days) after placement were in the damaging larval stage during soybean germination.

In 1980 and 1981, soil tests were made immediately following planting. Percentage soil moisture was determined by taking 2 core samples (3.81-cm diam x 4.5-cm depth) at each trap site, sealing them in plastic bags, and returning them to the laboratory for subsequent weighing, drying, and data calculations.

Percentage weed and residue cover also were quantified at each trap location immediately after planting. For these data, a 1 x 0.2-m Plexiglass® sheet (emergence trap dimensions) with 100 systematically-arranged holes was used. The sheet was located where the emergence trap would subsequently be placed, and the number of holes with sighted residue and weed cover was recorded.

Soil temperatures at the 6.4-cm soil depth were recorded in an area adjacent to the plots. When ca. 722 day-degrees had accumulated (569 occurring since trap placement), adult emergence was believed complete.

RESULTS AND DISCUSSION

The cost of each trap was ca. \$2.20, and the time to construct ca. 0.2 man-hr/trap. Table 2 contains means of total SCM emergence per trap along with relative variation (RV) $[(SE/\bar{x}) \cdot 100]$ of each mean of transformed data $(\log (\text{total emergence} + 1)/\text{trap})$. Emergence in the traps was least in 1981 and greatest in 1980. The RV values were used to determine sample variability and to evaluate the feasibility of the trapping method for determining absolute population estimates. Mean RV by tillage treatment in 1979 was 15.2. Increasing the number of traps in 1980 and 1981 reduced mean RV to 7.0 and 11.9, respectively. Southwood (1978) stated that a value of ca. 10 is sufficient for most intensive sampling programs. Therefore, the relative variation values for 1980 and 1981 were considered acceptable for the sampling program.

Analyses of variance (Table 3) were conducted on total adult emergence transformed to common logarithms $(\log (\text{total emergence} + 1) / \text{trap})$ in 1979, 1980, and 1981. Differences of SCM emergence between tillage treatment were not significant in 1979 ($F_{3,6} = 3.65$). Tillage treatment differences were highly significant in 1980 and 1981 ($F_{3,6} = 15.8$ and 20.5, respectively; $P < 0.001$). Orthogonal comparisons were used to define these tillage treatment differences. Emergence in the fall chisel-plow plots was greater than emergence in all 3 other tillage systems in 1980 and 1981 ($F_{1,6} = 31.1$ and 60.5, respectively; $P < 0.001$). Further, SCM emergence in the till-plant plots was considerably greater than in the no-till and fall moldboard-plow plots in 1980 ($F_{1,6} = 14.6$; $P < 0.01$). This difference was not significant in 1981 ($F_{1,6} = 3.8$).

Table 2. Mean number and relative variation of total seedcorn maggot emergence in conventional and reduced-tillage soybean plots near Nashua, Iowa, in 1979, 1980, and 1981

Year	Treatment	N	Mean no./ 1-m row	RV ^a
1979	Till-plant	39	1.87	13.9
	No-till	39	6.03	11.3
	Fall Moldboard Plow	39	2.23	20.0
	Fall Chisel Plow	39	1.74	15.6
1980	Till-plant	79 ^b	5.57	5.9
	No-till	72	2.85	9.3
	Fall Moldboard Plow	68	3.28	8.2
	Fall Chisel Plow	63	8.27	4.7
1981	Till-plant	90	1.51	6.9
	No-till	90	0.78	17.6
	Fall Moldboard Plow	90	0.78	11.8
	Fall Chisel Plow	90	4.79	11.1

^aRelative variation of transformed data ($\log(\text{total emergence} + 1)/\text{trap}$).

^bLess than 90 traps/treatment in 1980 because of loss of 72 traps from extremely high winds on May 28.

Table 3. Analyses of variance and orthogonal comparisons showing effects of tillage treatment in 1979 and effects of tillage treatment, trap placement, and tillage treatment x trap placement interaction in 1980 and 1981 on seedcorn maggot emergence ^a

Source	1979			1980			1981		
	df	MS	F-value	df	MS	F-value	df	MS	F-value
Replication	2	1.09	4.68	2	0.15	0.96	2	0.18	2.31
Tillage treatment	3	0.85	3.65	3	2.53	15.8***	3	3.43	20.5***
Fall chisel plow vs. till-plant, no-till, and fall moldboard plow				1	4.98	31.1***	1	9.68	60.5***
Till-plant vs. no-till and fall moldboard plow				1	2.34	14.6**	1	0.60	3.8
No-till vs. fall moldboard plow				1	0.13	0.8	1	0.00	0.0
Replication x tillage treatment ^b	6	0.23		6	0.16		6	0.16	
Trap placement				1	0.64	10.2*	1	0.00	0.0
Tillage treatment x trap placement				3	0.13	2.1	3	0.59	1.0
Error ^c				8	0.063		8	0.060	

^aTransformed to $(\log(\text{total emergence} + 1)/\text{trap})$.

^bUsed as error for testing effects of tillage treatment.

^cUsed as error for testing effects of trap placement and tillage treatment x trap placement interaction.

*Significant at 5% level.

**Significant at 1% level.

***Significant at 0.1% level.

SCM emergence in the fall moldboard-plow and no-till plots was similar in 1980 and 1981 ($F_{1,6} = 0.80$ and 0.00 , respectively).

Table 4 contains means of total SCM emergence per trap according to trap placement along with the RV of each mean of transformed data ($\log(\text{total emergence} + 1)/\text{trap}$). Mean RV by trap placement (within row and between row) within tillage treatment in 1980 and 1981 was 10.6 and 16.4 , respectively.

Although greater numbers of adults emerged from within-row compared with between-row areas in 1980 ($F_{1,8} = 10.2$; $P < 0.05$), this difference was very small compared with differences of emergence between tillage treatments. In 1981, emergence was similar in between-row and within-row areas ($F_{1,8} = 0.00$). The similar numbers present in within-row and between-row areas in all tillage treatments suggest that the species is primarily saprophytic and that germinating soybeans are not highly attractive to ovipositing females under field conditions. The tillage treatment x trap placement interaction was not significant in 1980 or 1981 ($F_{3,8} = 2.1$ and 0.59 , respectively).

Because of the time required for pupal development, adults emerging 287 day-degrees after initial trap placement were potentially damaging larvae during soybean germination. In all 3 years, most of the emergence did occur after 287 day-degrees had accumulated. In 1979, 1980, and 1981, ca. 65, 66, and 56% of the total emergence occurred during this period, respectively. These results show that typical Iowa soybean planting dates correspond well with the most potentially damaging period of first-generation SCM development.

Table 4. Mean total seedcorn maggot emergence, mean percentage residue cover, and mean percentage soil moisture by tillage treatment and trap placement in conventional and reduced-tillage soybean plots near Nashua, Iowa, in 1980 and 1981

Year	Treatment	Placement	N	Emergence		Residue Cover		Soil Moisture	
				Mean no./1-m	RV ^a	Mean percentage	SE	Mean percentage	SE
1980	Till-plant	Within-row	41	5.80	8.7	17.5	1.4	12.1	0.3
		Between-row	38	5.32	9.0	86.0	2.7	14.0	0.5
	No-till	Within-row	34	3.03	13.3	44.4	5.0	12.6	0.5
		Between-row	38	2.68	14.6	80.9	4.4	14.0	0.6
	Fall Mold-board Plow	Within-row	33	4.15	10.2	3.9	0.8	7.0	0.3
		Between-row	35	2.46	15.0	5.9	1.0	5.8	0.4
	Fall Chisel Plow	Within-row	32	9.19	5.4	32.6	3.6	8.3	0.6
		Between-row	31	7.32	8.8	41.4	4.3	7.9	0.5
1981	Till-plant	Within-row	45 (36) ^b	1.29	16.7	13.6	1.1	16.9	0.7
		Between-row	45 (42)	1.73	16.7	85.1	2.6	14.0	0.6
	No-till	Within-row	45 (37)	0.78	16.7	65.8	3.9	12.7	0.4
		Between-row	45 (36)	0.78	18.8	86.7	1.9	11.2	0.4
	Fall Mold-board Plow	Within-row	45 (41)	1.00	20.0	5.4	0.6	11.7	0.6
		Between-row	45 (31)	0.56	21.4	5.4	0.8	10.4	0.7
	Fall Chisel Plow	Within-row	45 (45)	5.49	8.6	27.5	2.0	11.3	0.4
		Between-row	45 (45)	4.09	11.9	18.7	1.1	12.1	0.4

^aRelative variation of transformed data ($\log (\text{total emergence} + 1)/\text{trap}$).

^bNumber of soil moisture samples because of destruction of 47 preceding data calculation.

Mean percentage residue cover and standard error by tillage treatment and trap placement (Table 4) were similar in 1980 and 1981. As expected, residue cover was very small in the fall moldboard-plow system (<6%) in between-row and within-row areas. Residue cover also was similar in between-row and within-row areas of the fall chisel-plow system. It ranged from ca. 20-40% in these plots, with considerably less residue on the surface in 1981 compared with 1980. Greater residue was present in between-row areas compared with within-row areas of till-plant and no-till systems. Between-row areas in the no-till plots were greater than 80% covered while within-row areas were ca. 44% and ca. 66% covered in 1980 and 1981, respectively. In the till-plant plots, residue cover was ca. 15% in within-row areas and ca. 85% in between-row areas in both years.

Mean percentage soil moisture and standard error by tillage treatment and trap placement are contained in Table 4. Differences between tillage treatments were largest in 1980, probably because of drier conditions that year compared with 1981. In 1980, results for soil moisture between tillage systems and trap placements were similar to results for surface residue. Percentage soil moisture was similar in between-row and within-row areas of the fall moldboard-plow and fall chisel-plow plots. It was higher in between-row compared with within-row areas of the no-till and till-plant plots. No large differences by tillage system or trap placement were found in 1981.

In 1980 and 1981, stepwise regressions were used to determine relationships between percentage soil moisture, percentage residue cover,

and total SCM emergence at each trap location. Variables regressed on total SCM emergence were percentage residue cover, percentage soil moisture, percentage soil moisture x percentage residue cover, percentage residue cover squared, and percentage soil moisture squared. An arcsine transformation was used to normalize percentage data for analyses. Percentage weed cover was not included in the stepwise regressions, because it did not exceed 1.7% in any plot in any year. These low percentages at planting time did not warrant further investigations of weed cover as a factor influencing SCM oviposition. Percentage residue cover and percentage residue cover squared were significant in both years. However, these variables explained, at best, 8% of the variation (as noted by r^2 -values) in these relationships, and residue cover therefore was rejected as an important factor influencing oviposition and development.

Similar stepwise regressions were used to investigate the relationships between mean total SCM emergence, mean percentage residue cover, and mean percentage soil moisture by trap placement, tillage treatment, and replication. No variables were found to satisfy the requirements of at least a 5% significance level.

These results strongly indicate that corn residue had little influence on SCM oviposition and development. Perhaps most convincing were the similar SCM numbers emerging from between-row and within-row areas of the till-plant and no-till plots, which had very different amounts of surface corn residue. In this study, surface soil moisture had no effect on the numbers of emerging SCM.

Consequently, it is believed that the numbers of surviving SCM were dependent upon the tillage practices employed. Soybeans grown under a fall chisel-plow system showed the greatest potential for SCM problems when compared with soybeans grown in till-plant, no-till, and fall moldboard-ploy systems. The till-plant system showed a greater potential for SCM problems than did no-till and fall moldboard-pow systems, which were essentially equal. Surface corn residue and soil moisture, which vary considerably by tillage systems, were not believed important in influencing SCM oviposition and development. The reasons for differences in SCM survival according to tillage treatment remains unexplained.

In-field emergence suggests that females were not attracted for oviposition to areas of germinating soybeans. Although soybean planting dates in each year of the study corresponded with the most potentially damaging period of first-generation SCM development, numbers present were not economically damaging in any tillage system. Because it is expected that the SCM can survive as a saprophyte, considerably greater numbers must be present to cause economic damage than previously believed.

PART II: EFFECTS OF ACTUAL AND SIMULATED SEEDCORN MAGGOT DAMAGE
ON SOYBEAN GROWTH AND YIELD

ABSTRACT

Interactive damage effects of stand loss and plumule abscission from seedcorn maggot, Hylemya platura (Meigen), on soybean (Amsoy 71) growth and yield were investigated by using actual- and simulated-damage methods. Stand reduction affected seed yield more than the presence of surviving seedlings without plumules. Over all years, seed yields were greatest at 29.7 plants per 1-m row. At all plant stands, the seedlings without plumules were shorter and produced less leaf area, fewer flowers, and fewer pods than did normal plants. This retarded growth reduced leaf area index, flowers per unit area, and pods per unit area. The decrease in pods per unit area was accompanied by an increase in beans per pod. When some of the surviving seedlings lacked plumules, seed yields were reduced at poor plant stands in some years. Plant-growth characteristics were very similar for actual and simulated damage. Seed-yield comparisons between actual and simulated damage suggested that seedcorn maggot injury to cotyledons had a small, negative effect on seed yield.

INTRODUCTION

Adult seedcorn maggots (SCM), Hylemya platura (Meigen), are common throughout the spring in Iowa. The larvae can survive as soil saprophytes, but feed readily on soybeans planted in infested soil. They feed on the cotyledons and plumules of germinating seedlings, resulting in poor plant stands and damaged plants (Figure 2). Snakeheads (seedlings with plumules consumed) respond by producing a branch at each cotyledonary node (Figure 3).

Some stand reduction from SCM attack usually is not believed to substantially reduce yield because soybeans produce optimal yields over a wide range of plant density. Cartter and Hartwig (1963) surveyed the numerous studies concerning soybean plant density and determined that greatest yields were obtained from seeding rates of ca. 20-39 plants per 1-m row. Lodging often was a problem at populations exceeding 39 plants per 1-m row, and populations below 20 plants per 1-m row often produced less yield than did greater stand densities, but factors other than yield were important. For instance, stands with fewer than 30 plants per 1-m row were reported less competitive, resulting in greater weed problems (Hartwig 1957, Johnson and Harris 1967, Leffel and Barber 1961).

A study conducted by Weber and Caldwell (1966) demonstrated that cotyledon damage did not greatly affect soybean yield. Removing a cotyledon at emergence did not influence yield, although removing both cotyledons reduced yields 8.5%.

Figure 2. Soybean seedling with seedcorn maggot injury to the cotyledons

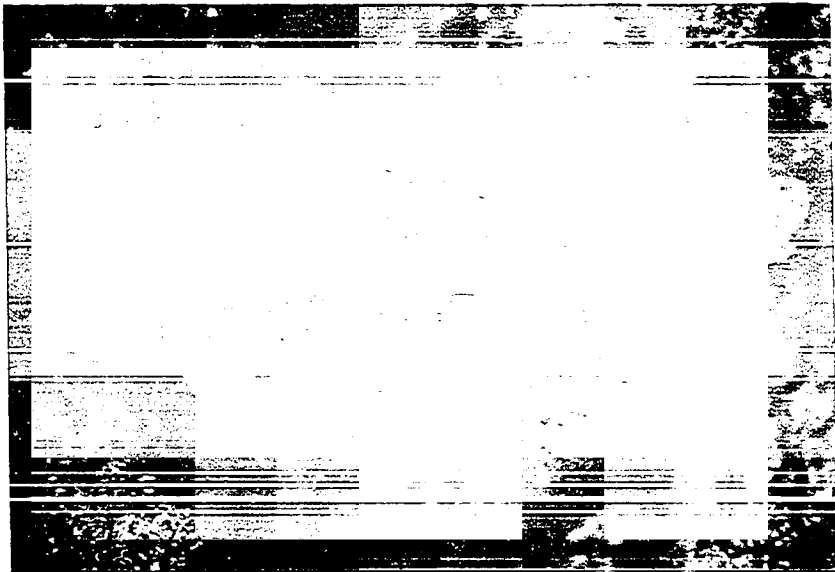


Figure 3. Typical snakehead soybean plant with a branch arising from each cotyledonary node



The major objective of the present study was to investigate soybean responses to SCM injury. Therefore, interactive effects of plant stand and snakehead presence on soybean growth and yield were determined. Another objective was to contrast soybean growth and yield response to actual and simulated SCM injury.

MATERIALS AND METHODS

Effects of SCM damage on Amsoy 71 soybean growth and yield were investigated by using actual and simulated methods in 1979, 1980, and 1981 near Ames, IA. Methodology used to establish actual- and simulated-damage plots was not similar; therefore, the trials were conducted each year as separate experiments. Soil type of plots was a Nicollet-Webster complex in 1979 and Coland clay loam in 1980 and 1981.

Covering knives and dragchains were removed from a 2-row John Deere Flex® Planter, and the presswheels were used to make shallow furrows. To enhance SCM oviposition, meat and bonemeal were applied in the furrows (12/5-m row) 3-5 days preceding planting. Soybeans then were planted in the baited furrows on May 14, 1979; June 9, 1980; and May 7, 1981 (76-cm row spacing). Treatment and border rows were seeded at the rates of ca. 52 and 29 viable seeds per 1-m row, respectively. Methodology was the same in the simulated-damage experiments, except that meat and bonemeal were not applied in the furrows.

Experimental design was a randomized complete block, with the simulated-damage experiments replicated 5 times in all years and the actual-damage experiments replicated 3 times in 1979 and 4 times in 1981. The actual-damage experiment was not successful in 1980 because of inadequate SCM damage. Plot size for the actual- (1979 and 1981) and simulated- (1979 and 1980) damage experiments was 1 row x 9 m, with all plots separated by 1 border row. Plot size for the 1981 simulated-damage experiment was 3 rows x 9 m. Treatments in the simulated-damage

experiments were a factorial arrangement of 5 plant (10.0, 19.7, 29.7, 39.3, and 49.3 plants per 1-m row) and 4 snakehead (0, 3.3, 6.7, and 10 snakeheads per 1-m row) densities. Treatments in the actual-damage experiments were the same, except for those at the greatest plant density. (No plots contained 49.3 plants per 1-m row because of stand reduction from SCM injury.)

After emergence, the appropriate plant and snakehead densities were established for each plot. In the simulated-damage experiments, excess plants were removed by thinning, and plumules were abscised with fine-pointed forceps to produce snakeheads. In the actual-damage experiments, treatments were situated within a row such that they contained the appropriate plant and snakehead density (small excesses of normal and snakehead plants removed by thinning). All treatments could not be replicated 4 times in the 1981 actual-damage experiment, so treatments containing 3.3 and 6.7 snakeheads per 1-m row were replicated 3 times. In both experiments, plots were rechecked after ca. 10 days and again after ca. 20 days to remove late-germinating soybeans.

Each 1-row x 9-m plot in the actual- (1979 and 1981) and simulated- (1979 and 1980) damage experiments was divided into 3 3-m sections. The middle row of each plot in the 1981 simulated-damage experiment was divided similarly. The inner 3-m section was used for final plot harvest in all years. The outer 3-m sections of 4 replications were used for plant measurements in the 1981 actual- and simulated-damage experiments. These plant measurements were taken in treatments containing 0 and 10 snakeheads per 1-m row. On each sample date (growth

stages V6, R2, R4, R6, and R8), random sampling consisted of at least 2 normal (treatments containing 0 and 10 snakeheads per 1-m row) and 2 snakehead (treatments containing 10 snakeheads per 1-m row) plants per plot. Height (ground level to growing point), number of nodes, leaf area, number of flowers, and number of pods were determined for each plant. At harvest, additional determinations were made on each plant of beans per pod, total bean wt, and seed size (wt/100 seeds). Soybean stages and number of nodes were determined as described by Fehr and Caviness (1977). Leaf areas were determined using a Li-Cor® Portable Area Meter. Plots were hand-harvested (September 26, 1979; October 7, 1980; and September 24, 1981) and threshed using an Almaco® Low Profile Plot Thresher. Rainfall data were obtained from a nearby NOAA recording station.

RESULTS AND DISCUSSION

Total precipitation from May through September, deviated +23.2, -13.1, and -13.6 cm from normal for 1979, 1980, and 1981, respectively. Rainfall in 1979 was near normal except for a very wet August. Although total rainfall over the growing season was similar in 1980 and 1981, rainfall patterns were different. In 1980, rainfall was moderately below normal from May through late July and normal for August and September. In 1981, the rainfall deficit was severe from May through late June, with a moderate deficit through July. Precipitation was above normal for the remainder of the growing season.

Table 5 contains mean seed yield (adjusted to 13% moisture) by year, plant density, and snakehead density in the actual- and simulated-damage experiments. These results were evaluated by using analyses of variance and orthogonal treatment comparisons. The effects of plant population were significant in the 1979, 1980, and 1981 simulated-damage experiments ($F_{4,76} = 14.3, 10.2, \text{ and } 7.8$, respectively; $P < 0.001$). Mean seed yields at 49.3, 39.3, and 29.7 plants per 1-m row in 1979 and 1980 were greater (23.7 and 9.2%, respectively) than those at fewer plants per 1-m row ($F_{1,76} = 45.8 \text{ and } 27.1$, respectively; $P < 0.001$). Seed yields were similar at 49.3, 39.3, and 29.7 plants per 1-m row ($F_{1,76} = 3.3 \text{ and } 0.1$ for 1979 and 1980, respectively). Also in 1979 and 1980, seed yields were greater (16.2 and 10.4%, respectively) at 19.7 plants per 1-m row than at 10.0 plants per 1-m row ($F_{1,76} = 7.7 \text{ and } 13.0$, respectively; $P < 0.01 \text{ and } 0.001$, respectively). Results in the 1981

Table 5. Seed yield (g/3-m plot) by plant and snakehead density of actual- and simulated-damage experiments conducted near Ames, IA, in 1979, 1980, and 1981

Total no. plants/1-m row	Actual Damage					Simulated Damage				
	Density Snakeheads (no./1-m row)					Density Snakeheads (no./1-m row)				
	0	3.3	6.7	10.0	Avg.	0	3.3	6.7	10.0	Avg.
1979										
10.0	413.1	430.5	481.4	401.3	431.6	573.9	428.9	518.1	471.1	498.0
19.7	626.0	465.7	518.7	460.8	517.8	674.4	533.0	544.7	564.1	579.0
29.7	674.7	596.4	628.0	472.0	592.8	627.8	702.7	590.6	620.1	635.3
39.3	616.2	564.3	607.8	610.6	599.7	703.7	671.1	664.2	661.5	675.1
49.3	-----	-----	-----	-----		682.4	684.3	667.1	716.7	687.6
Avg.	582.5	514.2	559.0	486.2		652.5	604.0	597.0	606.7	
1980										
10.0						744.2	660.0	646.4	637.1	671.9
19.7						758.4	746.0	780.3	683.0	741.9
29.7						783.2	784.3	756.5	760.7	771.2
39.3						735.2	783.2	722.0	813.1	763.5
49.3						758.8	806.6	781.3	778.8	781.4
Avg.						755.9	756.2	737.3	734.5	
1981										
10.0	848.9	845.7	872.4	916.7	870.9	938.5	975.6	885.1	949.7	937.2
19.7	887.9	874.1	924.7	987.6	918.5	970.3	941.4	880.6	881.1	918.4
29.7	857.8	883.4	883.4	832.4	864.3	857.7	859.8	902.2	912.9	883.2
39.3	900.8	783.7	838.3	917.9	860.2	777.9	794.3	839.5	906.4	829.6
49.3	-----	-----	-----	-----		749.5	875.8	767.7	818.1	802.8
Avg.	873.9	846.7	879.7	913.7		858.8	889.4	855.0	893.7	

simulated-damage experiment were very different. Lodging was severe at the greater plant densities, and, consequently, mean seed yield was 10.6% greater for 19.7 and 10.0 plants per 1-m row than for 49.3, 39.3, and 29.7 plants per 1-m row ($F_{1,76} = 22.6$, $P < 0.001$). Seed yield at 29.7 plants per 1-m row was 8.2% greater than mean seed yield for 49.3 and 39.3 plants per 1-m row ($F_{1,76} = 7.1$, $P < 0.01$). Seed yields were similar at plant densities of 49.3 and 39.3 plants per 1-m row ($F_{1,76} = 0.9$) and at plant densities of 19.7 and 10.0 plants per 1-m row ($F_{1,76} = 0.4$).

Effects of plant population were significant in the 1979 actual-damage experiment ($F_{3,30} = 14.9$, $P < 0.001$). Results were similar to those in the 1979 simulated-damage experiment. Seed yields at 10.0 and 19.7 plants per 1-m row were 24.3 and 13.2% less, respectively, than mean seed yield at 29.7 and 39.3 plants per 1-m row ($F_{1,30} = 34.8$ and 9.9, respectively; $P < 0.001$ and 0.01, respectively). Seed yields were similar at 39.3 and 29.7 plants per 1-m row ($F_{1,30} = 0.1$). The effect of plant density was not significant in the 1981 actual-damage experiment ($F_{3,37} = 0.9$). Lodging was not severe, and seed yields were not decreased at densities greater than 19.7 plants per 1-m row. Otherwise, results were similar in the 1981 actual- and simulated-damage experiment.

In all experiments, plant density influenced seed yield more than did snakehead density. The main effects of snakehead density were not significant in the 1979, 1980, and 1981 simulated-damage experiments ($F_{3,76} = 3.1, 1.5$, and 1.8, respectively). However, plant x snakehead density interactions demonstrated that snakehead density affected

soybean seed yield. At 49.3, 39.3, and 29.7 plants per 1-m row, seed yields were similar over all snakehead densities in 1979 and usually greater when snakeheads were present in 1980 and 1981. At 19.7 and 10.0 plants per 1-m row, seed yields were less when snakeheads were present in 1979 and 1980 and similar over all snakehead densities in 1981. The differences in seed yield response by plant density at 0 and 10 snakeheads per 1-m row were significant in 1980 and 1981 ($F_{1,76} = 10.8$ and 5.4 , respectively; $P < 0.01$ and 0.05 , respectively) and approached the 0.05 significance level in 1979 ($F_{1,76} = 3.6$).

The main effect of snakehead density was significant in the 1979 actual-damage experiment ($F_{3,30} = 4.6$, $P < 0.01$). As in the 1979 simulated-damage experiment, seed yields usually were reduced when snakeheads were present. Unlike the 1979 simulated-damage experiment, these reductions were uniform over all plant densities. Seed yields were 19.8% less for treatments containing 10 snakeheads per 1-m row than for treatments containing no snakeheads ($F_{1,30} = 11.2$, $P < 0.01$). Differences in seed yield response between other snakehead densities were not significant. The main effect of snakehead density was not significant in the 1981 actual-damage experiment ($F_{3,37} = 0.4$). No plant x snakehead density interactions were found in the 1979 and 1981 actual-damage experiments ($F_{9,30} = 1.5$ and $F_{12,37} = 0.5$, respectively).

Height, node number, leaf area, flower number, and yield components of normal and snakehead plants were compared by using analyses of variance and orthogonal treatment comparisons. Height and node number at growth stage R8 (Figures 4 and 5, respectively) were similar to earlier growth

Figure 4. Height at full maturity by plant population of normal plants (normal A) in treatments containing no snakeheads and of normal (normal B) and snakehead plants in treatments containing 10 snakeheads per 1-m row of 1981 actual- and simulated-damage experiments conducted near Ames, IA

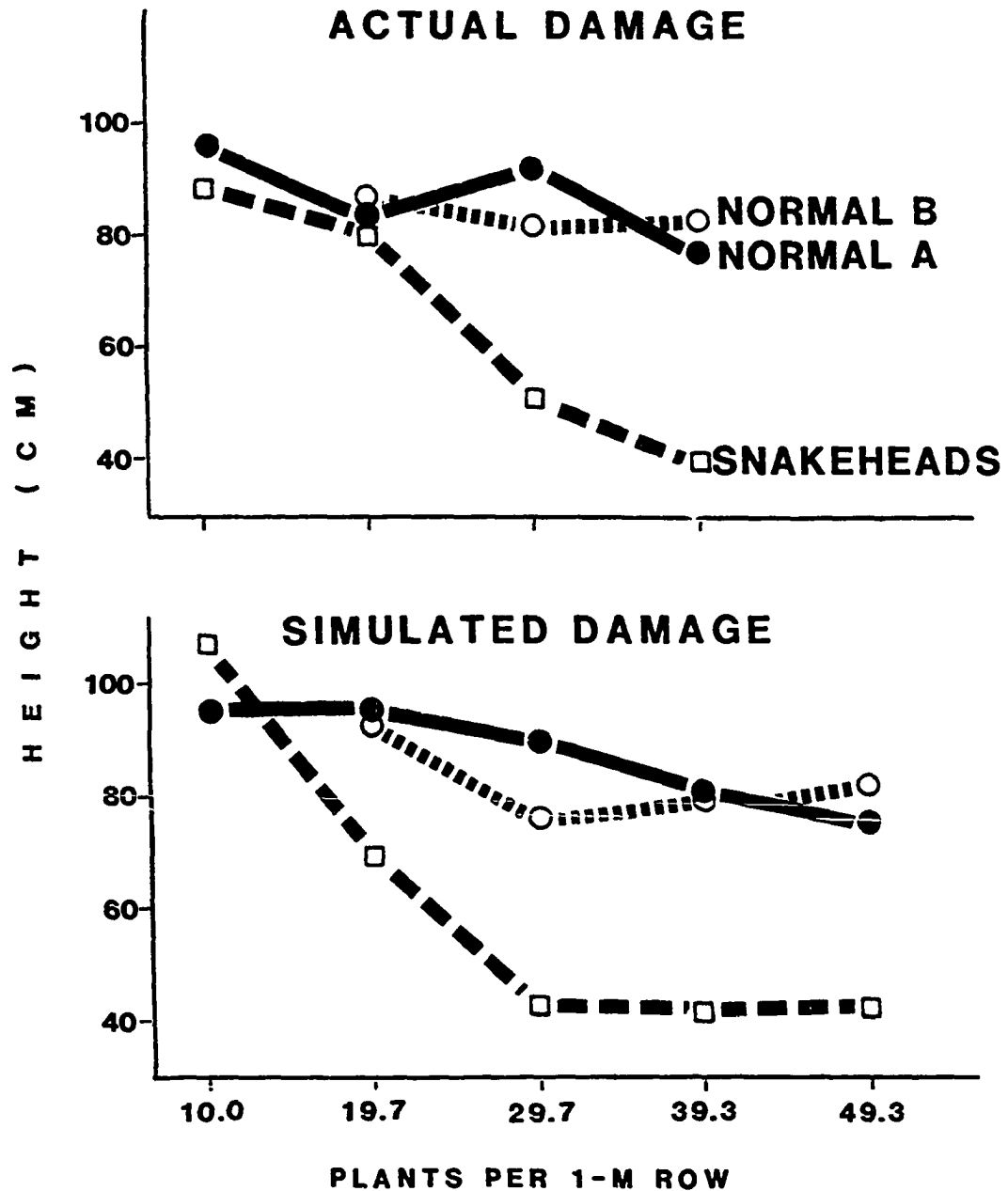
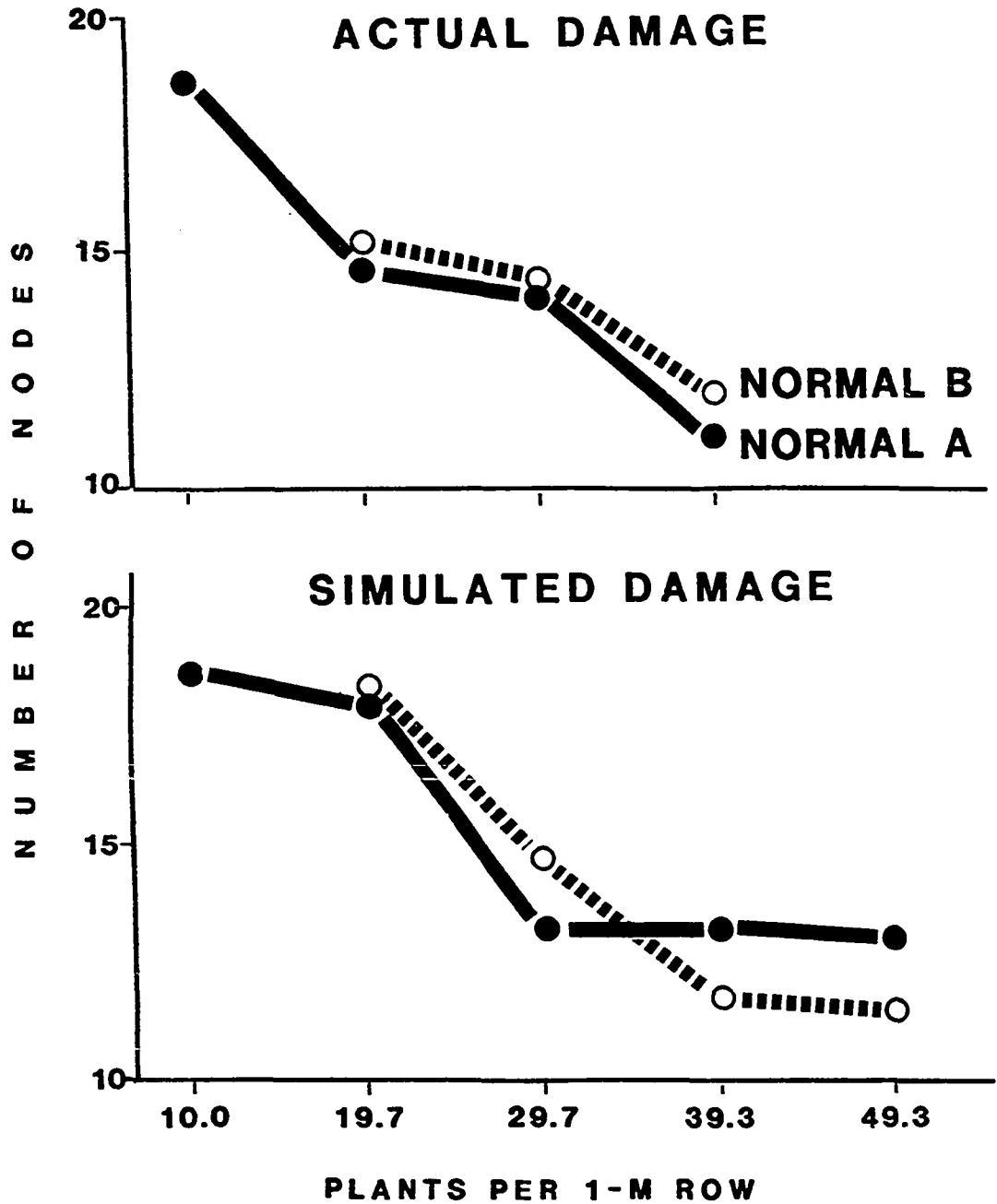


Figure 5. Number of nodes at full maturity by plant population of normal plants (normal A) in treatments containing no snakeheads and of normal plants (normal B) in treatments containing 10 snakeheads per 1-m row in 1981 actual- and simulated-damage experiments conducted near Ames, IA



stages. As plant density increased, normal plants decreased in height ($F_{3,9} = 4.5$ and $F_{4,12} = 4.2$ for actual- and simulated-damage experiments, respectively; $P < 0.05$) and node number ($F_{3,9} = 16.8$ and $F_{4,12} = 37.8$ for actual- and simulated-damage experiments, respectively; $P < 0.001$). Normal plants in treatments containing 0 and 10 snakeheads per 1-m row were similar in height ($F_{1,15} = 0.2$ and $F_{1,21} = 1.4$ for actual- and simulated-damage experiments, respectively) and node number ($F_{1,15} = 0.5$ and $F_{1,21} = 0.0$ for actual- and simulated-damage experiments, respectively). Snakeheads were shorter than normal plants at plant densities greater than 19.7 plants per 1-m row in the actual-damage experiment ($F_{1,21} = 69.3$, $P < 0.001$) and at plant densities greater than 10.0 plants per 1-m row in the simulated-damage experiment ($F_{1,27} = 82.9$, $P < 0.001$). However, normal and snakehead plants were similar in height at the other plant densities, as demonstrated by interactions of plant type x plant density ($F_{3,21} = 34.1$ and $F_{4,27} = 12.3$ for actual- and simulated-damage experiments, respectively; $P < 0.001$). Likewise, results were similar at growth stages R4 and R6. At growth stages V6 and R2, snakeheads were shorter than normal plants at all plant densities.

Table 6 contains mean leaf area for normal and snakehead plants according to plant density. At growth stages V6, R2, R4, and R6, leaf area was less for snakeheads than for normal plants at all plant densities in the actual- ($F_{1,21} = 32.6$, 31.0, 59.3, and 75.9, respectively; $P < 0.001$) and simulated- ($F_{1,27} = 67.4$, 78.2, 44.2, and 7.5, respectively; $P < 0.001$, 0.001, 0.001, and 0.01, respectively) damage experiments. On most sample dates in both experiments, leaf area was

Table 6. Mean leaf area and flowers for normal (treatments containing 0 and 10 snakeheads per 1-m row) and snakehead (treatments containing 10 snakeheads per 1-m row) soybeans by plant population in actual- and simulated-damage experiments, Ames, Iowa, 1981

Treatment	Plant Type	Mean Leaf Area (cm ²)/Plant					
		V6		R2		R4	
		A ^a	S	A	S	A	S
10 ^b - 0 ^c	Normal	776.8	935.4	2520.0	2495.0	3272.3	2287.1
10 - 10	Snakehead	535.8	548.5	1509.1	1631.9	2197.4	2522.3
19.7 - 0	Normal	516.0	680.9	1464.6	1781.9	1811.5	1916.0
19.7 - 10	Normal	580.0	549.4	1591.9	1887.8	1919.9	1780.3
	Snakehead	491.3	392.0	1024.8	766.6	1228.3	535.3
29.7 - 0	Normal	417.6	581.0	1096.2	1108.6	1285.5	1023.4
29.7 - 10	Normal	502.6	597.1	1100.6	1251.1	1048.9	954.3
	Snakehead	242.6	204.3	489.8	349.6	468.8	246.5
39.7 - 0	Normal	413.6	348.9	1078.4	526.6	1061.5	523.3
39.7 - 10	Normal	501.0	328.4	1175.3	703.9	972.3	598.4
	Snakehead	186.1	128.8	291.4	205.3	189.9	182.0
49.7 - 0	Normal		380.5		627.0		474.1
49.7 - 10	Normal		481.3		589.3		571.0
	Snakehead		134.0		147.6		115.3

^aA = Actual-damage experiment S = Simulated-damage experiment.

^bNo. total plants/1-m row.

^cNo. snakehead plants/1-m row.

		Mean No. Flowers/Plant			
R6		R2		R4	
A	S	A	S	A	S
3528.1	4117.3	56.6	54.6	89.7	100.9
2538.3	2691.4	25.5	23.8	50.9	67.0
1958.5	1625.4	33.8	43.4	56.0	56.6
2066.3	2693.4	34.9	48.0	59.6	63.0
846.0	726.3	21.3	11.3	44.1	18.5
1301.0	864.6	37.5	31.8	42.5	32.9
1576.0	1288.9	31.9	42.0	33.9	24.6
446.5	380.4	10.8	7.9	20.4	8.0
1208.3	789.8	23.9	11.3	29.8	25.9
1201.0	832.3	37.9	26.6	33.5	19.8
131.3	116.1	7.6	3.4	9.9	5.3
	499.0		24.8		17.4
	477.9		17.5		23.4
	80.3		2.5		3.8

similar for normal plants at each plant density in treatments containing 0 and 10 snakeheads per 1-m row. Only at stage R6 in the simulated-damage experiment was leaf area significantly greater for normal plants in treatments containing 10 snakeheads per 1-m row than for normal plants in treatments containing no snakeheads ($F_{1,21} = 21.0$, $\underline{P} < 0.001$). Mean leaf area index (LAI) (indicates the number of unit areas of leaf per unit area of ground surface) of growth stages V6, R2, R4, and R6 for treatments containing 0 and 10 snakeheads per 1-m row is shown in Figure 6. At all plant densities, mean LAI was significantly less for treatments containing 10 snakeheads per 1-m row than for treatments containing no snakeheads in the actual- and simulated-damage experiments ($F_{1,21} = 17.2$ and $F_{1,27} = 10.3$, respectively; $\underline{P} < 0.001$ and 0.01 , respectively). In the actual-damage experiment, LAI decreased as plant density decreased ($F_{3,21} = 11.8$, $\underline{P} < 0.001$). In the simulated-damage experiment, mean LAI was greatest at 29.7 and 19.7 plants per 1-m row ($F_{4,27} = 4.5$, $\underline{P} < 0.05$). Mean LAI was less at 49.3 and 39.3 plants per 1-m row because of lodging.

At growth stages R2 and R4, snakeheads had fewer flowers (Table 6) than normal plants at all plant densities in the actual- ($F_{1,27} = 25.6$ and 20.8 , respectively; $\underline{P} < 0.001$) and simulated- ($F_{1,27} = 105.9$ and 31.8 respectively; $\underline{P} < 0.001$) damage experiments. Except at the greater plant densities, mean flowers per unit area (Figure 7) was less for treatments containing 10 snakeheads per 1-m row than for treatments containing no snakeheads in the actual- ($F_{1,21} = 3.4$, $\underline{P} < 0.08$) and simulated- ($F_{1,27} = 19.5$, $\underline{P} < 0.05$) damage experiments. As with LAI

Figure 6. Mean leaf area index of 4 sample dates (growth stages V6, R2, R4, and R6) by plant and snakehead population in actual- and simulated-damage experiments, Ames, IA, 1981

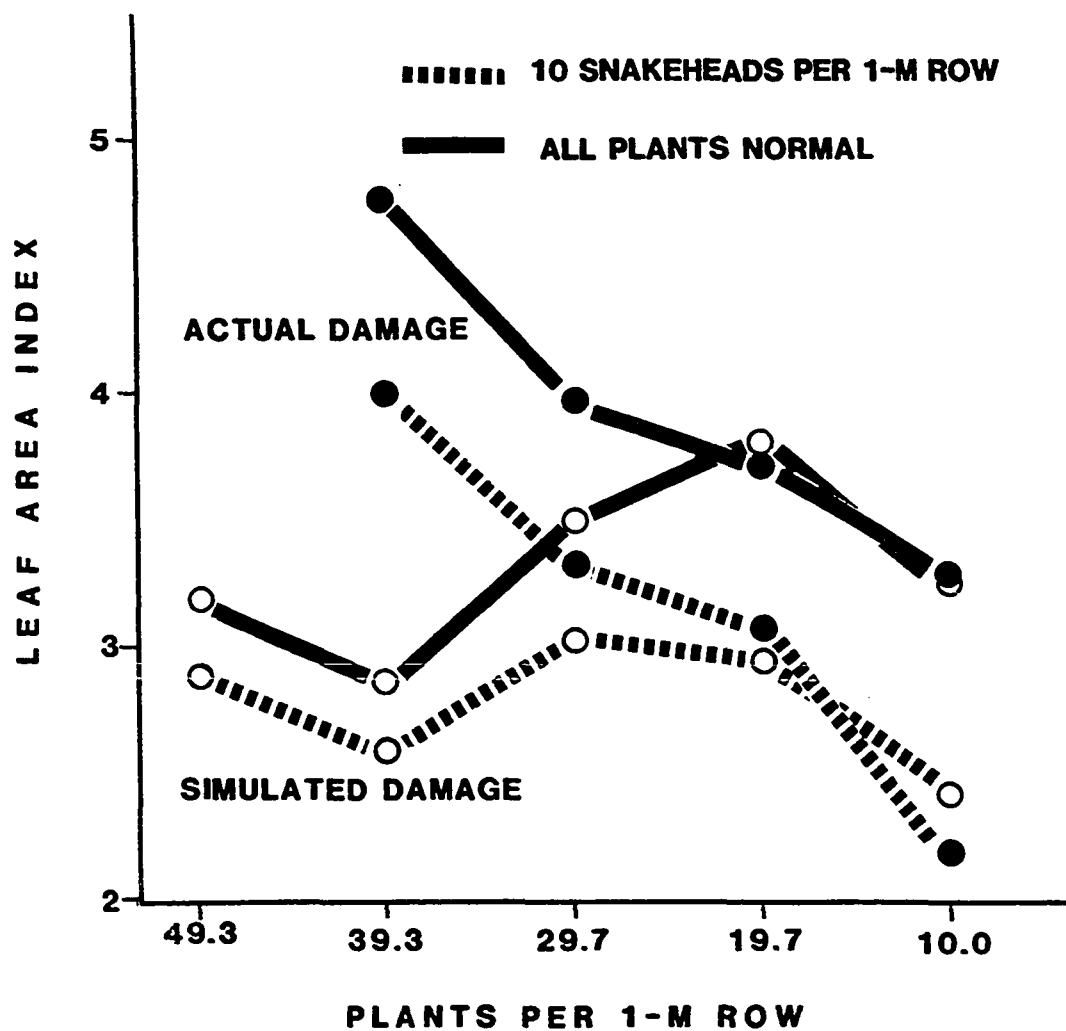
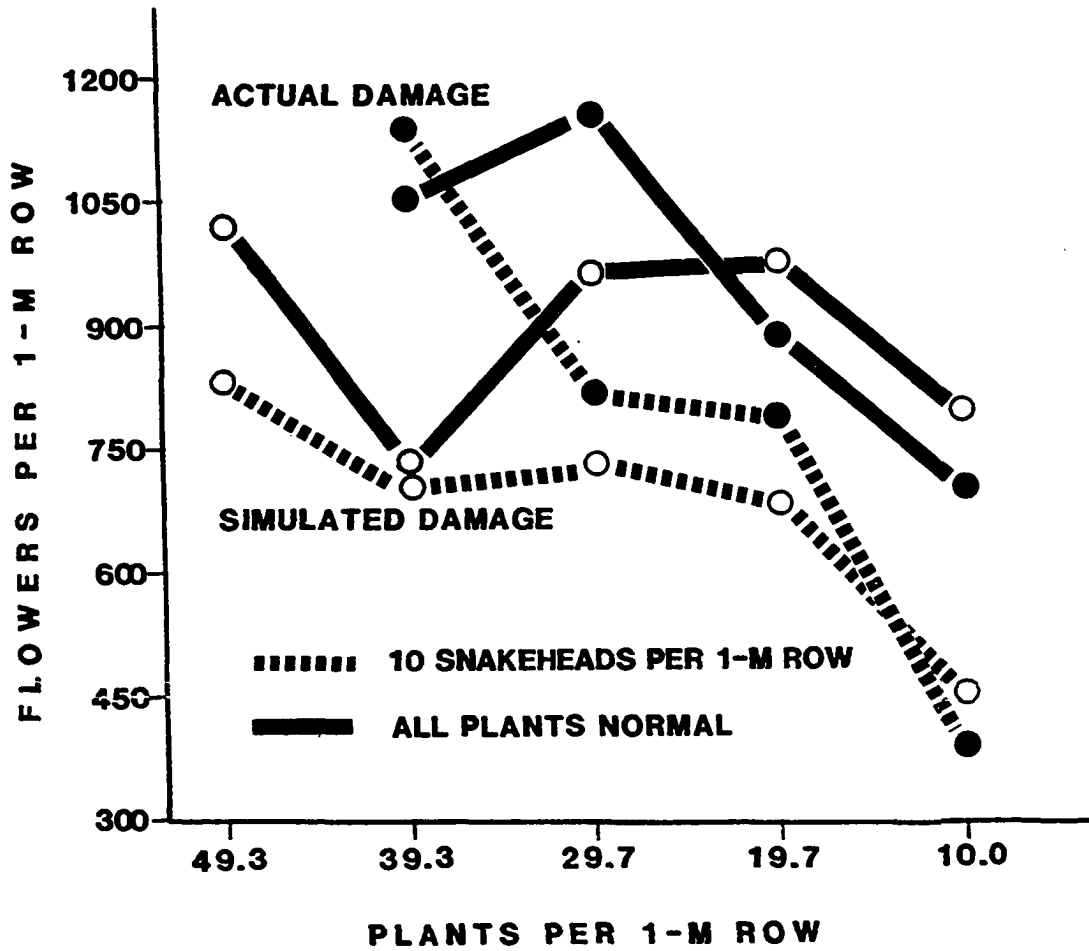


Figure 7. Mean no. flowers per 1-m row of 2 sample dates (growth stages R2 and R4) by plant and snakehead density in actual- and simulated-damage experiments, Ames, IA, 1981



and flowers per unit area, mean pods per unit area (Figure 8) was less for treatments containing 10 snakeheads per 1-m row than for treatments containing no snakeheads ($F_{1,21} = 15.3$ and $F_{1,27} = 20.8$ for actual- and simulated-damage experiments, respectively; $P < 0.001$).

Weight per 100 seeds (Table 7) was similar for normal plants at 0 and 10 snakeheads per 1-m row in the actual- and simulated-damage experiments ($F_{1,15} = 0.2$ and $F_{1,21} = 1.2$, respectively). Only at plant densities greater than 19.7 plants per 1-m row was seed size less for snakeheads than for normal plants in the actual- ($F_{1,21} = 3.4$, approaches 0.05 significance level) and simulated- ($F_{1,27} = 5.0$, $P < 0.05$) damage experiments. This reduction in seed size did not have a substantial impact on seed yield, because snakeheads produce practically no yield at greater plant densities (Table 7). Treatments containing 10 snakeheads per 1-m row had more beans per pod (Table 7) than treatments containing no snakeheads. At 19.7 and 10.0 plants per 1-m row in both experiments, beans per pod were greater for snakeheads than normal plants. At the greater plant densities in the simulated-damage experiment, normal plants in treatments containing 10 snakeheads per 1-m row had more beans per pod than did normal plants in treatments containing no snakeheads ($F_{1,21} = 6.1$, $P < 0.05$). This difference was not significant in the actual-damage experiment ($F_{1,15} = 0.1$).

Therefore, pods per unit area and beans per pod were altered by snakehead presence. In treatments containing 10 snakeheads per 1-m row in 1981, a decrease in pods per unit area was accompanied by an increase in beans per pod. Consequently, seed yields in 1981 were not reduced

Figure 8. Mean no. pods per 1-m row of 3 sample dates (growth stages R4, R6, and R8) by plant and snakehead density in actual- and simulated-damage experiments, Ames, IA, 1981

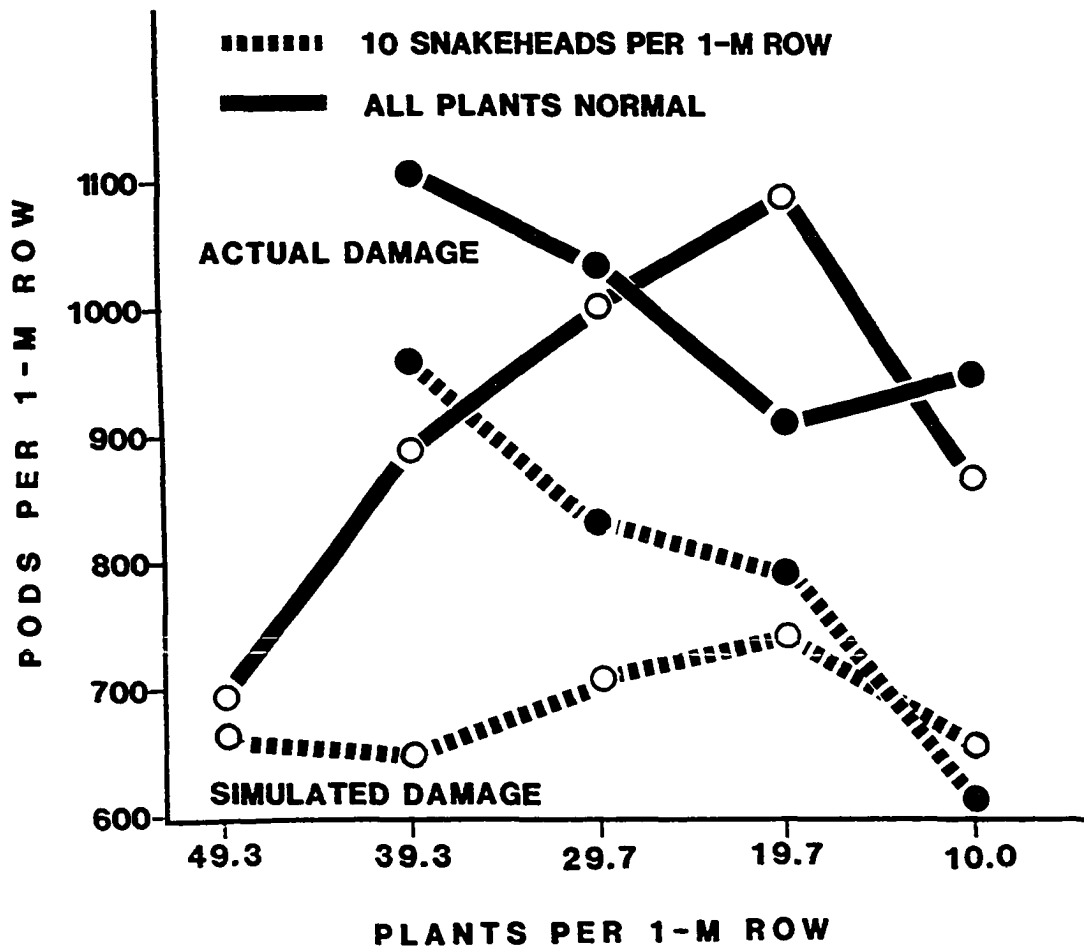


Table 7. Yield components for normal (treatments containing 0 and 10 snakeheads per 1-m row) and snakehead (treatments containing 10 snakeheads per 1-m row) soybeans by plant population in actual- and simulated-damage experiments, Ames, Iowa, 1981

Treatment	Plant Type	Mean No. Pods/Plant					
		R4		R6		R8	
		A ^a	S	A	S	A	S
10 ^b - 0 ^c	Normal	109.7	62.0	108.6	122.9	70.1	76.0
10 - 10	Snakehead	58.5	61.9	67.0	72.3	59.5	64.0
19.7 - 0	Normal	49.9	65.0	50.1	45.1	39.3	56.6
19.7 - 10	Normal	63.9	60.0	62.3	71.6	47.2	57.6
	Snakehead	32.9	12.5	18.8	15.6	27.6	11.5
29.7 - 0	Normal	42.4	38.0	36.4	32.6	27.3	31.1
29.7 - 10	Normal	35.0	34.9	51.5	37.6	28.1	25.6
	Snakehead	10.9	7.0	9.5	8.0	5.6	5.3
39.3 - 0	Normal	36.5	18.3	33.4	25.9	14.0	16.8
39.3 - 10	Normal	34.4	18.5	41.4	24.6	19.4	19.8
	Snakehead	3.8	3.9	2.5	2.6	2.0	3.8
49.3 - 0	Normal		11.4		15.8		15.1
49.3 - 10	Normal		16.6		13.3		19.1
	Snakehead		1.9		2.5		2.5

^aA = Actual-damage experiment S = Simulated-damage experiment.

^bNo. total plants/1-m row.

^cNo. snakehead plants/1-m row.

Mean No. Beans/ Pod		Mean Bean Wt/ Plant		Mean Wt/ 100 Seeds	
R8					
A	S	A	S	A	S
2.3	2.4	30.1	34.9	19.0	20.1
2.7	2.9	24.6	36.8	17.0	22.8
2.3	2.3	14.9	26.8	18.6	21.9
2.2	2.3	20.6	26.5	18.7	20.9
2.8	2.5	12.7	4.7	19.7	20.5
2.2	2.0	11.0	11.5	19.0	18.4
2.2	2.9	11.3	10.2	19.1	18.0
2.0	2.3	1.7	1.5	16.1	16.0
1.9	2.2	4.8	6.5	18.9	17.6
2.1	2.3	8.3	8.7	19.8	18.8
1.9	2.2	0.8	1.4	16.3	15.6
	2.1		4.9		17.6
	2.4		9.6		21.0
	1.9		0.9		14.1

in treatments containing snakeheads. At 19.7 and 10.0 plants per 1-m row in 1979 and 1980, seed yields were less in treatments containing 10 snakeheads per 1-m row than in treatments containing no snakeheads. Although yield components were not determined in those years, it can be hypothesized that increases, if any, in beans per pod did not fully compensate for decreases in pods per unit area.

SCM damage in the 1979 actual-damage experiment was great. Cotyledons of surviving soybeans were heavily damaged and, in many cases, completely abscised. The actual- and simulated-damage experiments were conducted separately and are not directly comparable. However, 1979 seed yields in the actual-damage experiment were 6% lower than in the simulated-damage experiment of the same year. SCM damage in the 1981 actual-damage experiment was light, and cotyledons were moderately damaged. In that year, seed yields in the actual-damage experiment were 1% lower than in the simulated-damage experiment. These results indicate that cotyledon feeding had a small effect on seed yield.

As expected, effects of plant population on soybean seed yield were variable over years. When rainfall was below normal in 1980 and 1981, seed yields were reduced at the greater plant densities, probably because of lodging and within-row plant competition for available moisture. Snakeheads were less competitive than normal plants, especially at greater plant densities. Therefore, seed yields often were better at plant densities greater than 29.7 plants per 1-m row when some of the plants were snakeheads. As in the only previous plant-population study involving Amsoy 71 soybeans (Cooper 1977), the

recommended seeding rate of 29.7 viable seeds per 1-m row gave the greatest seed yields over all years and experiments.

Except for 1981, seed yields were similar by year in the actual- and simulated-damage experiments. In 1981, lodging was severe at plant densities greater than 19.7 plants per 1-m row in the simulated-damage experiment, but not in the actual-damage experiment. This probably was not because of differences between actual and simulated damage. The actual-damage plots were protected from high winds (trees on 2 sides), but the simulated-damage plots were not. Plant-growth characteristics were similar at all plant densities for actual and simulated damage.

Although SCM damage studies previously have emphasized stand loss, results in this study demonstrated that a cryptic form of damage, i.e., surviving seedlings without plumules, also influenced soybean growth and yield. Both types of SCM damage are expected to interact with later-season stresses. For example, reductions in plant height and leaf area of snakeheads are expected to strongly affect the soybeans' competitive abilities with weeds. Therefore, stand density and the presence of snakeheads should be considered in soybean management decisions involving SCM damage.

CONCLUSIONS

Absolute population estimates of the seedcorn maggot with acceptable levels of precision for an intensive sampling program were obtained by using emergence trapping. This emergence-trapping method demonstrated that different numbers of seedcorn maggots were present during germination in conventional and reduced-tillage soybean systems. Emergence was greatest in the fall chisel-plow system, followed by the till-plant system. Emergence in the no-till and fall moldboard-plow systems was similar. Seedcorn maggot numbers present during germination in within-row and between-row areas in these tillage systems were similar, suggesting that germinating soybeans were not attractive for oviposition under field conditions. Further, surface corn residue and soil moisture, which differed considerably according to tillage practice, were not significant factors influencing seedcorn maggot oviposition and development.

Seedcorn maggot damage to soybeans, both stand reduction and injured seedlings which survived, greatly affected subsequent growth and yield. Stand reduction affected seed yield more than did the presence of surviving seedlings without plumules. Over all years, seed yields were greatest at 29.7 plants per 1-m row. When some of the surviving seedlings lacked plumules, seed yields were reduced at plant densities less than 29.7 plants per 1-m row in some years. At all plant stands, the seedlings without plumules were shorter and produced less leaf area, fewer flowers,

and fewer pods than normal plants. This retarded growth reduced leaf area index, flowers per unit area, and pods per unit area. The decrease in pods per unit area was accompanied by an increase in beans per pod. Plant-growth characteristics were very similar for actual and simulated damage.

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