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The Sunflower Moth and its Impact on Cultivated Sunflowers in Eastern South Dakota

Tom A. Royer

THE SUNFLOWER MOTH AND ITS IMPACT ON CULTIVATED SUNFLOWERS IN EASTERN SOUTH DAKOTA

BY

TOM A. ROYER

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THE SUNFLOWER MOTH AND ITS IMPACT

ON CULTIVATED SUNFLOWERS IN EASTERN SOUTH DAKOTA

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

David D. Walgenbach — Date
Thesis Adviser

Maurice L. Horton — Date
Head, Dept. of Plant Science

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I find myself with mixed emotions upon completing this thesis. I feel a sense of accomplishment and satisfaction, but also a twinge of sadness, because I know that I will be leaving. I learned a great deal in the classroom, but a significant portion of my education was obtained outside the formal setting. To the educators of South Dakota State University, I thank you.

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TAR

INTRODUCTION

Cultivated sunflowers (Helianthus annuus L.) are an increasingly important cash crop in the agricultural economy of South Dakota. Sunflower hectarage increased in South Dakota from an estimated 59,711 ha. in 1975 to approximately 250,900 ha. in 1982 (Anonymous, 1982). Most of the sunflowers are grown in the eastern half of South Dakota, and a large percentage is grown in the northeastern quarter of the state (Figure 1). The expanding hectarage has necessitated an increase in insecticide application to control the several insect pests associated with them. It is estimated that 181,900 ha. were treated with insecticides in 1982 (D. Walgenbach, South Dakota State University, Personal Communication).

The sunflower moth, Homoeosoma electellum (Hulst), is a serious pest of sunflowers and a major pest of cultivated sunflowers in Texas, California, and Nebraska (Teetes and Randolph 1969c, Carlson 1971, and Muma et. al. 1950). Yield loss is due to larval feeding in the florets and ovaries of the sunflower head. The presence of larvae in the sunflower head is indicated by the characteristic "trashy appearance" composed of larval webbing and exuviae (Carlson 1967). Rogers (1978a) stated that serious feeding damage doesn't occur until the larvae reach the late second or third instar. Carlson (1967) noted that one larva can damage nine seeds in a three week period, however Rogers (1978a) reported damage ranging from 8.2 to 22.8 seeds per larva. Severe infestations can cause a 30 to 60 percent seed loss and in some cases

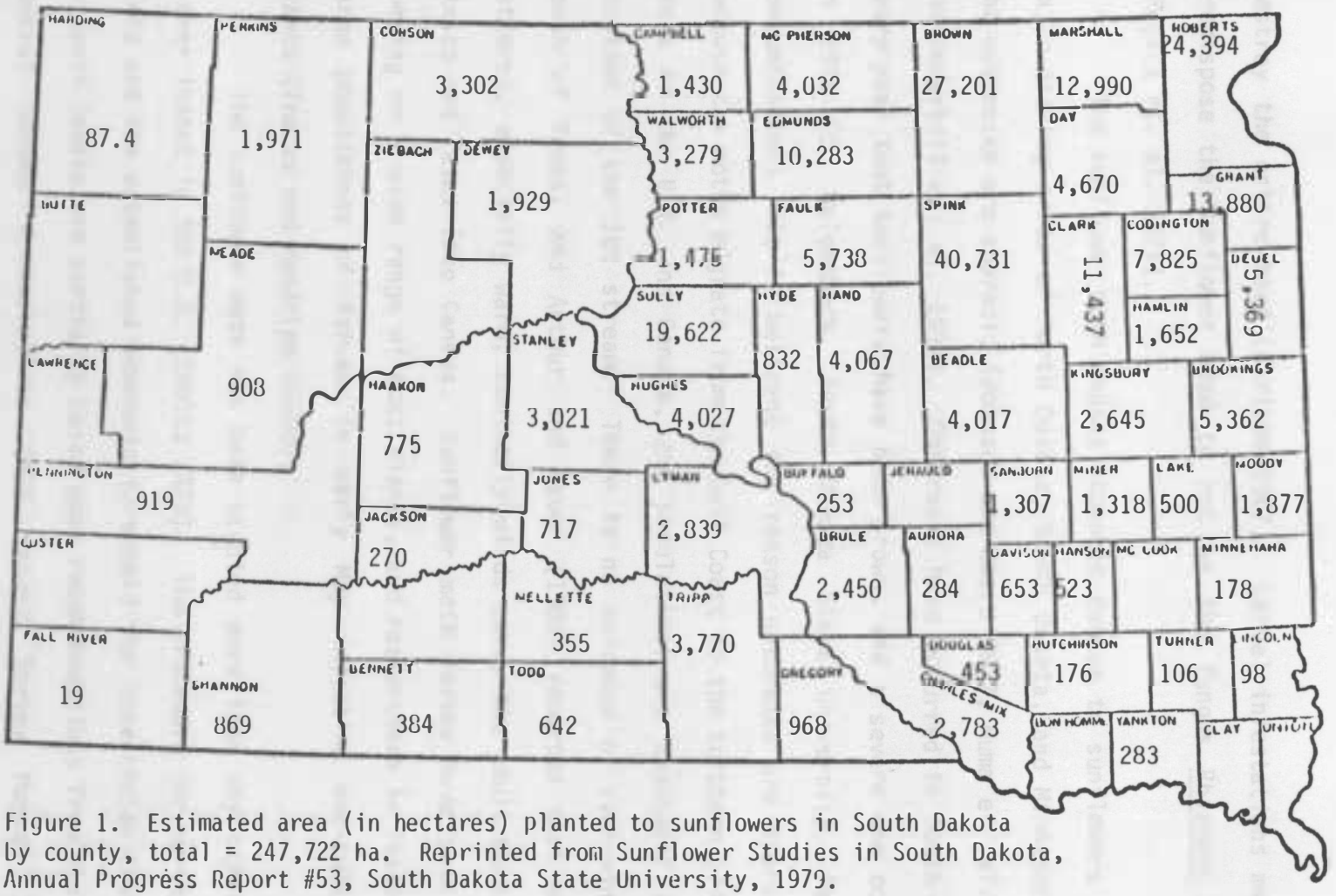

Figure 1. Estimated area (in hectares) planted to sunflowers in South Dakota by county, total = 247,722 ha. Reprinted from Sunflower Studies in South Dakota, Annual Progress Report #53, South Dakota State University, 1979.

destroy the entire head (Carlson 1967). Larval infestations may also predispose the sunflower head to rot by the fungus Rhizopus oryzae (Rogers et. al. 1976).

The sunflower moth causes economic damage to sunflowers in the major growing areas of North Dakota, South Dakota, and Minnesota, but the outbreaks are sporadic (Johnson and Beard 1977, Muma et. al. 1950, and Underhill et. al. 1982). Outbreaks have occurred in South Dakota every year that sunflowers have been grown, and a severe one occurred in 1975 (D. Walgenbach, South Dakota State University, Personal Communication). It is believed the reason outbreaks are sporadic is because the moths migrate from the Gulf Coast to the northern producing areas of the U.S. and Canada, and populations are dependent on the location of the jet stream. There is no evidence of over-wintering north of Texas, and Arthur and Bauer (1981) reported that weather patterns, especially warm, southerly winds carry the adult moths from Mexico and Texas into Canada. Sunflower moth larvae have been found feeding on a wide range of host plants, and researchers in Texas noted large populations of larvae in early May infesting non-cultivated plants (Teetes and Randolph 1969d).

The sunflower moth has been studied more than any other sunflower insect in the U.S. (Shultz 1978). The procedure for surveying a field and the established economic threshold for insecticide treatment in South Dakota are partially based upon recommendations from the North Central Survey Entomologists (NCS Insect Survey Manual 1981).

Insecticide treatment is recommended when an average of 1 to 2 adult moths per 5 plants are present.

The economic threshold has been empirically derived, based on the average number of seeds that one larva can destroy (Carlson 1967 and Teetes and Randolph 1968). Noetzel (1979) attempted to clarify the threshold, taking into account all of the quantitative data available on larval damage to seeds and by estimating larval mortality. He assumed a male to female ratio of 1 to 1, although it has yet to be documented. He reported a threshold of 1.4 adult moths per 5 plants and cautioned that fields should be surveyed carefully because outbreak occurrence was infrequent in Minnesota.

The lack of data on larval mortality is a barrier towards developing a more precise economic threshold. Rogers (1978a) published the only quantitative data on larval mortality in a greenhouse study. Larval recovery rates ranged from 28 to 54 percent in the experiment. A number of scientists have identified parisitoids of the sunflower moth. A substantial list of the sunflower moth's natural enemies has been published in Texas (Rogers 1980), however, there is no published information on the South Dakota fauna.

Entomophagous predators associated with sunflowers have not been studied in South Dakota. They could have an impact on sunflower moth populations. In crops where predation has been investigated (cotton, alfalfa, and soybeans), predators have been implicated in the suppression of certain pest populations. Pedigo et. al. (1972)

reported that a combination of Nabis sp. and Orius sp. caused significant mortality in eggs and early instars of the green cloverworm in Iowa soybeans. Turnipseed (1972) found that large nabid nymphs consumed an average of 20 Heliothis zea eggs per day. Predation of radioactive H. virescens eggs ranged from 48-100 percent in a Texas cotton field (McDaniel and Sterling 1979). A sophisticated management scheme has been developed for cotton insect pests because of problems that occurred with extensive pesticide use. The program recognizes the importance of arthropod predators in regulating certain pests (Apple and Smith 1976).

The objectives of this study were (1) to investigate the potential for using artificial infestations of sunflower moth larvae to quantify feeding damage on cultivated sunflowers, (2) to collect and identify entomophagous arthropods associated with sunflowers, (3) to investigate the seasonal abundance of the most common predators, and (4) to study the potential predator-prey relationships between the most common predators and the sunflower moth larvae.

LITERATURE REVIEW

Description and Life History of the Sunflower Moth

The sunflower moth (Homoeosoma electellum (Hulst), Lepidoptera: (Pyralidae), was described as Anerastia electella and placed in the family Pyralidae (Hulst 1888). Hulst (1890) later reclassified it in the genus Homoeosoma.

There are a number of recorded host plants for the sunflower moth. Forbes (1923) reported that larvae fed on the buds of Grindelia spp. and on sunflower seeds. Larvae feed on a wide variety of ornamental and wild flowers in the family Compositae (Drake and Harris 1926), and on sunflowers in the genus Helianthus (Bird and Allen 1936). Wene (1950) noted sunflower moth larvae feeding in the buds of young citrus trees (Citrus sp.), and they will feed on cotton bolls (Gossypium sp.) (Texas CEIR 1968). Teetes and Randolph (1969a) found larvae feeding on 11 plant species in Texas. They also reported that records from the USDA Plant Pest Control Division list citrus, Hubam clover (Melilotus alba), corn (Zea mays), oranges (Citrus sinensis), cotton, woolly globemallow (Sphaeralcen sp.), safflower (Carthamus tinctorius), and common sunflowers as observed host plants.

Satterthwait and Swain (1946) described the life stages of the sunflower moth. The egg is pearly white, elliptical, finely reticulated, and measures from 0.63 to 0.80 mm long and from 0.23 to 0.27 mm in diameter. The larva is purplish or reddish-brown with four blue-green longitudinal stripes on the dorsum. The pupa is spineless, brownish to

dark brown, and approximately 10 mm in length. The adult is a small grey to whitish-grey moth with a wingspan of 20 to 21 mm and a body length of 11 mm. Randolph et. al. (1972) studied the moth life cycle under laboratory conditions. The female laid an average of 97.8 eggs (range 26-173). They were usually deposited singly, or in small groups. There were four or five larval stadia. The length of the larval stage averaged from 14.6 (no fifth instar) to 16.6 days (with fifth instar), and ranged from 13-31 days. The pupal period ranged from one to two weeks. In field studies, the egg stage ranged from 2-4 days (ave. 2.4 days), the larval stage ranged from 19-28 days (ave. 21.5), and the pupal stage ranged from 7-14 days (ave. 8.9). The adult moth lived from 8-13 days. Head capsule widths averaged 0.222, 0.350, 0.565, 0.852, and 1.253 mm for larval stadia one through five, respectively.

The life cycle, courtship, and mating behavior of the sunflower moth was studied in the laboratory by Arthur (1978). Mortality averaged 29 percent for the species from the time the larvae were placed on artificial diet until adult emergence. He was able to raise nine successive generations without complications. The female became sexually active almost immediately upon exposure to light after being kept in darkness overnight. The courtship behavior is described as follows:

"The females call by separating their wings slightly, bending the posterior segments of their abdomen dorsally and extruding their ovipositors. The responding males approach the female from any

direction by walking, sometimes with wings fluttering, especially if they are walking up to her, and usually with antennae vibrating."

Arthur stated that a female could call for up to three hours. He also noted that the preliminary contacts initiated by the male seemed to be for the purpose of determining the exact position of the female. He found wing glands on the male that were similar in structure and location to ones found in Plodia interpunctella, and speculated that they may be male pheromone glands that produce a substance used to seduce a female prior to mating.

Underhill et. al. (1979) identified the components of the female sex pheromone. In laboratory studies, three substances (tetradecanol, Z-9,E-12-tetradecadienol, and Z-9-tetradecanol) had a stimulatory effect on adult males. In preliminary field tests, traps baited with 2 ug Z9, E12-14:OH + 20 ug Z9-14:OH, or 20 ug Z9,E-12-14:OH + 2 ug Z9-14:OH were just as effective as virgin females in their attractancy to males. Further studies (Underhill et. al. 1982) showed that Z-9, E-12-tetradecadienol was the main component attracting the adult male.

The seasonal abundance and flight activity of the sunflower moth have been studied in Texas and California. Teetes and Randolph (1969d) found two peaks of larval abundance in Texas. The first occurred on May 2 in non-cultivated plants. Gaillardia pulchella was the primary host plant with up to 59.7 percent of the flowers being infested. The second peak occurred from June 6 to July 25, and cultivated and wild sunflowers were the major host plants.

Carlson et. al. (1978) conducted light trapping studies in California. Flight activity began in mid-July and ended in October, with two peaks occurring. There was strong evidence that two generations occurred during the growing season. They also reported a temperature threshold of 56°F (13°C) for predicting the onset of flight activity using degree day accumulation.

Teetes and Randolph (1969c) exposed bagged cultivated sunflowers to sunflower moth oviposition for 24 hours over a period of 20 consecutive days. Oviposition peaked three days after the sunflower ray petals had opened, and 75 percent of the oviposition was completed six days after the start of anthesis.

In the northern sunflower producing areas, available data indicated that one brood per season is responsible for damage, although a partial second brood probably occurs. Noetzel (1979) noted that adult moths were present in Minnesota from mid-July through September, but oviposition virtually ceased after the 10th of July. A second brood was found in September, but it was too late to cause any damage.

Teetes and Randolph (1970a) studied the hibernation habits of the sunflower moth and 90 percent of the larvae overwintered in the soil. The induction of diapause is dependent on both photoperiod and temperature. Teetes et. al. (1969) reported that diapause was induced more frequently at 21°C than at 27°C, but only when the photoperiod was less than 11 hours in duration. Diapause induction in larvae subjected to 10 hours of light per day was independent of the photoperiodic exposure applied to the adults or eggs. Temperature and photoperiod

probably both influence the termination of diapause. Diapause terminated more rapidly at 27°C than at 21°C, and when larvae were subjected to more than 11 hours of light per day, they resumed development more rapidly than ones kept under shorter a photoperiod.

The sunflower moth has not been found to overwinter in the northern sunflower producing states or Canada. Arthur and Bauer (1981) placed traps impregnated with female sunflower moth sex pheromone in several fields and monitored trap catch throughout the growing season. They also checked weather maps of the North American continent for the presence of warm, southerly winds originating from the Gulf of Mexico. A major weather pattern developed each year during late June and July, and trap catches increased with the estimated arrival of the winds into Canada.

Several researchers have studied and recorded the natural enemies of the sunflower moth. Satterthwait and Swain (1946) recorded seven species of parasitic hymenoptera, five parasitic diptera, one predaceous beetle, and one fungal pathogen. Teetes and Randolph (1969d) recorded an additional five species of hymenoptera and one dipterous parasitoid in Texas. Other records of sunflower moth parasitoids are included in papers by Arthur and Campbell (1979), Bruner (1934), Shultz et. al. (1972), Shultz et. al. (1977), Tejada and Blanc (1976) and Westdal (1975). A list of the sunflower moth's natural enemies has been published by the Texas Agricultural Experiment Station (Rogers 1980).

A dearth of information exists on the entomophagous arthropod predators associated with sunflowers that could be potential natural enemies of the sunflower moth. Insect surveys have been undertaken in Kansas, (Walker 1936), North Dakota (Lipp 1972), Missouri (Satterthwait 1948), and Texas (Philips 1972). These surveys were undertaken to identify arthropods that damaged or were pollinators of sunflowers and made no mention of predaceous arthropods. Walker (1936) listed three predaceous insects identified to family that he found feeding on various phytophagous species.

Sunflower Moth Damage and Control

The sunflower moth was first reported as a pest of ornamental flowers (Drake and Harris 1926). At the time, it was called the flower webworm, but the common name was later changed. Satterthwait and Swain (1946) stated that the female oviposits within or among the florets of the sunflower head. The eggs hatch in 48 to 72 hours (Randolph et. al. 1972). The larvae feed on the florets of the sunflower and later burrow into the receptacle where they damage seeds during migration and feeding (Carlson et. al. 1972). Rogers (1978a) reported that first instar larvae feed primarily on pollen. Second instars feed on pollen, but also begin feeding on the corollas of the sunflower head. The third through fifth instar larvae are the most damaging, and feed on the ovaries of the sunflower. He reported that one larva can damage between 8.2 to 22.8 seeds. Heavy infestations can reduce yield up to

50 percent (Carlson et. al. 1972). In addition to direct feeding damage, the larvae produce webbing that causes a trashy appearance on the head (Carlson 1967). Rogers et. al. (1976) reported an association between larval infestations and an increase in incidence of infection by the fungus, Rhizopus oryzae in sunflowers.

Insecticide tests have been carried out in Texas and California. Carlson (1967, 1971) tested several chlorinated hydrocarbon, organophosphate and carbamate insecticides for control of the larvae. Yield increased with nearly all of the insecticides evaluated. He stated that spraying should begin at the onset of bloom. Two applications were necessary for adequate control, and three sprayings, spaced one week apart, were optimal for complete control. Commercial preparations of the bacterial insecticide Bacillus thuriengiensis B. did not adequately control larval numbers or increase yield. Teetes and Randolph (1969c) confirmed that three applications provided adequate control in Texas. Noetzel (Unpublished Data 1978) reported obtaining adequate control in Minnesota with one spraying of methidathion when the field was in 15 percent bloom, but found a greater reduction in larval numbers when three sprayings, spaced five days apart, were used. In South Dakota, one aerial spraying of methyl parathion at 100 percent bloom (50 percent anthesis completed) reduced larval numbers from an average of 21 larvae per head to 3 larvae per head (Walgenbach, Unpublished Data, 1982).

The results of date-of-planting studies have been variable, depending upon their geographic location. Moth populations in Texas

were low in sunflowers planted earlier (March 12), or in sunflowers planted after April 17 (Teetes and Randolph 1971). In Nebraska, sunflowers planted after April 11 had fewer larvae per head than ones planted on June 8 (Muma et. al. 1950). Minnesota researchers noted that sunflowers planted later (June 1) were not as likely to become infested as were sunflowers planted earlier (Noetzel unpublished data, 1978).

The survey procedure for the sunflower moth in South Dakota is based upon recommendations from the North Central Survey Entomologists (NCS Survey Manual 1981). Counts of adult moths should be taken on 20 plants per location at 5 locations per field during early morning or dusk, when the adults are most active. Field monitoring should begin at the onset of bloom. Insecticide treatment is recommended when 1 to 2 adult moths per 5 plants are present. Ethyl or methyl parathion and methidathion are registered for use in South Dakota. If the threshold is reached, one or two aerial applications of insecticide should be applied. The first application should be applied at 10 percent bloom, and the second, if necessary, should be applied one week later. To protect pollinators, it is recommended that insecticides be applied either before 7:00 AM or after 7:00 PM (Kantack and Berndt 1982).

Some sunflower varieties exhibit resistance to feeding damage by the larvae. According to Johnson and Beard (1977), a Russian scientist (Pustovoit 1961) noted sunflower resistance to feeding damage with a closely related species, Homoeosoma nebulella, due to the presence of a phytomelanin layer in the seedcoat. The structural appearance and

development of the layer had been described earlier by Putt (1940) and Kiewnick (1964). Arnoldova (1926) and Putt (1940) found evidence that the layer's occurrence was governed by a single gene. Carlson et. al. (1972) and Carlson and Witt (1974) evaluated varieties possessing the phytomelanin layer for resistance to sunflower moth larval feeding damage, and found that achenes possessing the layer were damaged less severely. Some lines not possessing the layer were found to be resistant, and they speculated that some other mechanism, possibly chemical, was responsible. Feeding resistance in the absence of the layer was also noted by Johnson and Beard (1977). Varietal resistance to larval feeding damage has also been investigated in Texas (Teetes et. al. 1971), and Iowa (Jarvis 1980).

The identification of components in the female sex pheromone has allowed for its potential use in a sunflower moth management program. Rogers (1982) speculated on its possible applications. It seems to be more effective in detecting the presence of moths in a field than the use of field scouts, and pheromone trapping is more time efficient. He stated that there is a need to correlate trap catches with larval populations, yield reductions, and with adult numbers present in the field before the pheromone can be used successfully.

MATERIALS AND METHODS

1981 Artificial Infestation Studies: Field studies were conducted to determine the effects of sunflower moth larval populations on sunflower damage and seed yields. Plots were established in three fields located near Brookings, South Dakota (Figure 2). Field 1 was located 12 km north of Brookings, field 2 was located 10 km north and two km west of Brookings, and field 3 was located seven km south and one km west of Brookings. All fields were planted with Interstate® 894 hybrids at a rate of 44,460 plants per ha. Trifuralin herbicide was pre-plant incorporated at a rate of 0.84 kg per ha for weed control in all fields. Field 1 was planted on May 1, field 2 on May 5 and field 3 on May 10.

Plots were located and plants were selected for infestation approximately one week before bloom. Pollinating bags (45 by 51 cm Delnet®) were placed over the unopened buds (6-10 cm diameter) and tied with string below the bud to prevent infestations of endemic pest populations. Plants were selected for uniform size, growth stage and spacing in the row.

Five larval population levels, replicated three times, were arranged in a randomized complete block design. Each larval population was applied to five plants (four plants in field 2) in each replication. Population levels of 0 larvae (unbagged), 0 larvae (bagged), 10, 25 and 50 second and small third instar sunflower moth larvae were placed on plants, since Rogers (1978a) reported that feeding damage to seeds does not occur until the larvae reach the third

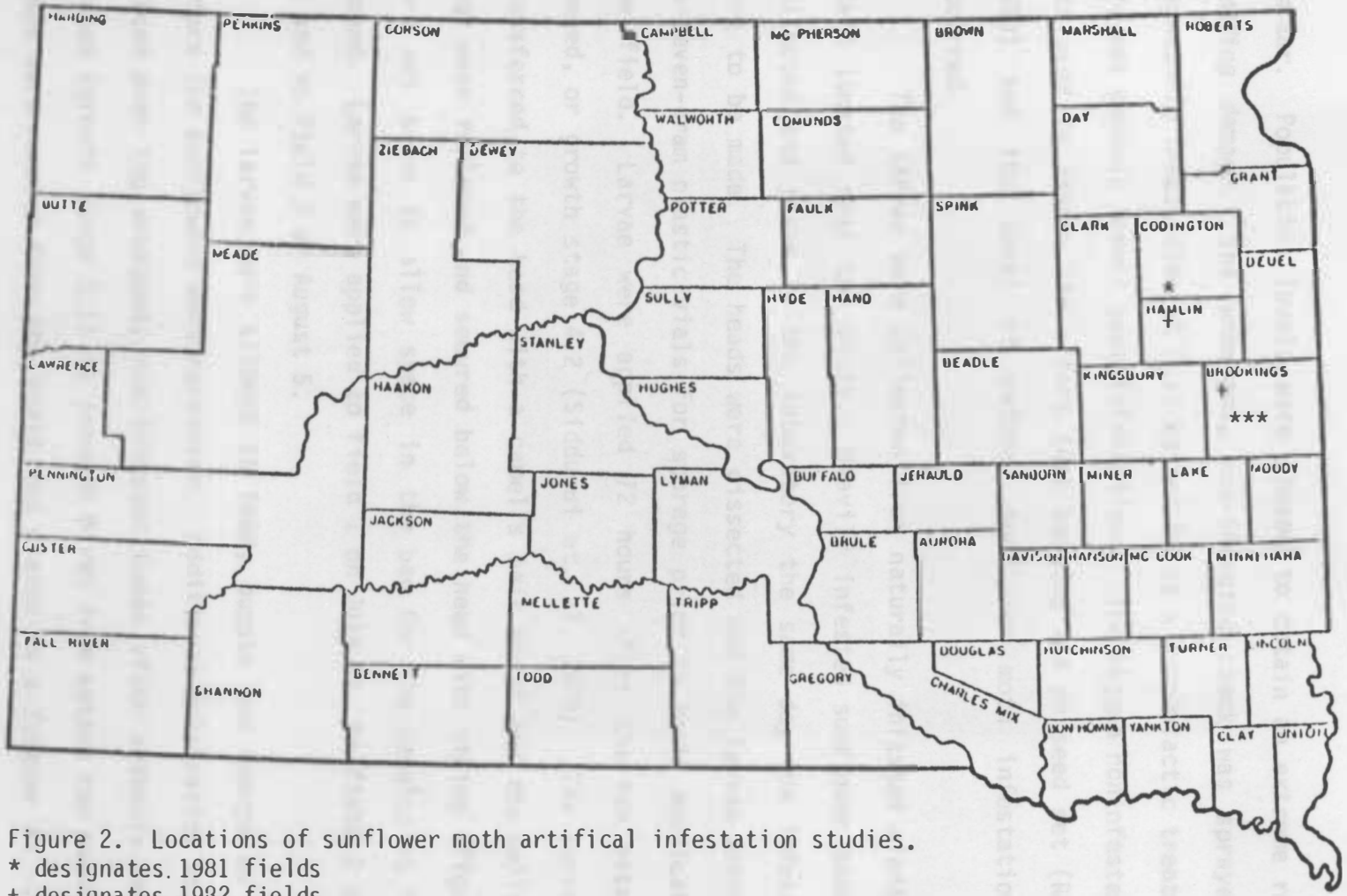

Figure 2. Locations of sunflower moth artifical infestation studies.
* designates 1981 fields
+ designates 1982 fields

instar. Population levels were chosen to obtain an extreme range of feeding damage. The unbagged, non-infested check was sprayed with permethrin insecticide at 0.11 kg per ha as a prophylactic treatment to prevent endemic insect pest infestations. The bagged noninfested check was used to assess the effect that bagging had on seed set (Robinson 1980) and the level of natural sunflower moth infestation that occurred.

The larvae were collected from naturally infested plants in a field located near the plots. Heavily infested sunflower heads were collected and taken to the laboratory the same day the infestations were to be made. The heads were dissected and the larvae transferred to seven-dram plastic vials for storage prior to their application in the field. Larvae were applied 72 hours after the ray petals had opened, or growth stage 4.2 (Sidduqui et. al. 1975). The larvae were transferred to the head with a camel's hair brush and the pollinating bags were replaced and secured below the head with string (Figure 3). Care was taken to allow space in the bag for the developing head to expand. Larvae were applied to field 1 on July 24, to field 2 on July 28 and to field 3 on August 5.

The larvae were allowed to feed, pupate and emerge as adults before the sunflowers were harvested. Additional pollinating bags were placed over the unbagged, non-infested heads after anthesis was completed (growth stage 5.1) to prevent birds from eating the seeds. The heads were removed from the field and placed in a freezer at -20^{o}C to kill live moths. The number of moths recovered and the number of

Figure 3. Delnet® bags were fastened to the base of the plant after infesting the larvae.

damage spots on the heads were recorded. A spot of damage is described as a "fairly discrete clump of webbing and frass" produced by the larvae (Carlson 1967). Visual criteria were used to determine a spot of damage. Criteria included the presence of a tunnel in the frass and visual evidence that the spot was discrete (Figure 4). If individual damage spots could not be visually separated and feeding tunnels could not be seen, then an area three cm in diameter was counted as one spot of damage.

The sunflower heads were air dried in a grain dryer. Head diameter was recorded by taking the average of two measurements at 90^{o} angles across the center of the head (Knowles 1978). The seeds were hand threshed and cleaned with a South Dakota Seed Blower® to remove empty or damage seeds and plant material. Seed yield was recorded for each head.

Differences in average seed yield, captured moths, damage spots and head diameter were compared with the bagged, non-infested check using Dunnett's test. Population effects on seed yield were assessed with regression analysis on a per plant basis, because the plants were selected for uniformity, therefore they did not represent a true plot.

A multiple linear regression procedure was employed on a per plant basis to determine which variables (damage spots, captured moths, infestation level or head diameter) were important in explaining seed yield response.

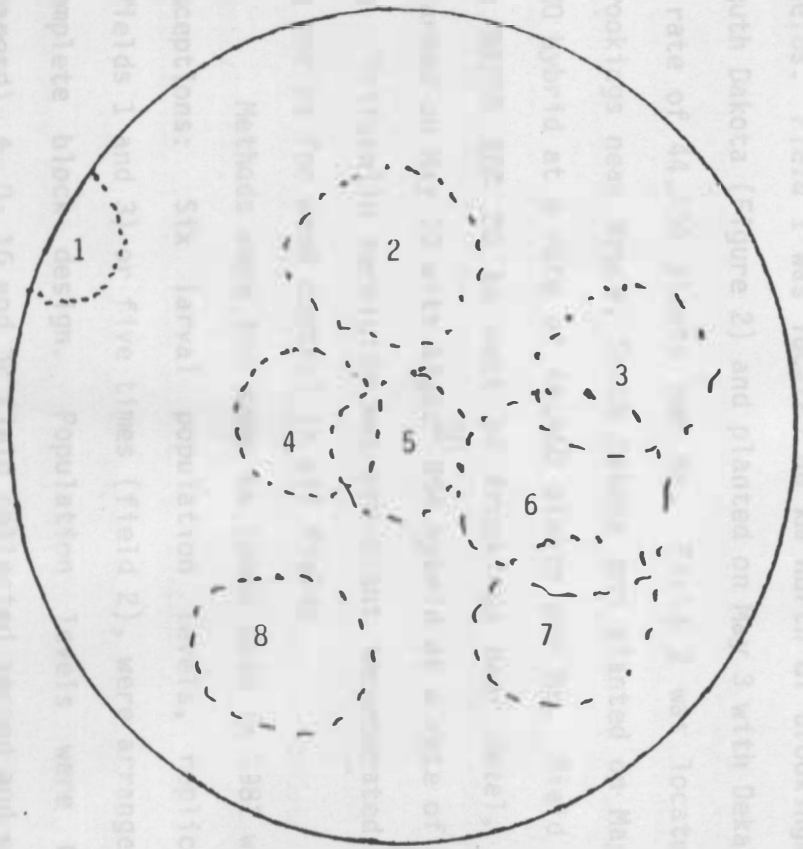

Figure 4. Schematic diagram of a "spot of damage" (eight spots represented), after Carlson, 1967.

The relationship between damage spots and captured moths was examined with regression analysis with data combined from all fields. Regressions were calculated on a per plant basis.

1982 Artificial Infestation Studies: Field studies were continued with several modifications. Plots were established in three fields. Field 1 was located 66 km north of Brookings near Watertown, South Dakota (Figure 2) and planted on May 3 with Dekalb® 894 hybrid at a rate of 44,460 plants per ha. Field 2 was located 12 km west of Brookings near Bruce, South Dakota and planted on May 3 with 4 Winds® 900 hybrid at a rate of 44,460 plants per ha. Field 3 was located 62 km north and 20 km west of Brookings near Hazel, South Dakota and planted on May 10 with Sigco® 894 hybrid at a rate of 44,460 plants per ha. Trifuralin herbicide was pre-plant incorporated at a rate of 0.84 kg per ha for weed control in all fields.

Methods were the same as those used in 1981 with the following exceptions: Six larval population levels, replicated four times (fields 1 and 3) or five times (field 2), were arranged in a randomized complete block design. Population levels were 0 (unbagged), 0 (bagged), 4, 8, 16 and 32 field collected second and early third instar larvae. Larvae were applied on July 23 in field 1, July 27 in field 2 and August 4 in field 3. These changes were made in an attempt to reduce variation in the study, and obtain a more linear larval population range. Analysis was similar to that used in 1981.

1982 Cage Studies: Studies were conducted in 1982 to assess the use of cages to quantify sunflower moth adult thresholds. Three

cages measuring 1.8 by 1.8 by 2.0 meters (Figure 5) were placed in a sunflower field (field 1, 1982 artificial infestation studies) located near Watertown, South Dakota. Dekalb® 894 hybrid sunflowers were planted on May 3 at a rate of 44,460 plants per ha. Trifuralin herbicide was pre-plant incorporated at a rate of 0.84 kg per ha for weed control.

Cages were constructed, covered with 1 by 1 mm mesh screen and erected in the field approximately two weeks prior to bloom. Each cage contained three rows of sunflowers spaced 90 cm apart with seven plants spaced 27 cm apart in each row. Female sunflower moths were collected with an aspirator and released into the cages 24 hours after the ray petals had opened on at least 50 percent of the flowers in the cages. Only moths observed ovipositing were collected for release. Populations of 0, 20 and 30 moths were released in cages one through three respectively. The cages were left undisturbed except for occasional examination of the cage screen for damage.

The sunflowers were hand harvested and damage spots on the heads were recorded. The heads were then air dried and head diameter was measured. The heads were threshed, cleaned and seed yield was recorded for each head. Individual plant response between seed yield and moth release level was determined with regression analysis.

Sex Ratio Studies: Samples were collected in 1981 and 1982 to investigate the sex ratio of adult sunflower moths present in cultivated sunflowers in South Dakota. Four fields were sampled in 1981 and three fields in 1982 using a D-Vac® vacuum-net backpack sampler with a

Figure 5. Cages used in the adult sunflower moth infestation studies.

20 cm diameter cone (Figure 6). Samples were collected in late afternoon or dusk to coincide with South Dakota recommendations, because empirical reports indicate that the moths are more active in the early morning or late dusk (NCS Survey Manual, 1981). The foliage and flowers were sampled for 20 minutes in each field. The captured moths were killed by freezing and sexed with the aid of a 10x dissecting microscope. Rogers (1978b) stated sunflower moths can be sexed by examining the tip of the abdomen according to the following criteria: The female's abdominal tip is pointed and the ovipositor usually protrudes whereas the male has a mesal slit in the last segment of the abdominal tip and is blunt. A chi square was calculated to determine if the male to female ratio was different from one to one.

Predator Survey: Insect surveys have been undertaken in cultivated sunflowers in North Dakota (Lipp 1972), Kansas (Walker 1936), Texas (Phillips et. al. 1971) and Missouri (Satterthwait 1948). These surveys were concerned with insects that were pests of or pollinators of sunflowers. Predaceous arthropods associated with cultivated sunflowers have not been identified.

Predaceous arthropods were collected in cultivated sunflowers in 1981 and 1982. The survey was designed to sample predators that were on the foliage or sunflower head while in bloom, as they would be potential predators of sunflower moth larvae and adults. Twenty-five fields (18 in 1981 and 7 in 1982) located in four counties (Figure 7) were sampled once during the period from July 20 through August 15.

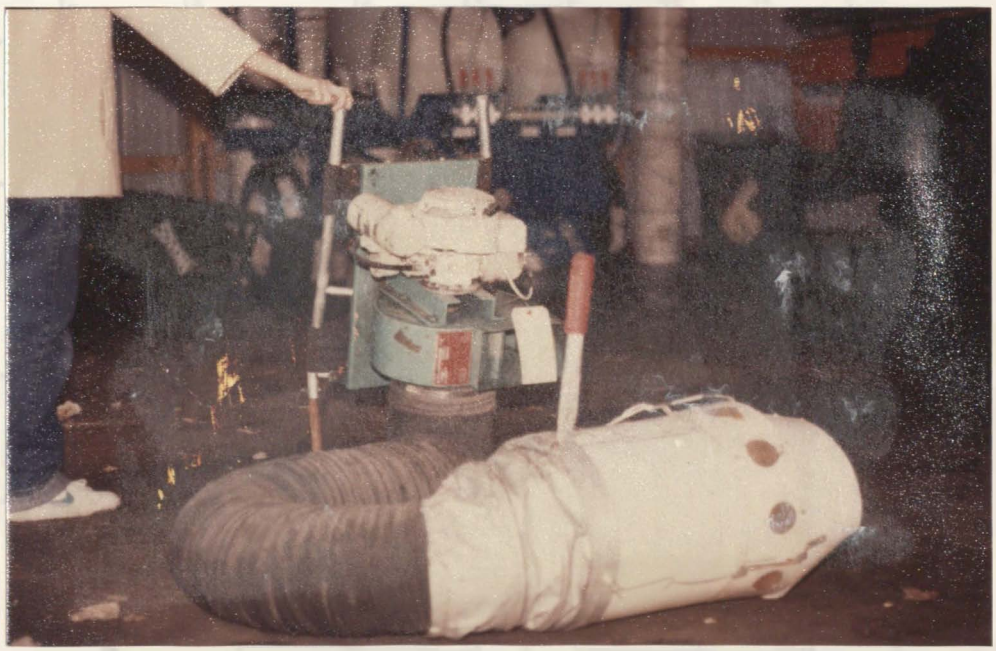

Figure 6. D-vac® backpack vacuum insect sampler.

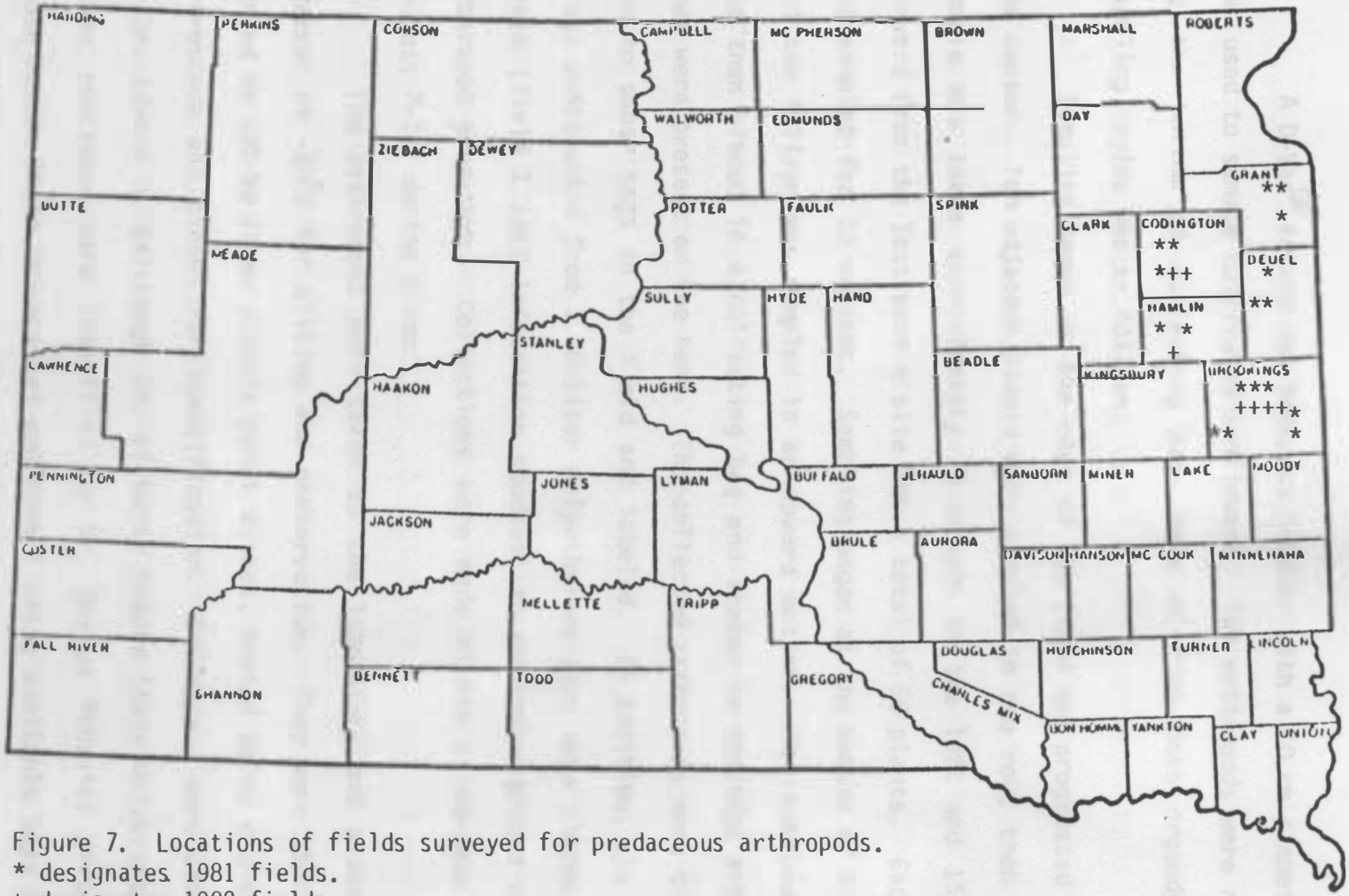

Figure 7. Locations of fields surveyed for predaceous arthropods.
* designates 1981 fields.
+ designates 1982 fields.

A D-Vac® vacuum net backpack sampler with a 20 cm diameter cone was used to sample cultivated sunflowers. The arthropods were retained at the bottom of collecting bags made of fine mesh organdy. The sampling regime was as follows:

Sampling began at the edge of the field and progressed towards the center. Ten adjacent plants were sampled in one row, then another sample was taken approximately 15 meters to the left and 15 meters forward from the last sample site for a total of 50 plants. Each plant was sampled for 10 seconds. Sampling began at the bottom of the plant and the foliage was sampled in an upward motion. The sunflower head was then placed in a collecting bag and shaken to dislodge arthropods that were present on the head. The collected arthropods were transferred to paper bags in the field and labeled. In addition, six pitfall traps constructed from 3.76 liter polyethylene jars were placed in one field (field 1 1982 infestation studies) to determine ground dwelling arthropod predators. Collections were made within a one-week period (August 7-14) during bloom.

The arthropods were taken to the laboratory and placed in a freezer at -20°C for killing and preservation. They were then transferred to 100 by 15 mm plastic petri dishes, sorted using a dissecting microscope and pinned for identification. Coleoptera were determined by Dr. Edward U. Balsbaugh Jr. of North Dakota State University. All other specimens were identified by Dr. Burrus McDaniel (Professor, South Dakota State University) and myself using available keys and the South Dakota State University Insect Collection.

Seasonal Abundance Studies: Samples were collected in 1982 to monitor the seasonal abundance of the most common predators found in 1981. A 50 by 50 m plot was established in a sunflower field located near Brookings, South Dakota. The field was planted on May 25 with 4 Winds® 900 hybrids at a rate of 44,460 plants per ha. Trifuralin herbicide was pre-plant incorporated at a rate of 0.84 kg per ha, and a cultivation was made on June 10 and June 20 for weed control. The plot was divided into five quadrats measuring 15 by 15 meters. Samples were collected in each quadrat once weekly at 1000 hrs with a D-Vac® back-pack vacuum sampler. Each plant was sampled for 10 seconds. A total of 20 plants were sampled in each quadrat. Sampling began on June 20 and ended on August 11. Plant stage of growth was recorded as described by Sidduqui et. al. (1975).

The samples were transported to the laboratory and placed in a freezer at -20°C. The insects were transferred to 100 by 15 mm plastic petri dishes and counted with the aid of a 10x dissecting microscope. Counts were recorded for Orius insidiosus (Say), Chrysopa spp., Nabis sp. and Coccinelidae. The data was converted to arthropods per 5 row meters and transformed using the square root transformation described by DeLoach and Peters (1972) and Marston et. al. (1976).

Feeding Studies: Laboratory feeding studies were conducted to determine if four predators; O. insidiosus, Nabis alternatus (Parshley), Sinea diadema adults and Chrysopa sp. larvae would feed on sunflower moth larvae. The experiement was arranged in a completely random design with seven replications and kept under a 16-hour

photophase at 20°C (± 1°C). The predators were placed in 100 x 15 mm plastic petri dishes lined with filter paper covering the dish bottom. The filter paper was moistened with distilled water to prevent the larvae from dessicating. One or three predator species were placed in a petri dish with either five first instar, five third instar, or one fifth instar sunflower moth larvae. Because of their small size, three O. insidiosus were used in the studies to insure feeding occurrence. Only one fifth instar larva was used because they produced so much webbing that the predators became immobile in the petri dishes. The same number of larvae were placed in a petri dish with no predator as a check. The instar stage was determined by measuring head capsule width with a vernier caliper (Randolph et. al. 1972). Larvae used in the study were either newly hatched laboratory reared first instars, or field collected third and fifth instars. Larval remains were counted as dead. Data was analyzed using a chi square.

RESULTS AND DISCUSSION

1981 Artificial Infestation Studies: A two way analysis of variance showed that there were significant (F = 0.05) differences in seed yield, captured moths, and damage spots in all fields (Appendix I).

Noetzel (1979) noted the paucity of available information concerning sunflower moth egg and larval mortality in the field. Larval recovery was estimated in the infestation studies using the formula $\frac{N-M}{I} \times 100$: where N = the number of adults captured in the infestations, M = the number of moths captured in the bagged, non-infested check, and I = the number of larvae infested. Larval recovery ranged from 12 to 37 percent in the infestation studies (Appendix II). This estimate is slightly lower than the 28 to 54 percent recovery reported by Rogers (1978a) in a greenhouse study.

Regression analysis was employed to estimate seed yield response to the number of moths recovered in the pollinating bags. The only significant response (F = 0.05) was found in Field 1. The regression coefficient was Y = 60.13 - 0.92 M where Y = seed yield per plant (gms) and M = the number of moths recovered per bag. The regression predicted that one moth caused a yield reduction of 0.92 grams and accounted for 23 percent of the variation in seed yield.

Regressions were also calculated to examine the relationship between larval infestation level and seed yield for each field. A linear response (F = 0.05) was found in field 1 that explained 30 percent of the variation in seed yield (Figure 8). The regression predicted a seed yield loss of nearly 0.4 grams for each larva infested.

A quadratic component was significant (F = 0.05) in the regression calculated for data in field 2 (Figure 9). Seed yield was reduced 7.3 grams when 10 larvae were applied, 16.6 grams when 25 larvae were applied and 10.5 grams when 50 larvae were applied (R^2 = 0.17). The response of seed yield to infestation level was more variable in field 3, accounting for nine percent of the variation in yield differences. The regression predicted a linear yield reduction of 0.25 grams for each larva infested (Figure 10).

The low correlation between yield and infestation level indicated that other variables may influence sunflower yield, both extrinsic and inate. Fick (1978) reported that soil fertility, soil moisture, and plant population, among other factors, can influence head size and seed production. Robinson (1980) showed that the presence of pollinating bags can affect seed production in sunflowers. He also showed that 100 percent self-fertilizing sunflowers are affected by pollinating bags and compensate by producting larger, heavier achenes.

LDS's were employed to test the effect that pollinating bags placed on the plants may have had on seed production. There were significant differences in mean seed yield per plant between the bagged and unbagged non-infested checks in fields 2 and 3 (Appendix II). This reduction may have been due to the bags, or from natural sunflower moth infestations that occurred.

The potential interactions between seed yield and larval numbers, captured moths and head size were examined with multiple regressions using a stepwise regression program (SAS Institute 1979).

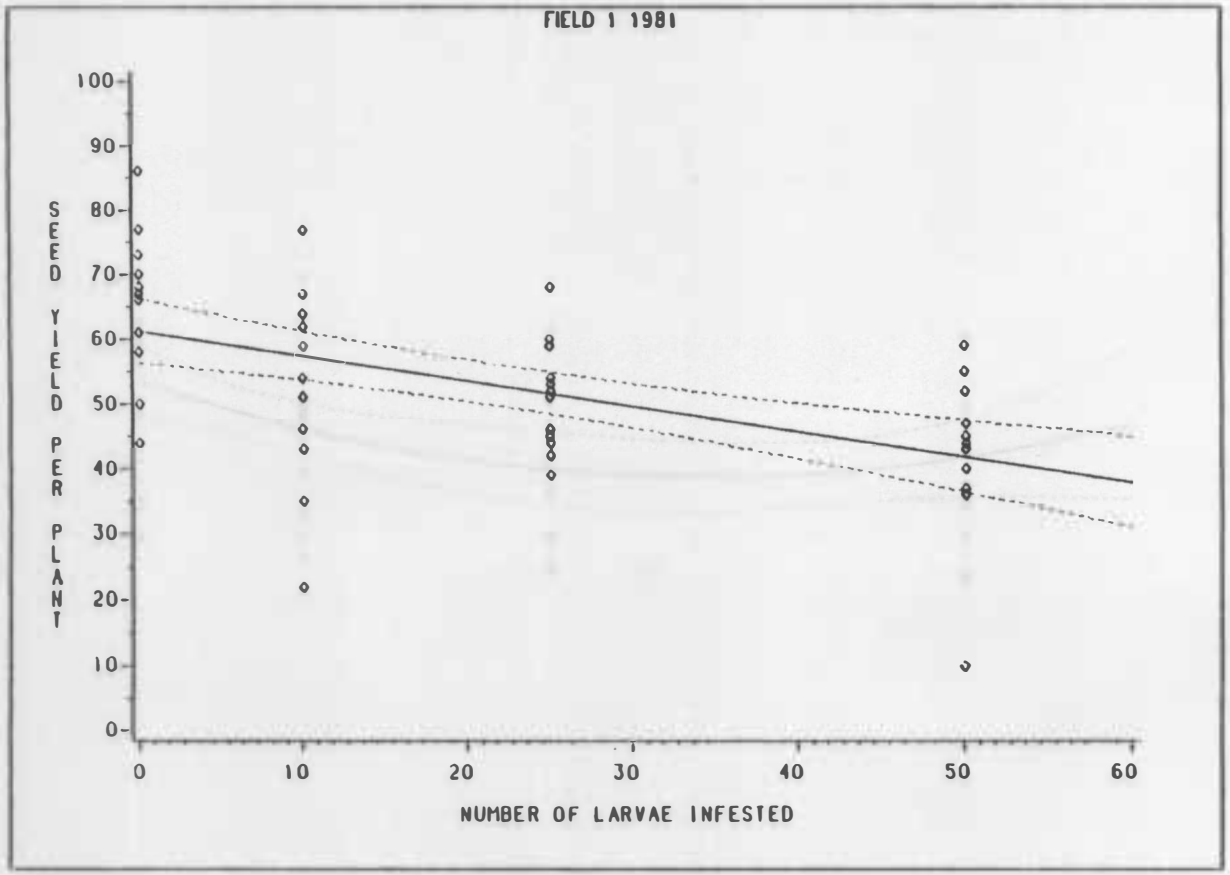

Figure 8. Regression and 95% confidence limits comparing seed yield per plant vs. the rate of artificial infestation of sunflower moth larvae in field 1, 1981. ($Y = 61.14 - 0.387\ X$, $R^2 = 0.30$). Regression was significant ($F = 0.05$).

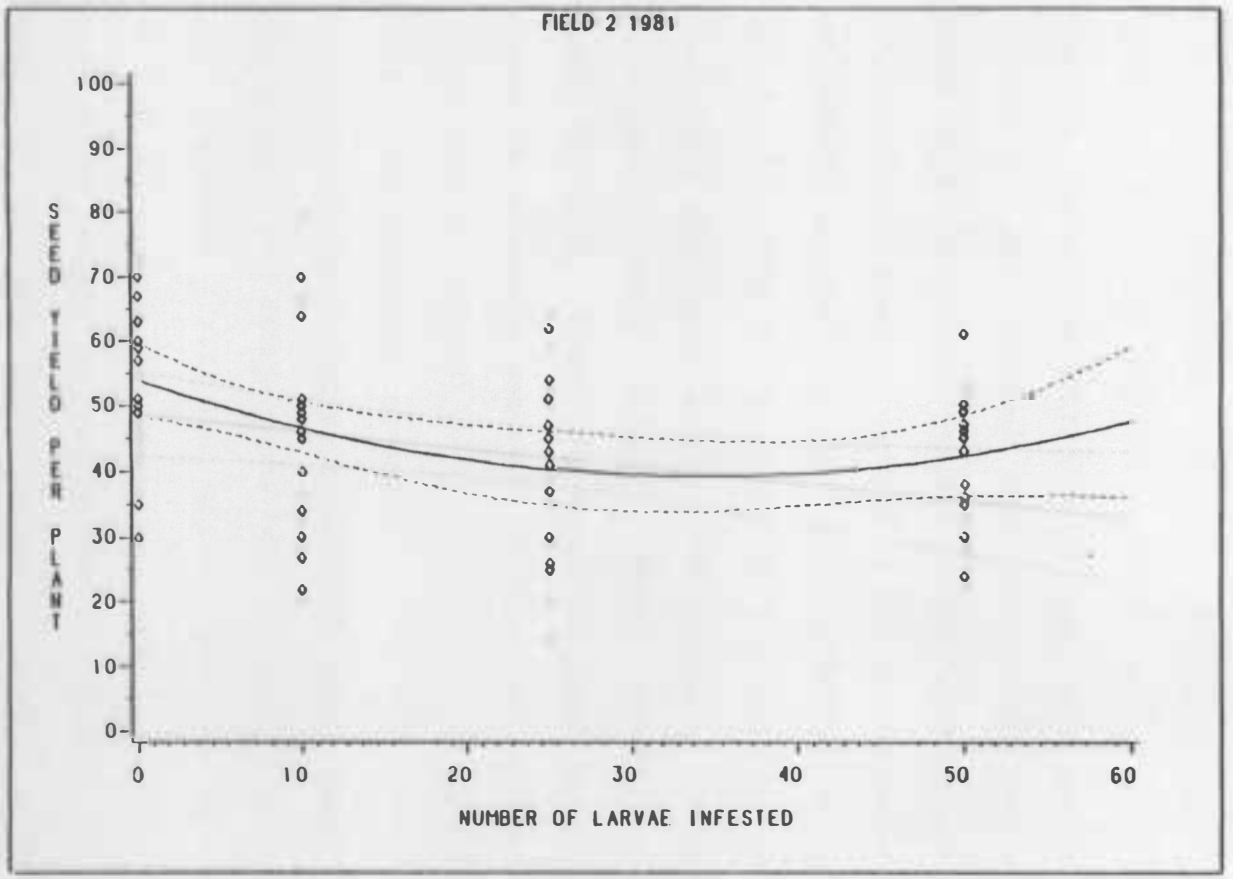

Figure 9. Regression and 95% confidence limits comparing seed yield per plant vs. the rate of artificial infestation of sunflower moth larvae in field 2, 1981. ($Y = 53.92 - 0.85 X + 0.013 X^2$, $R^2 = 0.18$). Regression was significant ($F = 0.05$).

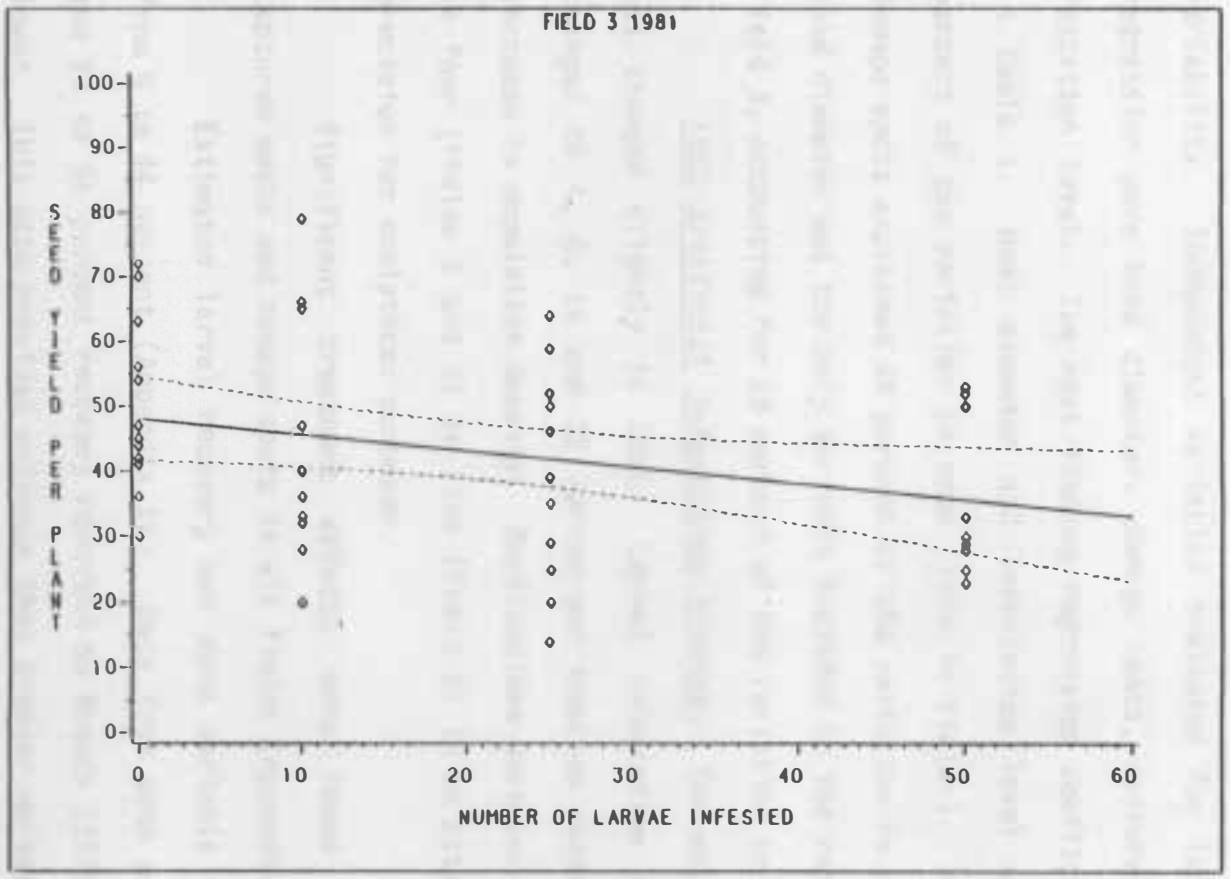

Figure 10. Regression and 95% confidence limits comparing seed yield per plant vs. the rate of artificial infestation of sunflower moth larvae in field 3, 1981. ($Y = 48.00 - 0.25\ X$, $R^2 = 0.09$). Regression was significant ($F = 0.05$).

The best fitting, significant (F = 0.05) multiple linear regression model was calculated for each field in an attempt to explain seed yield variability. Independent variables evaluated for inclusion into the regression were head diameter, damage spots, captured moths and infestation level. The best fitting regression coefficients are listed in Table 1. Head diameter and infestation level accounted for 48 percent of the variation in seed yield in field 1. Head diameter and damage spots explained 48 percent of the variation in yield in field 2. Head diameter was the only variable included in the regression model in field 3, accounting for 28 percent of the variation in yield.

1982 Artificial Infestation Studies: The experimental design was changed slightly in 1982. Larval infestation populations were changed to 4, 8, 16 and 32 larvae per head to obtain a more linear increase in population density. Replications were increased from three to four (Fields 1 and 3) or five (Field 2) in an attempt to gain some precision for analytical purposes.

Significant treatment effects were found in seed yield, captured moths and damage spots in all fields (Appendix III).

Estimated larval recovery was more variable in 1982, ranging from 0 to 44 percent (Appendix IV). Data from both years is close to the 28 to 54 percent recovery reported by Rogers (1978a), but slightly lower. This data provides evidence that greater mortality may occur in a situation where abiotic and biotic environmental factors (eg. ambient temperature, humidity, precipitation, predation and disease) are not controlled. It is not known how accurately this data correlates with

Table 1. Best fitting regression model for seed yield differences per plant in artificial infestation studies, 1981. All regressions were significant (F = 0.05).

Field No.	Independent Variable	R^2	Regression Model*
1	Diameter	0.37	S = -20.53 + 0.46 D
	Lar. Lev.	0.48	S = 1.61 - 0.25 L + 0.35 D
2	Diameter	0.42	S = -23.48 + 0.45 D
	Spots	0.48	S = -10.40 = 0.85 P + 0.41 D
3	Diameter	0.28	S = -20.60 - 0.38 D
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* S = Seed Yield
D = Head Diameter
P = Spots
M = Captured Moths
L = Larval Infestation Level

larval mortality in natural populations, since egg and first instar mortality was not determined and the pollinating bags may have protected the infested larvae from endemic predation.

The relationship between captured moths and seed yield was subjected to regression analysis. A significant response was calculated on field 2 only. The regression coefficient was Y = 50.01 - 0.70 M. The regression predicted a reduction of 0.7 grams of seed for each moth recovered and accounted for 5.6 percent of the variation. Data from two years show that there was not a consistently predictable relationship between captured moths and seed yield. Although this study could not determine the reasons for the lack of relationship between adult recovery and seed yield, it may be because larval mortality was variable and adult recovery did not index damage caused from larvae that failed to complete their lifecycle.

Regressions were calculated to analyze seed yield response to larval populations. Significant (F = 0.05) responses were determined in fields 2 and 3. A linear response was calculated for field 2 (R^2 = 0.06) and showed that yield was reduced 0.36 grams per larva infested (Figure 11).

A quadratic component was significant in the regression coefficient calculated for field 3, accounting for six percent of the variation in seed yield. Damage averaged 1.18 grams per larva when four larvae were applied, and decreased to 0.34 grams per larva when 32 larvae were applied (Figure 12).

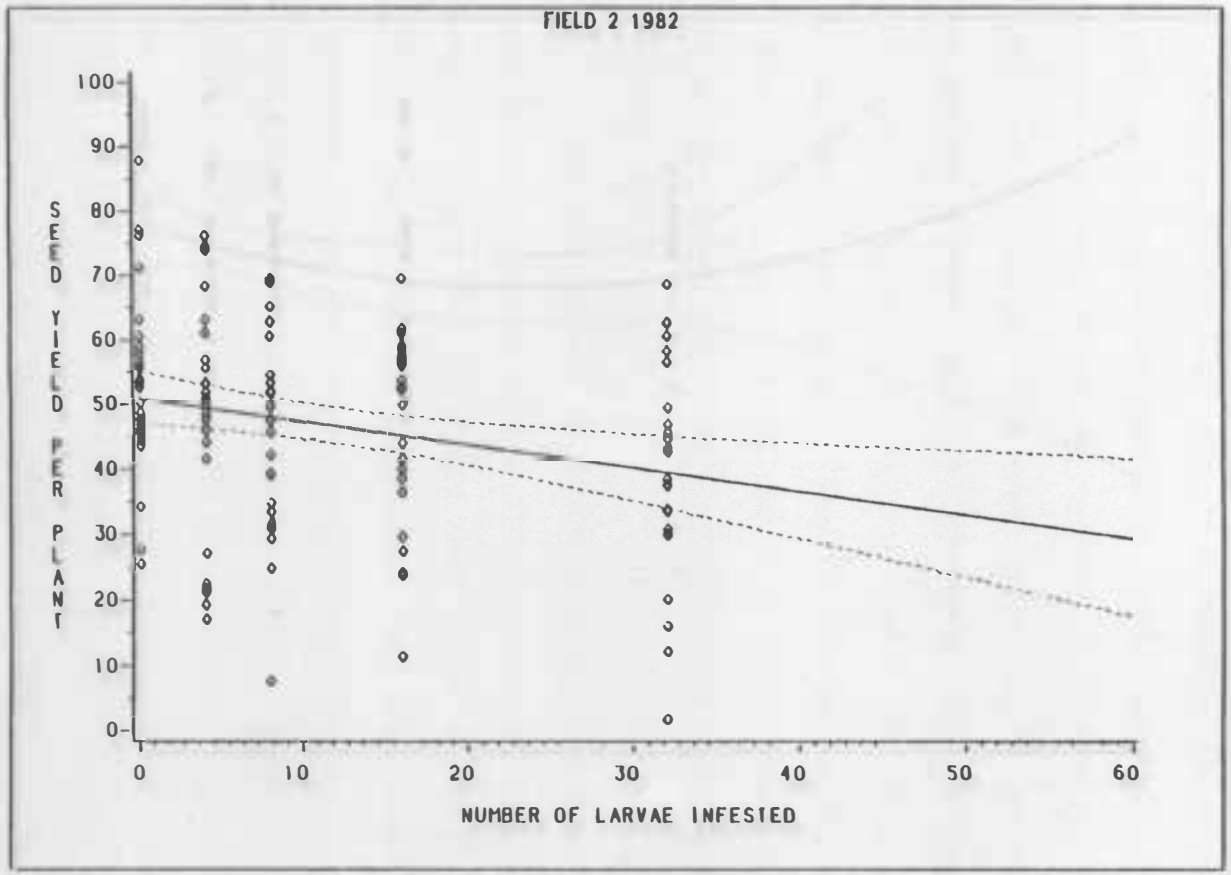

Figure 11. Regression and 95% confidence limits comparing seed yield per plant vs. the rate of artificial infestation of sunflower moth larvae in field 2, 1982. ($Y = 50.97 - 0.36\ X$, $R^2 = 0.065$). Regression was significant ($F = 0.05$).

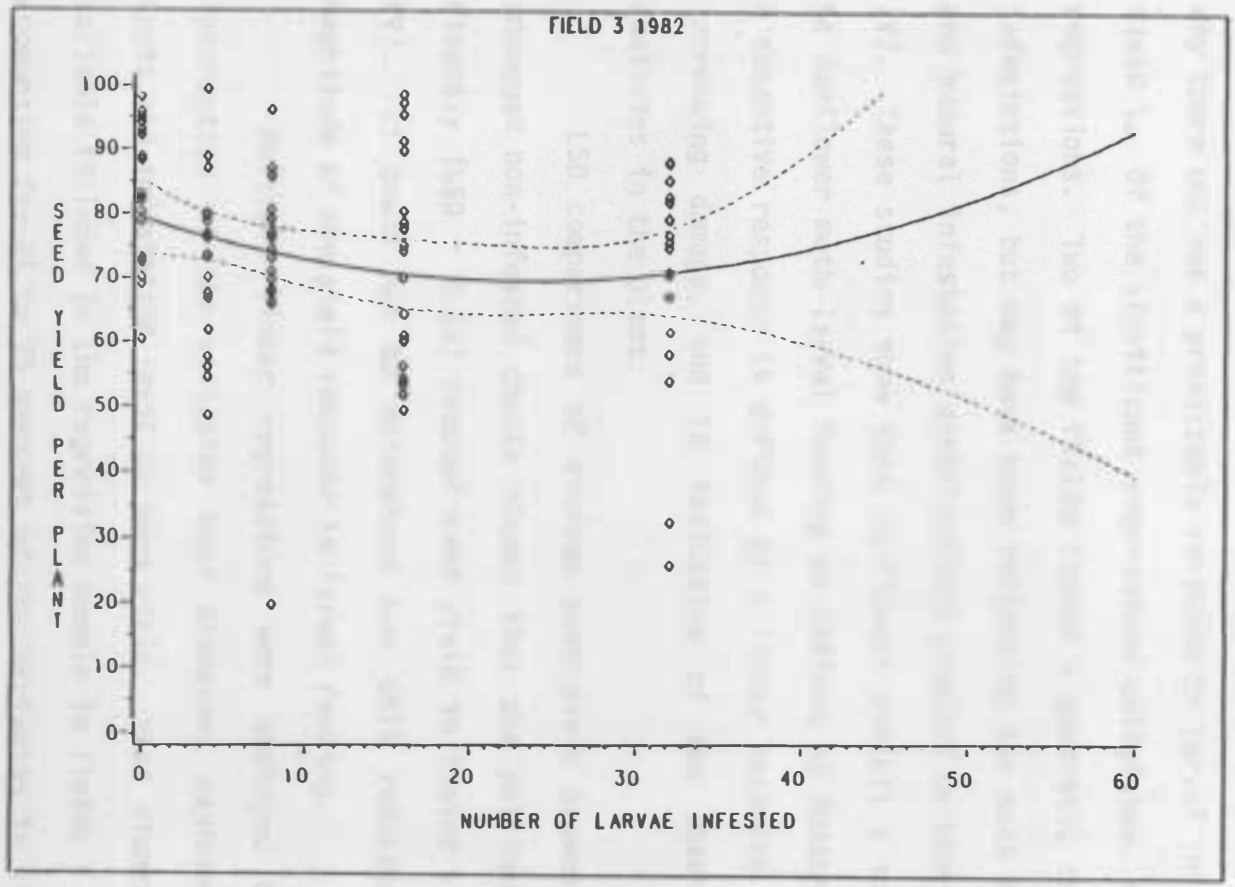

Figure 12. Regression and 95% confidence limits comparing seed yield per plant vs. the rate of artificial infestation of sunflower moth larvae in field 3, 1982. ($Y = 82.74 - 1.30\ X + 0.03\ X^2$, $R^2 = 0.06$). Regression was significant ($F = 0.05$).

The variable response surfaces and the low correlation in the regressions are consistent with the results from 1981. It is not known why there was not a predictable response to larval infestation level in field 1. Of the significant regressions calculated, three were linear regressions. Two of the fields showed a quadratic response to larval infestations, but may have been reflecting the moth recovery patterns and natural infestation distributions present in them (Appendix II and IV). These studies show that sunflowers exhibit a suseptive response to sunflower moth larval feeding as defined by Poston et. al. (1983). A suseptive response is defined as a linear response to increments of increasing damage, and is indicative of the absence of resistant qualities in the plant.

LSD comparisons of average seed yield between the bagged and unbagged non-infested checks showed that the pollinating bags significantly (LSD = 0.05) reduced seed yield in fields 1 and 2 (Appendix IV). It could not be determined how this reduction affected the magnitude of the yield response to larval feeding.

Multiple linear regressions were employed to evaluate the interaction of the variables head diameter, captured moths, damage spots and infestation level on seed yield. Head diameter was the only variable included in the regression models in fields 1 and 2 (Table 2), accounting for 21 to 75 percent of the variation in yield in fields 1 and 2 respectively. Head diameter and infestation level accounted for 48 percent of the variation in yield in field 3 (Table 2).

Table 2. Best fitting regression model for seed yield differences per plant in artificial infestation studies, 1982. All regressions were significant (F = 0.05)

Field No.	Independent Variable	R^2	Regression Model*
1	Diameter	0.75	S = -50.01 + 0.64 D
2	Diameter	0.21	S = -20.86 + 0.36 D
3	Diameter	0.43	S = -51.80 + 0.70 D
	Lar. Lev.	0.48	S = -51.21 - 0.32 L + 0.72 D

* S = Seed Yield
D = Head Diameter
P = Spots
M = Captured Moths
L = Larval Infestation Level

The consistent reoccurrence of head diameter in the multiple regressions supports Johnson and Schneiter's (1983) data concerning the variability of adjacent plants when trying to obtain accurate yield estimates. This data supports their argument that a small number of plants are needed to get accurate estimates of yield, especially since these plants were selected for uniformity.

This data can be applied to help clarify the economic threshold of the sunflower moth in South Dakota. Noetzel (1979) chose a yield reduction of ten percent as a base for calculating an economic injury threshold in Minnesota. If ten percent is used as a base in the infestation studies, then the larval threshold would be 15.6 larvae per plant in field 1 (1981), 7.5 larvae per plant in field 2 (1981), 19 larvae per plant in field 3 (1981), 14.2 larvae per plant in field 2 (1982) and 8.2 larvae per plant in field 3 (1982). Randolph et. al. (1972) reported that one female can lay 100 eggs. Noetzel stated that available data indicated that the male to female ratio was one to one. Noetzel calculated the economic injury threshold based on that information. This data would support his contention that the low end of the threshold (i.e. one moth per plant) is too conservative. If the threshold was one moth per five plants, and the male to female ratio is one to one, then 50 eggs would be produced, averaging 10 eggs per plant. A ten percent reduction in yield was not predicted in three of the fields until 14 or more larvae were infested. Additionally, egg mortality did not occur in this study. It must be pointed out that no infections of Rhizopus were observed, and Rogers et. al., (1976)

established an association between larval feeding and Rhizopus. Rhizopus could greatly increase yield loss, should it occur. This data points out the need for further quantification of the sunflower moth adult threshold in South Dakota.

It was noted earlier that damage spots were included in the multiple regression model measuring seed yield response to larval feeding. Carlson (1967) developed a visual rating index using counts of damage spots to evaluate insecticidal control of sunflower moth larvae in California. The underlying assumption is that a relationship exists between damage spots and larval survival. The number of moths captured in the pollinating bags was regressed on counts of damage spots to test that assumption. Data from all fields within each year were combined.

A significant (F = 0.05) cubic response was calculated for data in each year. The regression explained 60 percent of the variation in captured moths in 1981, and 70 percent of the variation in 1982 (Figures 13 and 14). Error in the estimations occurred from larval and adult moth escape from torn bags, but a positive correlation was found between larvae completing their lifecycle and damage spots.

Cage Studies: Cages were placed in a field in 1982 to evaluate them for use in studying the adult sunflower moth injury threshold. Cages have been used to study the impact of predators of green cloverworm Plathypena scabra (F.) in Iowa soybeans (Pedigo et. al. 1972) and to study the effects of Heliothis zea larval feeding on soybeans in Arkansas (Mueller and Engroff, 1980).

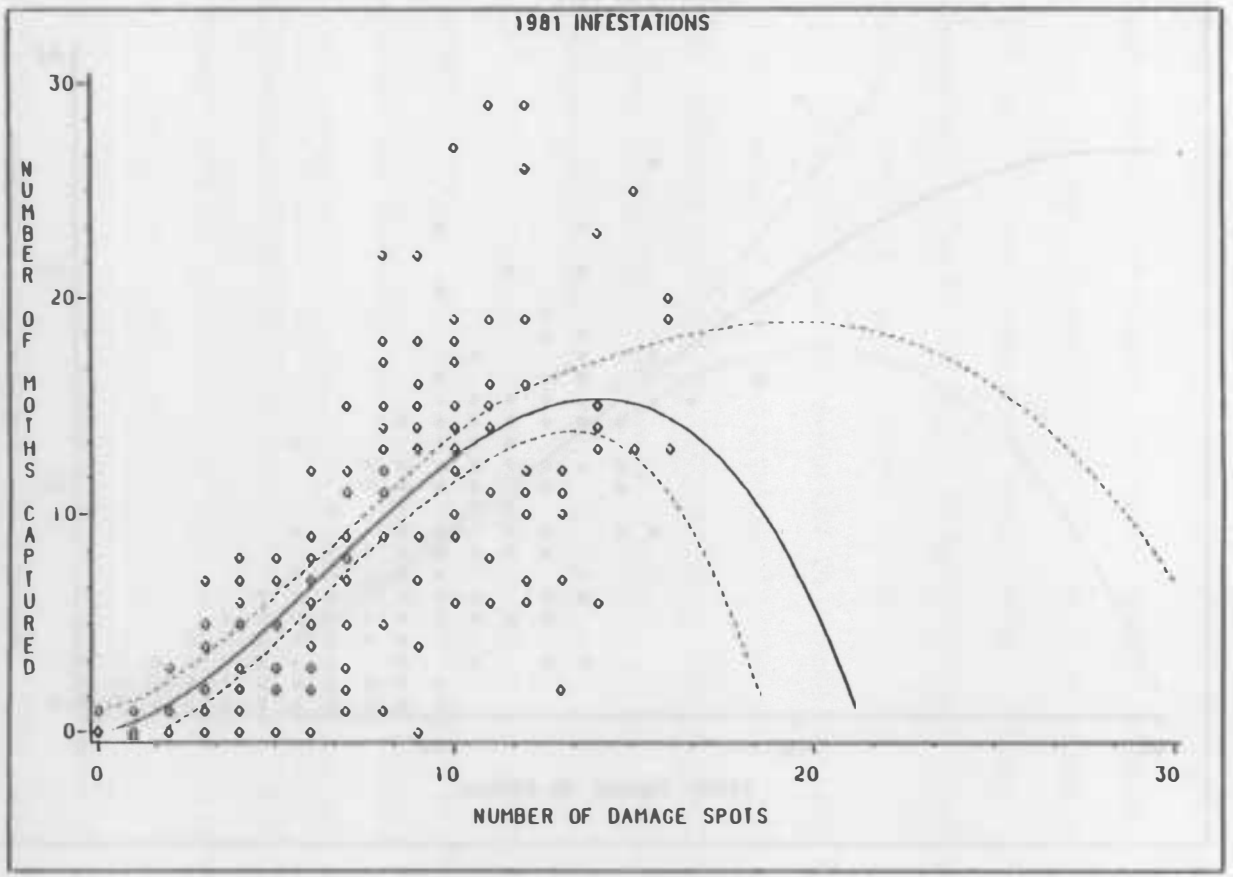

Figure 13. Regression and 95% confidence limits comparing the number of adult sunflower moths recovered vs. the number of damage spots per plant with artificial infestations of sunflower moth larvae, 1981. ($M = -0.05 + 0.28S + 0.20\ S^2 - 0.01\ S^3$, $R^2 = 0.60$). Regression was significant ($F = 0.05$).

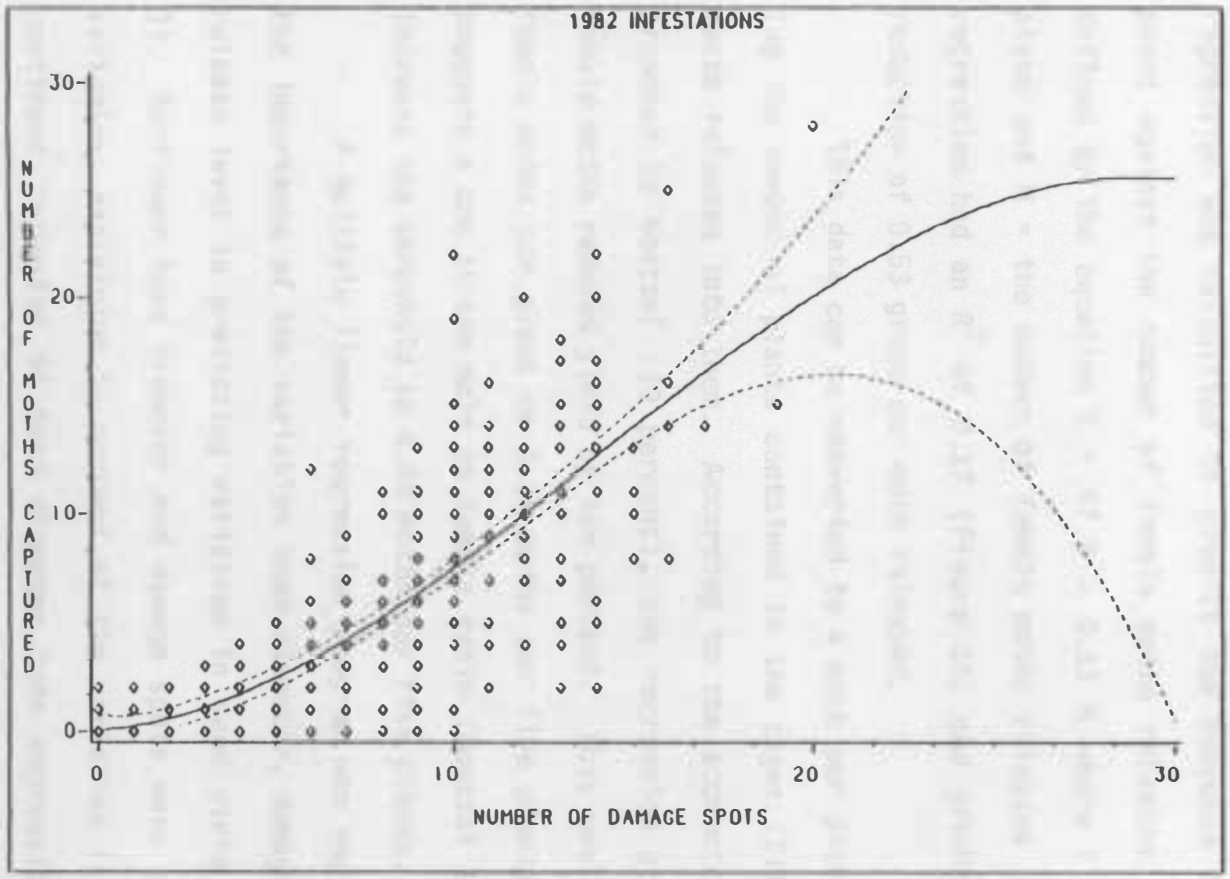

Figure 14. Regression and 95% confidence limits comparing the number of adult sunflower moths recovered vs the number of damage spots per plant with artificial infestations of sunflower moth larvae, 1982. ($M = -0.17 + 0.53\ S - 0.0003\ S^2 + 0.002\ S^3$, $R^2 = 0.695$). Regression was significant ($F = 0.05$).

A two-way analysis of variance showed that moth populations had a significant (F = 0.05) effect on seed yield (Appendix VI). A linear regression was calculated to predict the response of seed yield per plant against the number of female moths released. The response is defined by the equation Y = 47.8 - 0.53 M where Y = seed yield per plant and M = the number of female moths released in the cages. The regression had an R^2 of 0.17 (Figure 15) and predicted a seed yield reduction of 0.53 grams per moth released.

This data can be converted to a moth per plant basis by dividing the number of plants contained in the cages (21) by the number of moths released into them. According to the economic injury threshold proposed by Noetzel (10 percent), the regression predicted that nine female moths reduced yield by ten percent. This would convert to 0.42 female moths per plant or 2.14 moths per five plants. Available data suggests a one to one male to female ratio (Noetzel 1979), which would increase the threshold to 4.28 moths per five plants.

A multiple linear regression program was employed to evaluate the importance of the variables head diameter, damage spots, and adult release level in predicting variation in seed yield per plant (Table 3). Sunflower head diameter and damage spots were the most important variables, explaining 51 percent of the variation in seed yield. The continued inclusion of head diameter into regression models of sunflower yield in artificial infestation studies indicate the need for using small plot experiments to evaluate yield response in the field. The inclusion of damage spots into the regression model indirectly

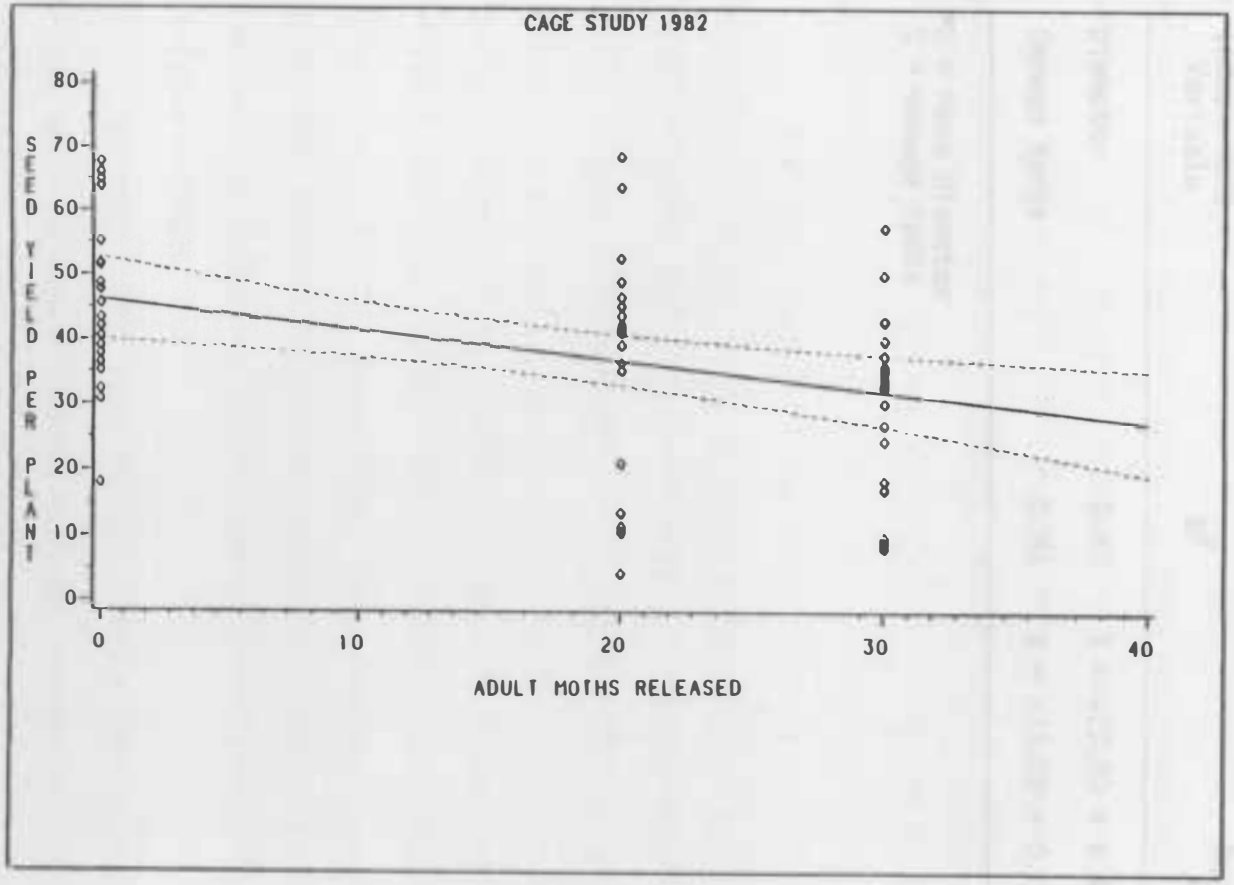

Figure 15. Regression and 95% confidence limits comparing seed yield per plant vs. the number of adult sunflower moths released in cages, 1982. ($Y = 47.80 - 0.53\ M$, $R^2 = 0.17$). Regression was significant ($F = 0.05$).

Table 3. Best fitting regression model for seed yield differences per plant in cages, 1982. All regressions were significant (F = 0.05).

Independent Variable	R^2	Regression Model*
Diameter	0.42	S = -27.03 + 0.45 D
Damage Spots	0.51	S = -14.08 = 0.09 S + 0.40 D

*D = Head Diameter
S = Damage Spots

suggest the relationship between visual damage and the larvae that complete their lifecycle.

Although the moths collected in this study were already ovipositing and therefore some may have had depleted reserves of eggs, the results of the cage infestations show that the current economic threshold may be overestimating the amount of damage that the sunflower moth causes. Additional studies evaluating the damage threshold of the sunflower moth are needed, and cages would provide an acceptable way of doing so.

Sex Ratio Studies: The male to female ratio of adult moths was determined from collections made in seven fields in 1981 and 1982. Collection times coincided with South Dakota recommendations concerning survey times. The expected ratio was assumed to be one to one for purposes of analysis. The sex ratio was different in six out of seven fields (Table 4). In fields 2 (1981), 5 (1982) and 6 (1982), collections consisted almost entirely of females ($P < 0.001$); in fields 1 (1981) and 3 (1981), significant more females ($P < 0.001$) were collected than males. More males were collected in field 4 (1981), and there was no difference in the observed ratio from the expected ratio in field 7 (1982).

Noetzel (1979) reasonably assumed a male to female ratio of one to one when he calculated an economic threshold for Minnesota. The collections in this study do not agree with that ratio. This may be due to the fact that the sunflower moth does not overwinter in South Dakota. Windborn populations may not contain the same ratio that an

Table 4. Goodness of fit of X^2 of adult moths (males and female) collected in cultivated sunflowers in eastern South Dakota, 1981-1982.

Field	Year	Females	Expected	Males	Expected	X^2	P
1	1981	38	27	16	27	20.04	0.001
2	1981	65	33.5	2	33.5	61.01	0.001
3	1981	63	51.5	40	51.5	21.04	0.001
4	1981	3	6.5	10	6.5	11.08	0.001
5	1982	59	30	1	30	56.01	0.001
6	1982	58	30.5	3	30.5	53.01	0.001
7	1982	10	11.5	13	11.5	1.34	0.250
	TOTALS	296		85			

endemic population would. Little information is available concerning the behavior of the sunflower moth as it relates to sex differences, or the difference in survival between them. Another possibility is that there may be discrimination in behavior between the sexes of the sunflower moth as it relates to spatial and temporal distribution in the field.

A deviation in the male to female ratio of sunflower moth populations from one to one could radically affect the reliability of making judgment on the potential for damage in a sunflower field. This data indicated that there may be such a difference. Further work is needed to determine how variable the ratio is, and what factors influence changes in that ratio.

Predator Survey: More than 40 species representing 24 families of insect and arachnid predators were collected and identified from the total of 3,276 predator specimens (Table 5). Previous surveys of sunflower predators have not been reported, so it is not known how this list compares with other areas. Bechinski and Pedigo (1982) collected over 80 species of predaceous arthropods from Iowa soybeans, and many of the species they identified were present in this sunflower insect collection. They felt that their collection was a conservative representation of the actual fauna present, therefore it cannot be assumed that this list completely represents the predaceous fauna present in South Dakota sunflowers.

Orius insidiosus (Say) was the most abundant species collected (1,153 specimens) followed by Nabis spp. (543 specimens), Chrysopa spp.

Table 5. Predaceous arthropods collected from cultivated sunflowers in eastern South Dakota, 1981-1982.

HEMIPTERA

Anthocoridae
  Orius insidiosus (Say)
Lygaeidae
  Geocoris bullatus (Say)
  G. pallens
Nabidae
  Nabis alternatus (Parshley)
  N. subcoleopteratus (Kirby)
Phymatide
  Phymata fasica Melin
Reduviidae
  Sinea diadema

NEUROPTERA

Chrysopidae
  Chrysopa carnea Stephens
  C. oculata Say
Hemerobiidae
  Micromus sp.

DIPTERA

Asilidae
  Protocanthus sp.
Dolichopodidae
  Condysostylus sipho (Say)
  Neosystormon sp.
Empidae
  Tachypeza sp.
Syrphidae
  no further identification
Therevidae
  Thereva sp.

ODONATA

Aeshnidae
  Aeshna sp.

HYMENOPTERA

Formicidae
  no further identification

ARANEIDEA

Lycosidae
  no further identification
Tetragnathidae
  no further identification
Theridiidae
  no further identification
Thomisidae
  no further idenfification

COLEOPTERA

Anthicidae
  Anthicus cervinus de La ferte-Senectere
  Anthicus sp.
Carabidae
  Amara carinata LeConte*
  A. obesa Say*
  Chlaenius platyderus Ghaudior*
  C. sericeus Forster*
  Evarthrus sodalis (Say)*
  Harpalus caliginosus (Fab.)*
  H. erraticus Say*
  H. pensylvanicus DeGeer*
  Pterostichus chalcites (Say)*
Cicindelidae
  Cicindela punctulata Oliver*
Cleridae
  Trichodes sp.
  Phyllobaenus sp.
Coccinelidae
  Brachyacantha ursina stellata Casey
  Coleomegilla maculata (DeGeer)
  Hyppodamia convergens Guerin-Meneville
  H. tridecimpunctata tibialis
Staphylinidae
  no further identification

*denotes captured by pitfall trap.

(466 specimens), and coccinelid beetles (315 specimens). Together, they comprised more than 70 percent of the total predator specimens collected (Table 6). There were numerous spiders present, but these were identified to family only. Condysostylus sipho (Say) was the most abundant dipterous predator collected. The other predators were collected only occasionally.

The pitfall traps were employed for one week, and the list of ground dwelling predators is not complete. Carabid beetles comprised most of the pitfall captured specimens.

Clausen (1940) provides a general account of the life histories of the insect predators collected, and Comstock (1940) gives information of the spider familes. Orius spp., Nabis spp., Chrysopa spp. and coccinelid beetles have all been reported as predaceous on the eggs and/or larvae of lepidoptera in various cultivated crops (Bell and Whitcomb 1964, McDaniel and Sterling 1979, and Pedigo et. al. 1972).

The main objective of this survey was to collect information on the presence of predators on both the foliage and flowers of cultivated sunflowers concurrent with potential peak densities of sunflower moth eggs and larvae. There was a diverse fauna present at the time. During the survey period, Chrysopa larvae and thomosid spiders were observed feeding on adult sunflower moths and larvae. Their presence in the field, their documented feeding on lepidoptera eggs and larvae, and the lack of data on sunflower moth egg and larval mortality in the field, indicate a potential area of future research.

Table 6. Relative abundance of predaceous arthropods collected from cultivated sunflowers in eastern South Dakota, 1981-1982.

Predator Type	Species	Number	Percent
Anthocoridae	Orius insidiosus	1153	35.2
Nabidae	Nabis spp.	543	16.6
Chrysopidae	Chrysopa spp.	466	14.2
Coccinelidae		315	9.6
Aranedia		261	8.0
Dolicopodidae		165	5.0
Formicidae		101	3.1
OTHERS		172	5.2
TOTAL		3176	100.0

Seasonal Abundance Studies: The seasonal abundance of O. insidiosus, Nabis spp., Chrysopa spp., and coccinelid beetles was examined because they were the most numerous predators collected in the survey. Observed population trends are shown in Figure 16. The abundance of all predators increased as the sunflower field matured. There appeared to be two population peaks for Chrysopa spp., one occurring in early July and the other in early August. Coccinelid adults were more abundant in mid-July, and populations decreased when the sunflowers began to bloom (Appendix VII). Nymphs of all four predators were collected, so it can be assumed that they reproduce in cultivated sunflowers. Immature lifestages were not separated from adults in the counts, so generations were not determined during the growing season.

The arthropods in this survey were collected without consideration of the weather, ambient temperature, or time of day. Dumas et. al. (1964) reported that those factors among others, influenced capture efficiency with a D-Vac for certain predators in soybeans. Marston et. al. (1976) found that the use of the vacuum-net did not accurately estimate population densities of some predators in Missouri soybeans. The high standard error of the samples collected in this study (Appendix VII) may reflect the lack of precision of the sampling regime used.

Feeding Studies: Laboratory feeding studies were conducted using first, third, and fifth instar sunflower moth larvae and four predators. Expected survival of the larvae was determined with a

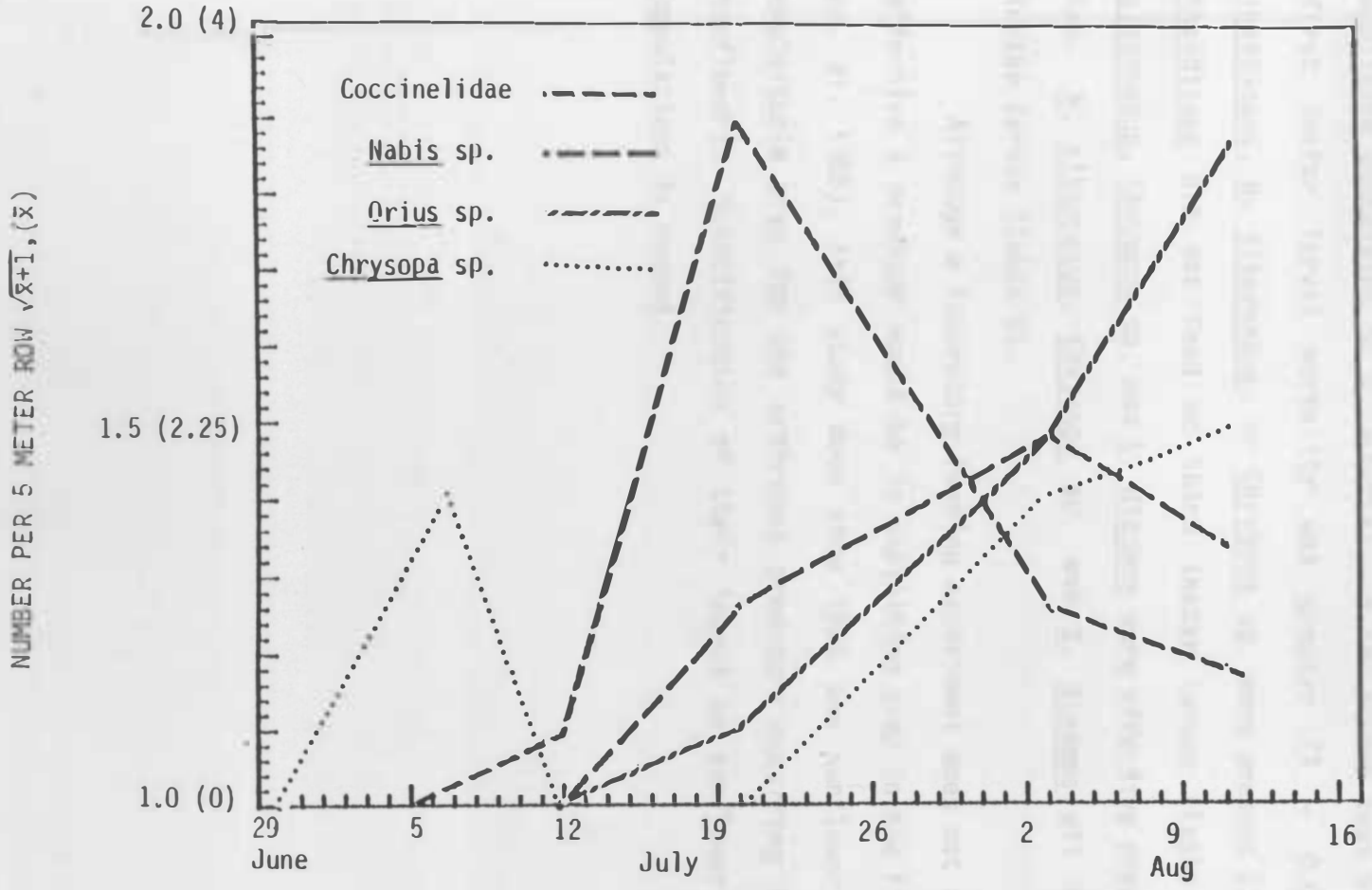

Figure 16. Population trends of four common predators sampled from sunflowers [$\sqrt{\bar{x}+1}$, ($\bar{x}$) = mean number of predators collected on each sampling date],1982.

duplicate containing no predator(s). A chi square test indicated that first instar larval mortality was greater ($P < 0.01$) when *O. insidiosus*, *N. alternatus*, or *Chrysopa* sp. were present (Table 7). *O. insidiosus* did not feed on third instar larvae (Table 8), but *N. alternatus*, *Chrysopa sp.* and *S. diadema* were effective predators in the lab. *N. alternatus*, *Chrysopa* sp. and *S. diadema* all fed on fifth instar larvae (Table 8).

Although a laboratory feeding experiment does not determine how effective a predator would be in exploiting prey in the field (Lingren et. al. 1968), this study does show that the sunflower moth is an exploitable prey for the arthropod predators occurring in cultivated sunflowers. Quantification of their impact on sunflower moth larval populations is needed.

Table 7. Goodness of fit of X^2 of dead first instar sunflower moth larvae in predator feeding study.

	Alive		Dead	
Classes	Observed	Calculated	Observed	Calculated
Check	30	20	5	15
Orius sp.	10	20	25	15
	df = 1	X^2 = 21.17	P .01	

	Alive		Dead	
Classes	Observed	Calculated	Observed	Calculated
Check	30	16	5	19
Nabis sp.	2	16	33	19
	df = 1	X^2 = 41.98	P .01	

	Alive		Dead	
Classes	Observed	Calculated	Observed	Calculated
Check	30	17	5	18
Chrysopa sp.	4	17	29	18
	df = 1	X^2 = 33.74	P .01	

Table 8. Goodness of fit of X^2 of dead third instar sunflower moth larvae in feeding study.

	Alive		Dead	
Classes	Observed	Calculated	Observed	Calculated
Check	30	30	5	5
Orius sp.	30	30	5	5
	df = 1	X^2 = 0.217	P .50	

	Alive		Dead	
Classes	Observed	Calculated	Observed	Calculated
Check	30	20	5	15
Nabis sp.	10	20	20	15
	df = 1	X^2 = 21.1	P .01	

	Alive		Dead	
Classes	Observed	Calculated	Observed	Calculated
Check	30	22	5	13
Chrysopa sp.	14	22	19	13
	df = 1	X^2 = 13.76	P .01	

	Alive		Dead	
Classes	Observed	Calculated	Observed	Calculated
Check	30	17	5	18
Sinea sp.	5	17	30	18
	df = 1	X^2 = 35.74	P .01	

Table 9. Goodness of fit of X^2 of dead fifth instar sunflower moth larvae in feeding study.

	Alive		Dead	
Classes	Observed	Calculated	Observed	Calculated
Check	7	4	0	3
Nabis sp.	2	4	5	3
	df = 1	X^2 = 9.92	P .01	

	Alive		Dead	
Classes	Observed	Calculated	Observed	Calculated
Check	7	4	0	3
Chrysopa sp.	1	4	6	3
	df = 1	X^2 = 7.29	P .01	

	Alive		Dead	
Classes	Observed	Calculated	Observed	Calculated
Check	7	4	0	3
Sinea sp.	0	4	7	3
	df = 1	X^2 = 7.30	P .01	

CONCLUSIONS

The effects of sunflower moth larval populations on cultivated sunflowers were studied with artificial infestations. Population effects on seed yield were analyzed with regressions. Adult moth recovery averaged slightly lower than was reported in a greenhouse study, indicating more mortality may have occurred in the field. Results showed that the number of captured adult moths did not adequately index the amount of damage to individual sunflowers, however the number of larvae that were initially applied to the plants did. The number of larvae did not account for a large portion of the variation in individual plant response, ranging from 6 to 30 percent of the variation. It was discovered that 7 to 19 larvae reduced average seed yield per plant ca. 10 percent.

Multiple regressions were used to determine the importance of several variables (ie. damage spots, captured moths, head diameter or larval infestation level) in a seed yield model for individual sunflower plants. Head diameter was the only consistant variable included in the regressions. Several of the fields proved to be too variable to establish a significant response to larval populations when head diameter was included in the regression model. The best fitting models for each field accounted for 20 to 75 percent of the variation in seed yield. The results showed that there was a great deal of variation between sunflower plants despite their being selected for uniformity.

The relationship between damage spots on sunflower plants caused by sunflower moth larval feeding and recovered adult sunflower moths was examined. A positive correlation was found between damage spots and captured moths, accounting for 60 to 70 percent of the variation on individual plants. Evidence was provided that visual damage could index the severity of larval infestation.

Cages were employed to evaluate their potential use for investigating adult sunflower moth damage thresholds. A regression comparing individual sunflower plant yield and adult moth populations indicated that a level of 2.14 females were needed to reduce yield by 10 percent ($R^2 = 0.17$).

The results of a survey undertaken to investigate the male to female ratio of the sunflower moth in cultivated sunflowers indicated that the ratio could deviate from the expected ratio of one to one.

The faunal composition of arthropod predators was sampled in cultivated sunflowers. An abundant and diverse arthropod predator population was found concurrent with the expected presence of sunflower moth larval populations. Laboratory feeding studies showed that the most abundant predators found (ie. Orius insidiosus (Say), Nabis spp., Chrysopa spp. and Sinea diadema), would readily feed on sunflower moth larvae.

These studies provided evidence that the current economic threshold used for determining treatment with insecticides may be overestimating the damage caused by the sunflower moth. Furthermore, there is an abundant fauna present that could feed on sunflower moth

larvae in the field. Further research on the bionomics of the sunflower moth in South Dakota would be useful in establishing a more precise economic threshold.

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APPENDICES

APPENDIX I

Analysis of variance of larval treatments vs. seed weight, damage spots, and moths 1981.

FIELD 1

Source	df	Anova SS	Observed F	Required F .05	Required F .01
	Seed Weight				
Replication	2	101.915	0.31	3.16	5.01
Treatment	4	6129.389	9.24**	2.54	3.68
Rep x Trt	8	844.102	0.64	2.11	2.85
Error	53	8786.567	----	----	----
	Damage Spots				
Replication	2	40.782	7.16**	3.16	5.01
Treatment	4	1190.805	104.60**	2.54	3.68
Rep x Trt	8	45.689	2.01	2.11	2.85
Error	53	150.850	----	----	----
	Moths				
Replication	2	53.930	1.55	3.16	5.01
Treatment	4	2503.742	36.51**	2.54	3.68
Rep x Trt	8	32.620	0.24	2.11	2.85
Error	53	907.550	----	----	----

*Significant at the $F_{.05}$ level

**Significant at the $F_{.01}$ level

APPENDIX I (continued)

FIELD 2

Source	df	Anova SS	Observed F	Required F .05	Required F .01
	Seed Weight				
Replication	2	191.036	0.68	3.16	5.01
Treatment	4	1617.299	2.86*	2.54	3.68
Rep x Trt	8	914.986	0.81	2.11	2.85
Error	54	7634.400	----	----	----
	Damage Spots				
Replication	2	79.438	6.74**	3.16	5.01
Treatment	4	1148.805	48.70**	2.54	3.68
Rep x Trt	8	64.830	1.37	2.11	2.85
Error	54	318.450	----	----	----
	Moths				
Replication	2	273.509	4.19*	3.16	5.01
Treatment	4	1329.389	10.18**	2.54	3.68
Rep x Trt	8	250.213	0.96	2.11	2.85
Error	54	1763.200	----	----	----

*Significant at the $F_{.05}$ level

**Significant at the $F_{.01}$ level

APPENDIX I (continued)

FIELD 3

Source	df	Anova SS	Observed F	Required F .05	Required F .01
	Seed Weight				
Replication	2	1367.621	3.20*	3.21	5.12
Treatment	4	3620.432	4.24**	2.58	3.78
Rep x Trt	8	1725.351	1.01	2.16	2.95
Error	44	9400.250	----	----	----
	Damage Spots				
Replication	2	10.429	0.92	3.21	5.12
Treatment	4	583.531	25.63**	2.58	3.78
Rep x Trt	8	33.388	0.73	2.16	2.95
Error	44	250.417	----	----	----
	Moths				
Replication	2	75.697	1.50	3.21	5.12
Treatment	4	1692.085	16.76**	2.58	3.78
Rep x Trt	8	229.409	1.14	2.16	2.95
Error	44	1110.250	----	----	----

*Significant at the $F_{.05}$ level

**Significant at the $F_{.01}$ level

APPENDIX II

Means (and standard error) of damage spots, captured moths, head diameter and seed yield in artificial infestation studies, 1981.

Field No.	Infestation Rate	Damage Spots	Captured Adults	Head Diameter (mm)	Seed Yield (gms)
1	0 (bagged)	2.60 (0.45)	1.98 (1.15)	174.33 (5.04)	65.62 (3.46)
	10	6.71 (0.50)	3.33 (1.22)	165.47 (5.33)	52.01 (3.80)
	25	8.83 (0.45)	11.03 (1.11)	156.78 (4.85)	50.20 (3.46)
	50	11.33 (0.44)	15.67 (1.07)	153.67 (4.66)	43.07 (3.22)
	0 (unbagged)	0.00 (0.45)*	0.00 (1.11)	167.60 (4.85)*	67.41 (3.46)
	LSD 0.05	2.20	2.03	6.40	4.58
2	0 (bagged)	6.02 (0.65)	4.95 (1.54)	162.75 (4.58)	54.32 (3.20)
	10	7.53 (0.63)	7.53 (1.48)	154.33 (4.40)	45.07 (3.07)
	25	11.67 (0.70)	13.00 (1.65)	148.58 (4.92)	41.50 (3.43)
	50	11.03 (0.65)	10.53 (1.54)	151.83 (4.58)	41.91 (3.20)
	0 (unbagged)	0.17 (0.65)*	0.08 (1.54)*	155.72 (4.58)*	49.80 (3.20)*
	LSD 0.05	2.41	3.38	5.86	4.67
3	0 (bagged)	4.17 (0.69)	5.08 (1.45)	173.25 (4.71)	50.00 (4.22)
	10	4.83 (0.69)	6.42 (1.45)	165.25 (4.71)	43.83 (4.22)
	25	5.70 (0.69)	12.83 (1.45)	172.25 (4.71)	40.42 (4.22)
	50	9.30 (0.73)*	14.92 (1.52)*	148.61 (4.96)	35.92 (4.45)
	0 (unbagged)	0.00 (0.69)*	0.00 (1.45)*	179.08 (4.71)	58.58 (4.22)*
	LSD 0.05	2.04	3.30	5.56	5.48

*Means are significantly different from the bagged non-infested check at the 0.05 level (Dunnets test).

APPENDIX III

Analysis of variance of infestation treatments vs. seed weight, damage spots, and moths in 1982.

FIELD 1

Source	df	Anova SS	Observed F	Required F .05	Required F .01
	Seed Weight				
Replication	3	1029.229	3.63*	2.72	4.04
Treatment	5	1093.329	2.32*	2.32	3.23
Rep x Trt	15	1149.828	0.81	1.78	2.25
Error	96	9066.984	----	----	----
	Damage Spots				
Replication	3	13.260	0.99	2.72	4.04
Treatment	5	2161.767	96.89**	2.32	3.23
Rep x Trt	15	84.433	1.26	1.78	2.25
Error	96	428.400	----	----	----
	Moths				
Replication	3	32.733	1.49	2.72	4.04
Treatment	5	2580.267	70.45**	2.32	3.23
Rep x Trt	15	217.667	1.98*	1.78	2.25
Error	96	703.200	----	----	----

*Significant at the $F_{.05}$ level

** Significant at the $F_{.01}$ level

APPENDIX III (continued)

FIELD 2

Source	df	Anova SS	Observed F	Required F .05	.01
	Seed Weight				
Replication	4	539.646	0.52	2.45	3.48
Treatment	5	29704.937	22.87**	2.29	3.17
Rep x Trt	20	4867.679	0.94	1.66	2.03
Error	120	31166.400	----	----	----
	Damage Spots				
Replication	4	18.973	0.83	2.45	3.48
Treatment	5	2182.053	76.06**	2.29	3.17
Rep x Trt	20	86.947	0.76	1.66	2.03
Error	120	688.400	----	----	----
	Moths				
Replication	4	113.733	3.84**	2.45	3.48
Treatment	5	3067.600	82.82**	2.29	3.17
Rep x Trt	20	93.467	0.63	1.66	2.03
Error	120	889.200	----	----	----

*Significant at the $F_{.05}$ level

**Significant at the $F_{.01}$ level

APPENDIX III (continued)

FIELD 3

Source	df	Anova SS	Observed F	Required F .05	.01
	Seed Weight				
Replication	3	1181.838	1.37	2.72	4.04
Treatment	5	3732.525	2.59*	2.32	3.23
Rep x Trt	15	5552.596	1.29	1.78	2.25
Error	95	27345.780	----	----	----
	Damage Spots				
Replication	3	105.331	5.07**	2.72	4.04
Treatment	5	1523.574	44.03**	2.32	3.23
Rep x Trt	15	249.329	2.40**	1.78	2.25
Error	95	657.400	----	----	----
	Moths				
Replication	3	179.828	2.28	2.72	4.04
Treatment	5	937.242	7.12**	2.32	3.23
Rep x Trt	15	383.636	0.97	1.78	2.25
Error	95	2501.550	----	----	----

*Significant at the $F_{.05}$ level

**Significant at the $F_{.01}$ level

APPENDIX IV

Means (and standard error) of damage spots, captured moths, head diameter and seed yield in artificial infestation studies, 1982.

Field No.	Infestation Rate	Damage Spots	Captured Adults	Head Diameter (mm)	Seed Yield (gms)
1	0 (bagged)	3.30 (0.48)	1.75 (0.70)	146.95 (5.24)	46.15 (2.63)
	4	4.42 (0.48)	2.50 (0.70)	146.60 (5.24)	44.04 (2.63)
	8	8.25 (0.48)	5.60 (0.70)	142.80 (5.24)	43.21 (2.63)
	16	10.30 (0.48)	8.65 (0.70)	159.55 (5.24)	43.77 (2.65)
	32	12.50 (0.48)	13.65 (0.70)	143.10 (5.24)	44.24 (2.65)
	0 (unbagged)	0.25 (0.48)*	0.05 (0.70)	156.80 (5.24)*	51.34 (2.65)
	LSD 0.05	1.75	2.23	5.52	3.63
2	0 (bagged)	2.36 (0.48)	0.76 (0.54)	195.36 (3.67)	53.60 (3.22)
	4	4.64 (0.48)	2.08 (0.54)	193.48 (3.67)	48.36 (3.22)
	8	5.64 (0.48)	2.24 (0.54)	192.12 (3.67)	45.56 (3.22)
	16	9.00 (0.48)	5.60 (0.54)	185.88 (3.67)	45.80 (3.22)
	32	11.60 (0.48)	13.32 (0.54)	178.79 (3.67)	39.95 (3.22)
	0 (unbagged)	0.28 (0.48)*	0.00 (0.54)	211.56 (3.67)*	82.82 (3.22)*
	LSD 0.05	1.46	1.49	4.94	4.01
3	0 (bagged)	6.65 (0.59)	4.80 (1.15)	186.45 (3.38)	86.20 (3.79)
	4	8.85 (0.59)	5.30 (1.15)	176.85 (3.38)	73.34 (3.79)
	8	8.23 (0.59)	3.74 (1.15)	179.02 (3.38)	73.58 (3.79)
	16	11.05 (0.59)	9.70 (1.15)	181.65 (3.38)	72.95 (3.79)
	32	11.25 (0.59)	7.25 (1.15)	185.65 (3.38)	73.43 (3.79)
	0 (unbagged)	0.65 (0.59)*	0.70 (1.15)*	189.20 (3.38)	84.01 (3.79)
	LSD 0.05	2.04	3.60	5.56	5.48

*Means are significantly different from the bagged non-infested check at the 0.05 level (Dunnetts test).

APPENDIX V

Analysis of variance of adult moth treatments vs. seed weight, damage spots, and diameter in cages, 1982.

Source	df	Anova SS	Observed F	Required F .05	Required F .01
	Seed Weight				
Treatment	2	2815.618	5.97**	3.15	4.98
Error	58	13672.925			
	Damage Spots				
Treatment	2	1694.522	196.20**	3.15	4.98
Error	58	250.462			
	Head Diameter				
Treatment	2	1598.587	1.42	3.15	4.98
Error	58	32714.822			

*Significant at the $F_{.05}$ level

**Significant at the $F_{.01}$ level

APPENDIX VI

Analysis of variance for regressions comparing captured moths vs. damage spots in artificial infestation studies, 1981-1982.

Source	df	Anova S.S.	Anova M.S.	Observed F	Required 0.05
		1981			
Regression	1	155.42	155.42	7.36	2.66
Error	192	4052.34	21.11		
		1982			
Regression	1	39.42	39.42	4.19	2.64
Error	385	3619.23	9.40		

APPENDIX VII

Average number (and standard error) of selected predators sampled per 5 meter row of sunflowers per day at a field located near Brookings, South Dakota.

Date	GS*	*Orius* sp.	*Nabis* sp.	*Chrysopa* sp.	Coccinelidae
6/29	2.1	0.0 (0.00)	0.0 (0.00)	0.0 (0.00)	0.0 (0.00)
7/7	2.3	0.0 (0.00)	0.0 (0.00)	1.0 (0.50)	0.0 (0.00)
7/12	2.5	0.0 (0.00)	0.0 (0.00)	0.0 (0.00)	0.2 (0.20)
7/20	3.2	0.2 (0.20)	0.6 (0.80)	0.0 (0.00)	2.6 (3.80)
8/3	4.1	1.2 (1.20)	1.2 (0.20)	1.0 (1.70)	0.6 (0.30)
8/11	4.4	2.4 (1.30)	0.8 (0.70)	1.2 (1.70)	0.4 (0.30)

*Growth Stage after Siddiqui et. al. 1975.

APPENDIX VIII

Total number of dead first instar Sunflower moth larvae in predator feeding studies.

Check		Orius sp.	
Replicate	Dead larvae	Replicate	Dead larvae
1	1	1	3
2	0	2	3
3	0	3	5
4	2	4	3
5	0	5	4
6	1	6	5
7	1	7	2

Nabis sp.		Chrysopa sp.	
Replicate	Dead larvae	Replicate	Dead larvae
1	5	1	4
2	5	2	4
3	4	3	4
4	5	4	5
5	5	5	5
6	4	6	4
7	5	7	5

APPENDIX IX

Total number of dead third instar Sunflower moth larvae in predator feeding studies.

Check		Orius sp.	
Replicate	Dead larvae	Replicate	Dead larvae
1	1	1	0
2	0	2	2
3	1	3	0
4	0	4	1
5	2	5	1
6	0	6	0
7	1	7	1

Nabis sp.		Chrysopa sp.	
Replicate	Dead larvae	Replicate	Dead larvae
1	4	1	3
2	4	2	3
3	3	3	4
4	2	4	2
5	4	5	2
6	3	6	3
7	5	7	4

Sinea sp.	
Replicate	Dead larvae
1	5
2	4
3	5
4	3
5	4
6	5
7	4

APPENDIX X

Total number of dead fifth instar Sunflower moth larvae in predator feeding studies.

Check		Nabis sp.	
Replicate	Dead larvae	Replicate	Dead larvae
1	0	1	1
2	0	2	0
3	0	3	1
4	0	4	1
5	0	5	1
6	0	6	0
7	0	7	1

Chrysopa sp.		Sinea sp.	
Replicate	Dead larvae	Replicate	Dead larvae
1	1	1	1
2	1	2	1
3	1	3	1
4	0	4	1
5	1	5	1
6	1	6	1
7	1	7	1