INSECT PEST PROBLEMS OF SUNFLOWER WITH PARTICULAR REFERENCE TO THE SUNFLOWER BEETLE, *ZYGOGRAMMA EXCLAMATIONIS* (FABRICIUS), IN MANITOBA

by

Yakub Daud Deedat

A THESIS

presented to the University of Manitoba

in partial fulfillment of the

requirements of the degree of

DOCTOR OF PHILOSOPHY

IN

THE DEPARTMENT OF ENTOMOLOGY

Winnipeg, Manitoba, 1987

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This thesis is dedicated to my beloved mother, Khatija Daud Deedat, and my late father, Daud Hussien Deedat.

May it also serve as a source of inspiration to my nephews, Daud, Mohmed and Zubair; and my nieces, Zainub, Summayya, Amina and Khatija.

Deedat, Yakub Daud, Ph.D.

The University of Manitoba; 1987

Insect Pest Problems of Sunflower with Particular Reference to the Sunflower Beetle, *Zygogramma exclamationis* (Fabricius), in Manitoba.

Major Professor: Dr. P.A. MacKay

ABSTRACT

Data for this study were collected during the summers of 1983 to 1985. Field and grower surveys were conducted to determine the status of the sunflower-insect pest complex as well as their management by growers. Sunflower beetle, sunflower midge, sunflower maggot, banded sunflower moth and sunflower moth were the most prevalent species and found in at least 10 of the 12 fields that were surveyed. However, pests of primary concern to growers were the sunflower beetle, the sunflower midge and cutworms. Cultural control did not play a major role in the management of these pests. More than 80% of the growers indicated that they use economic thresholds when available. However, data from the field survey on sunflower beetle showed that growers applied insecticides at well below the currently recommended threshold values.

Insect densities were manipulated on individual plants in caged and open studies to determine the effect of defoliation of sunflower by sunflower beetle. Head

diameter, yield and seed weight decreased, whereas oil content increased with increasing beetle densities. A curvilinear relationship between pest density and yield was obtained for adults and larvae. These quadratic polynomial regressions were used to estimate the economic thresholds which ranged from 2-3 adults and 5-10 larvae per plant.

Sunflower plants were artificially defoliated at five growth stages using four levels of defoliation to simulate time of damage and time of insecticide application in relation to the sunflower beetle. Growth and yield components generally decreased with increasing levels of defoliation. Plants in their early growth stages (V4-V8) were most sensitive to defoliation. Plants showed compensation at low levels of defoliation. Depending on the duration of defoliation, a linear or a quadratic relationship between yield and defoliation was obtained. These relationships were used to calculate defoliation thresholds for individual growth stages.

A sequential decision plan for the control of sunflower beetle larvae was developed from studies of larval dispersion in growers' fields. Iwao's patchiness regression technique was used as a basis for the sequential model since it provided a consistently good fit to the data. The plan should minimize sampling efforts and provide a reliable method of assessing whether control is required.

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CHAPTER 1

INTRODUCTION

1.1 PROBLEMS

Commercial sunflower, Helianthus annuus var. macrocarpus (Decandolle) Cockerell, is one of the four most important annual crops grown for edible oil (Putt 1978). Sunflower ranked tenth as a world source of vegetable oil in 1930 (Cobia 1976) and is currently third only to soybean and palm (Anonymous 1986). In recent years, production has undergone rapid expansion, particularly in North America. Since 1966, production has increased more than tenfold in Canada and the U.S.A. (Cobia 1978; Putt 1978). The development of high yielding disease-resistant hybrids was the major factor contributing to the increase in sunflower production in these countries (Heiser 1978; Campbell 1979).

In Canada, sunflower was initially grown in Saskatchewan and Alberta, but later, production shifted almost entirely to the Red River Valley region of south-central Manitoba (Putt 1978). From 1976 to 1985 an average of 82,200 hectares were sown to sunflower in Manitoba (Anonymous 1986). Although sunflower hectarage has declined significantly since 1980, Manitoba has continued to be the most important producer in Canada, contributing more than 80% to the total Canadian production of sunflower (Anonymous 1986).

Sunflower is native to North America (Heiser 1978) and a large number of insect species are associated with it. Over 150 species of phytophagous insects have been recorded from wild and cultivated varieties of *H. annuus* L. in North America north of Mexico (Hilgendorf and Goeden 1981). Although the number of species is large, pests of economic importance are relatively few. The life cycles, seasonal activity, damage characteristics, host preference, and control of the more important head-infesting, foliage and stem-feeding, and root-infesting species have been discussed (Schulz 1978; McMullen 1985). Pertinent references on economically important insect pests of sunflower have also been published (Rogers 1979).

With increased production there has been a corresponding increase in insect infestation. Insect depredation has been an important deterrent to sunflower production both in Canada and the U.S.A. (Schulz 1978). In the U.S.A., a different species occurred in outbreak numbers in each year from 1970 to 1975 (Schulz and Oseto 1979). In North Dakota alone, over 15 species are of current concern (McBride *et al*. 1985b). Several of these insects have caused moderate to severe yield reductions in recent years (Cobia and Zimmer 1978; Schulz 1982). In Manitoba, insect damage to sunflower has been restricted to about five species (Westdal and Barrett 1955; Westdal 1975). The occurrence, as well as economic significance of these pests, has fluctuated from year to year (Westdal 1975; Anonymous

1987). In recent years there has been no systematic documentation of the insect pests that attack sunflower in Manitoba; neither is there any information to indicate the importance of these insects to growers or how growers manage these pests.

The sunflower beetle, *Zygogramma exclamationis* (F.), is considered one of the five most important insect pests of commercial sunflower in Manitoba (Westdal and Barrett 1955) and one of the six most important sunflower pests in North Dakota (Schulz and Lipp 1969). In Manitoba, extensive use of insecticides was required to control the outbreaks of this pest on three occasions: 1952, 1957-59, and 1971 (Westdal 1975). Although no major outbreaks have been reported in recent years, the beetle is present annually. Both adults and larvae defoliate plants. Even moderate defoliation may result in delayed maturity and seed losses of up to 8 percent (Westdal *et al*. 1976).

Chemical control is the only method currently used for the control of the sunflower beetle. But, the effectiveness of chemical control is dependent upon, among other things, well documented economic thresholds. Economic thresholds for adults and larvae have been reported. However, the adult threshold levels in Manitoba (Westdal *et al*. 1976) are at variance with those in North Dakota (McBride *et al*. 1985b). There are no reports from either region to indicate the basis for the difference in these thresholds; neither is there any published information on how the thresholds were developed.

Insecticides used for the control of adults are also effective for the control of larvae (Anonymous 1987). If properly timed, one application is adequate to obtain control of either the adults or the larvae (Westdal _et al_. 1976). Timing of application is critical since the insecticides for the control of adults must be applied before the eggs are laid, and for the larvae, after all the eggs have hatched (Westdal _et al_. 1976).

Neill (1982) emphasized larval control and proposed the mid-point in the development of the second instar as the optimal time for control. At that time most eggs will have hatched and little foliar damage will have been done by the larvae. The mid-point in the larval development occurs 21 days after the first egg hatch is noted. Determining the date of first hatch is not only difficult but also time consuming since the grower is required to monitor the field at three to four day intervals.

Neill's (1982) method of determining the optimal time of control is based on larval phenology. But, plants differ in susceptibility to insect damage depending on the growth stage at the time of infestation (Bardner and Fletcher 1974). Thus, for practical application, Neill's (1982) recommendation must be supplemented with information on the plant's phenology. There are no reports to indicate the stage of crop development at which insecticides should be applied to minimize damage; neither is there any information on the critical stage of plant growth and infestation level at which damage occurs.

The effectiveness of chemical control is dependent upon efficient and practical monitoring systems. The recommended procedure for monitoring the sunflower beetle is to sample randomly 100 plants in an "X" pattern, starting 30 m away from the field margins (McBride *et al*. 1985b). There are no reports in the literature to show how this sampling procedure was developed. What growers need is a rapid and statistically reliable method of classifying populations into those that require control and those that do not. This objective can be met through the use of sequential decision plans (Waters 1955; Iwao 1975). No studies have attempted to develop such a sampling technique for the sunflower beetle. Thus, there is little reliable information which growers can use to make sound management decisions with regard to the control of sunflower beetle.

1.2 OBJECTIVES

The study was designed to achieve the following objectives:

i) To evaluate the status of sunflower insect pests and their management by growers in Manitoba.

Information on the type of insect pests and their importance to growers would be useful in developing pest management programs. It would aid researchers and extension personnel in identifying current and future research needs.

ii) To determine the effect of defoliation of sunflower by the sunflower beetle and develop economic thresholds.

Economic thresholds would enable growers to apply insecticides only when necessary. This would prevent prophylactic sprays and in turn reduce production costs and increase farm net income.

iii) To determine the stage of plant growth most sensitive to defoliation in relation to the sunflower beetle.

Information on the level of defoliation at various growth stages of the plant would lead to the determination of defoliation thresholds. This knowledge would also help researchers to determine the optimum time of control and identify the plant stage at which insecticide should be applied.

iv) To establish the spatial dispersion of sunflower beetle larvae in growers' fields and develop a sequential sampling plan.

Information on the spatial dispersion of the larvae could lead to the development of a sequential sampling scheme, thus enabling growers to determine rapidly and efficiently whether a particular population warrants control. Knowledge on the dispersion pattern would also aid in determining whether the entire field must be sprayed or if only border treatments are necessary.

1.3 THESIS ORGANIZATION

The results reported in this thesis are from experiments conducted during the summers of 1983, 1984 and 1985. The status of sunflower insect pests and their management by growers was determined using field and grower surveys. Damage assessment studies were conducted at the Glenlea Research Station, using field cages. Studies on economic thresholds were done by artificially infesting individual plants in plots at Glenlea. The critical stage of plant growth and the optimum time of control were determined by artificially defoliating the plants in plots at Glenlea. Growers' fields were used to establish the distribution of the larvae by systematically sampling entire fields along eight transects.

The thesis is written in chapters, each covering a separate aspect of the research. In Chapter 1 the problems are identified. Chapter 2 reviews the literature pertaining to the crop and the sunflower beetle. Chapter 3 describes the experimental studies and is written in four sections in a style suitable for publication as a series of scientific papers. Results of field and grower surveys are reported in Section I. Economic threshold studies and damage assessment experiments are presented in Section II. Damage simulation studies are reported in Section III, while Section IV covers the studies on spatial dispersion and sampling. Chapter 4 provides a general discussion and Chapter 5 presents conclusions.

CHAPTER 2

LITERATURE REVIEW

2.1 THE SUNFLOWER PLANT

2.1.1 Domestication and Development

The origins and early history of the sunflower plant including its introduction, distribution and adoption as a commercial crop in Europe and North America have been reviewed (Heiser 1978; Putt 1978). Sunflower is among the few food plants to have been domesticated in prehistoric times on the North American continent (Heiser 1978). It has been part of the culture of North American Indians for 30 centuries or more (Heiser 1955). The Indians utilized the plant not only for food but also for ceremonial and medicinal purposes (Heiser 1951).

Using carbon-14 dating, archaeologists have found evidence of sunflower in the Mississippi-Missouri basin 2,800 years ago (Lees 1965 in Putt 1978). It is thought that sunflower may have been domesticated before corn (*Zea mays* L.) was introduced to North America (Whiting 1939 in Putt 1978). It is not clear whether the sunflower was independently domesticated in several places or domesticated in one place and then radiated to several areas.

The sunflower was initially introduced into Europe via Mexico and Spain during the early 16th century (Zukovsky

1950 in Putt 1978). By the end of the 18th century, sunflower began to be cultivated on a commercial scale in Russia. Russian varieties of sunflower were subsequently introduced to North America. Most sunflower historians agree that the present cultivated sunflower was established in North America after 1880 following introduction of improved varieties developed in Russia; however, the precise date or route of the introduction is not clear (Heiser 1978).

During the early 1900's, sunflower was grown mainly for silage, both in Canada and the U.S.A. (Geise 1974). Commercial production of sunflower as an oilseed crop began in Canada in 1943 and in the U.S.A. in 1947 (Geise 1974). Since the first introduction of the crop, a number of oilseed cultivars have been grown in Canada. Early breeding work at Saskatoon, using Russian varieties of sunflower, resulted in the release of cultivars Mennonite and Sunrise, and the hybrids Advance, Advent and Admiral (Putt 1978). In 1964, production for oil gained new interests with the introduction of Russian cultivars such as Peredovik and Krasnodarets. The oil content of these cultivars had been increased from about 28% to over 40%, rendering the earlier cultivars obsolete (Putt 1978).

Another major advancement during this period was the discovery of cytoplasmic male sterility and fertility restorer genes (Fick 1978). These discoveries provided a practical method of producing hybrid sunflower. The first hybrids produced by the cytoplasmic male sterility and genetic fertility restorer system were released for commercial production in the U.S.A. in 1972. By 1976, these hybrids accounted for over 90% of the sunflower production in the U.S.A. (Fick 1978). In Canada, the first of these hybrids was licensed in 1978 (Dedio *et al*. 1980) and within four years, accounted for 95% of the plantings (Anonymous 1981).

The new hybrids yielded an average of 25% more than the Russian cultivars and still maintained a high oil content of 40-50%. Further, most of these hybrids were resistant to three of the major diseases of sunflower, namely rust (*Puccinnia helianthi* Schw.), downy mildew [*Plasmopara halstedii* (Farl.) Berl and de Toni], and Verticillium wilt (*Verticillium dahliae* Kleb.) (Fick 1978). Thus, the production of hybrids, and of types resistant to diseases along with the increase in oil content were among the notable developments which have made sunflower economically competitive with other crops (Heiser 1978). These developments along with other agronomic improvements in the culture of sunflower, enabled growers to obtain yields 30 to 50% higher than those of the 1960's with open-pollinated cultivars, making the latter obsolete (Dedio *et al*. 1980).

2.1.2 Culture and Production

Robinson (1978) provided a detailed account on the agronomic characteristics and cultural requirements of sunflower. Sunflower performs well in most temperate zones and the same cultivars are grown on all five continents (Robinson 1978). It is a long-season crop requiring 115 to 130 days to mature. The length of the growing season is the most important factor used in identifying production areas (Geise 1974; Campbell 1979). Sunflower can be grown in soils ranging in texture from sand to clay as it does not require high fertility soils to produce satisfactory yields. Sunflower is not highly drought tolerant, but it often performs well when other crops are drought damaged, because of its extensive and heavily branched tap root system which has a potential lateral spread and depth exceeding two meters (Robinson 1978).

Sunflower is either solid seeded or planted as a row crop at a depth of 3 to 10 cm, depending on the moisture content of the soil. For northern U.S.A. and Canada, planting is recommended from 1 to 20 May (Robinson 1978). Although seedlings are relatively frost resistant up to the four leaf stage (Anonymous 1983), planting in April is not advised in parts of northern U.S.A. and Canada where frost may occur in late May or early June (Robinson 1978).

Sunflower planted in May is usually ready for harvest in late September or October. Plants are mature when the back of the head turns yellow (Browne 1978; Robinson 1983) or the bracts of the head become brown (Schneiter and Miller 1981). At this stage the moisture content of the heads ranges from 40 to 80% (Robinson 1983). Thus, physiological maturity usually occurs before the heads are dry enough to be harvested. Harvesting can be enhanced by applying dessicants (Schuler et al. 1978). To reduce shattering losses during harvest and loss of seeds from birds, sunflower is harvested at moisture contents ranging as high as 20-25% (Campbell 1979). The seed is then dried to a moisture content of approximately 9% for long term storage (Schuler et al. 1978).

Sunflower is third only to palm and soybean in world vegetable oil production (Anonymous 1986). Worldwide, a total of 14.431 million hectares were sown to sunflower in 1985. With an average yield of 1313 kg per hectare, a total of 18.944 million tonnes of sunflower seed was produced in that year (FAO 1986). Europe is the largest producer, contributing more than 50% of the world production. Among individual countries, the U.S.S.R. has consistently been the leading producer, contributing over 30% of world production. Argentina and the U.S.A. are the second and third largest producers contributing more than 13 and 12% respectively, toward the world total. Among the major producing countries, Canada was ranked last in the 1985-86 world production forecast (Anonymous 1986).

In the last 15 to 20 years, production in the U.S.A. and Canada has increased more than tenfold (Cobia 1978). Manitoba is the leading producer of sunflower in Canada. From 1976 to 1985 an average of 104,600 tonnes of sunflower was produced in Manitoba, with a high of 208,700 tonnes in

1979 (Anonymous 1986). The tremendous increase in sunflower production in 1979 was probably due in part to farmers shifting almost completely from open-pollinated cultivars to hybrids. Sunflower production in Canada has decreased significantly since the record high in 1979. The production for 1985 (77,100 tonnes) represented a drop of 63% from 1979. The decline in production was attributed to disease problems, depressed prices, increased flax-seed production and a reduction in contracting. The sunflower midge may also have contributed to the decline in production.

2.1.3 Uses and Future

Two types of sunflower are grown. One type called oilseed sunflower, produces a small, well filled, round, thin-hulled seed which is used for the extraction of edible oil. Seeds of oilseed cultivars contain between 40-50% oil on a whole seed basis. The second type, called nonoilseed or confectionery sunflower, produces a large, long seed with a thick, heavy hull and is used primarily for direct human consumption and as bird feed (Putt 1978). Seeds of confectionery cultivars generally contain less than 30% oil on a whole seed basis.

Sunflower oil is used primarily as a premium salad oil because of its light color and bland flavour. It is also useful as a cooking oil because of its high smoke point (Geise 1974). Eighty percent of the sunflower produced in Canada is sold as a salad oil and most of it is marketed as pure rather than as blended oil. In the U.S.A., the oil is usually blended with soybean oil to increase the level of unsaturation. Of the vegetable oils produced in North America, only safflower oil exceeds Canadian sunflower oil in the content of linoleic acid, a desirable poly-unsaturated fatty acid (Dedio et al. 1980).

After the oil is removed the meal is most commonly used as a protein supplement for livestock feed. The meal contains from 38 to 46% protein and 8 to 12% fibre, and although low in lysine, it is high in thiamin and niacin. The hulls, which contain about 3% oil and 3-4% protein, are pelleted and fed to livestock while unpelleted hulls are used as chicken litter (Geise 1974).

Seed of confectionery type sunflower is roasted and used as a snack or dehulled and incorporated into candy, cookies or cereals. Further details on the use of sunflower can be found in Dorrell (1978) and Lofgren (1978).

With world population and global per capita consumption of fats and oils increasing, the demand for edible vegetable oils will continue to rise. Sunflower oil, because of its unusual combination of nutritional and storage qualities is capable of meeting the demand (Dotty 1978). Sunflower can still be further improved. Most cultivars have a potential seed yield exceeding 3000 kg per hectare, but average yields in North America are less than 1500 kg per hectare (Robinson 1978). Considerable unexplored genetic material exists for improving sunflower

(Heiser 1978) and plant breeders will most certainly develop improved and more productive cultivars in the future.

In Canada, sunflower has been grown primarily in the Red River Valley region of southern Manitoba (Putt 1978) where corn and soybean have not performed well, because of either a short growing season, or lack of rainfall during critical periods (Cobia 1978). Research trials conducted in southern Alberta and Saskatchewan have shown that sunflower can be profitably grown over a much wider area than has been generally recognized (Campbell 1979). Thus, there is potential for regional expansion.

Most of the sunflower produced in Canada and the U.S.A. is exported to Europe. In the past, restricted delivery opportunities, low cereal prices, along with strong demand for sunflower oil in Europe provided excellent marketing opportunities for sunflower. Future production in North America will depend on these factors and particularly on improved export demand. Sunflower, because of its yield potential and superior agronomic characteristics (Robinson 1978), is likely to become a more important economic crop (Dotty 1978). With an increase in sunflower production it is only logical to assume that sunflower associated insects will also increase. The question is what impact will the insect pests have on increased sunflower hectarage and/or increased yield potential.

2.2 THE SUNFLOWER BEETLE

2.2.1 Geographic Distribution and Status

The sunflower beetle, *Zygogramma exclamationis* (F.), is an oligophagous insect which feeds on a few members of the genus *Helianthus*. The most important member within the genus is the cultivated sunflower *H. annuus* (Rogers and Thompson 1978, 1980). Like its principal host, the sunflower beetle is native to North America (Wilcox 1972; Heiser 1978). The beetle has been recorded from most states and provinces of the Great Plains area of North America, including the Canadian prairies (Criddle 1922; Westdal and Barrett 1955), the northern Great Plains states of the U.S.A. (Schulz 1978), Montana (Cooley 1918), Arizona (Brisley 1925), Nebraska (Powell 1932), Texas (Rogers 1977), Kansas (Walker 1936) and Utah (Knowlton and Smith 1935).

As Criddle (1922) predicted, the sunflower beetle has spread from native plants to cultivated sunflower. It is the most important defoliating species of sunflower pest in Manitoba (Westdal and Barrett 1955) and the northern sunflower-growing region of the U.S.A., that is, North Dakota, South Dakota and Minnesota (Schulz 1978). However, it is not an economically important pest in the southern sunflower-growing regions of the U.S.A. (Cobia and Zimmer 1978; Rogers and Thompson 1980).

2.2.2 Life History and Biology

Details on the biology of the sunflower beetle in Manitoba were first provided by Criddle (1922). Additional biological information on the beetle on the Canadian prairies was given by Westdal and Barrett (1955) and Westdal (1975). In the U.S.A., notes on the beetle's life cycle were made by Walker (1936) in Kansas and detailed information on the bionomics of the beetle, based on laboratory studies was provided by Rogers (1977) in Texas. The most recent and comprehensive study on the beetle's bionomics is that of Neill (1982) who also provided an extensive review on the biology of the beetle. Neill (1982) studied the rate of development of the sunflower beetle in Manitoba and used the data to predict the occurrence of the various life stages in the field.

In Manitoba, the beetle has one generation per year, and it overwinters as an adult in the soil (Criddle 1922; Westdal and Barrett 1955), usually at a depth of 15 cm or less (Neill 1982). The beetles overwinter as sexually immature adults and neither mating nor egg-laying takes place prior to hibernation. Sexual maturation is initiated either before or shortly after emergence from the soil (Gerber et al. 1979). The overwintering adults emerge during the latter part of May (Westdal 1975; Westdal et al. 1976). Shortly after emergence the adults begin to feed, mate and lay eggs.

Eggs are laid either singly or in irregular groups. Females oviposit almost daily during the oviposition period (Criddle 1922; Neill 1982), which lasts from 6-7 weeks (Gerber _et al_. 1979). The eggs hatch in about one week (Westdal 1975), whereupon the larvae begin feeding and pass through four instars (Rogers 1977; Neill 1982).

Following completion of the fourth instar, larvae enter the soil to pupate towards the end of July (Criddle 1922). Pupation occurs in earthen chambers at depths of 2.5-7.5 cm (Walker 1936; Rogers 1977) and the pupal period lasts about two weeks (Walker 1936; Rogers 1977; Westdal 1975). Upon emergence from pupation, adults feed for 1-3 weeks before entering the soil to overwinter (Neill 1982).

2.2.3 Damage and Control

Both adults and larvae defoliate plants. Adults emerge from overwintering about the time sunflower seedlings emerge and begin feeding on the true leaves of the young plant. Adults seldom feed on cotyledons (Westdal 1975). Damage by adults produces a "jagged-edge" effect on the leaves (Neill 1982). Larvae are nocturnal feeders, and during the day congregate among the bracts of the flower bud and in the axils of the leaves. Initial feeding by the larvae gives the leaves a "shot-hole" appearance (Westdal 1975). During severe infestations both adults and larvae can completely defoliate the plant.

Studies on the impact of defoliation of sunflower by the sunflower beetle are limited and the results are conflicting. Westdal _et al_. (1973) studied the effect of defoliation of sunflower by the sunflower beetle in Manitoba. Adults were caged on sunflower seedlings in the 2 to 4 leaf stage at the rate of 0, 0.5, 1 and 2 per plant. After 2 weeks of feeding, leaf defoliation was estimated to be 0, 15, 20 and 50%, respectively, for the 4 treatments. These authors observed that severely damaged plants were considerably shorter, and this observation was confirmed by them in similar tests where plants were artificially defoliated. Due to the effect of Sclerotinia wilt and a storm in that year, seed yields for the experiment were not obtained. In a later study, Westdal _el al_. (1976) reported that plant maturity is delayed and seed losses up to 8% could occur, even with moderate defoliation. The methods leading to these conclusions were not reported. Recently, Charlet (1983a) in North Dakota found that infestations of only 2 adults per plant resulted in a significant yield loss of over 20%. The yield loss was a combined effect of adult and larval feeding. For practical purposes, it is necessary to establish the impact of adults alone, especially if only adult control is desired.

Westdal _et al_. (1973) also studied the effect of larval defoliation on sunflower at Morden, Manitoba. Plots were sprayed with azinphos-methyl when larval densities averaged 29 per plant. From these studies they concluded that larval densities of 25 or more per plant could result in yield reductions of 30%. This study was conducted during one field season only. Also, during that year, the field became heavily infected with Sclerotinia wilt and as a result a large percentage of plants from the test plots was lost. Thus, the yield reduction could also have been due to the disease. Charlet (1981) in North Dakota showed that beetle larvae as numerous as 20 per plant can be tolerated without significant reduction in sunflower yield. Clearly, the apparent differences in yield reduction caused by adult and larval feeding need to be verified. Studies are also needed to establish the critical stage of the plant in relation to adult or larval feeding.

Chemical control is the only method currently used to control the sunflower beetle. In Manitoba, insecticide application is recommended when populations average one adult per 2 or 3 plants (Westdal et al. 1976; Anonymous 1987), while in North Dakota, the recommendation is to spray when 1 to 2 adults per plant are found (Schulz and Oseto 1983; McBride et al. 1985b). It is difficult to conceive why the threshold levels for the two neighboring jurisdictions are at variance. No information could be located to explain the basis for the difference in these thresholds.

Insecticides applied for the control of adults are also used for larval control. An economic threshold value of 10 to 15 larvae per plant has been established (Westdal et el. 1976; McBride et al. 1985b). There are no reports to indicate how these thresholds were developed. According to

McBride et al. (1985b), 10 to 15 larvae per plant will cause approximately 25% defoliation on the upper 8 to 12 leaves. Control is advised if defoliation reaches a level of 25-30%. However, control is not necessary if the majority of the larvae have reached maturity at about 25% defoliation.

One application of insecticide is adequate to obtain control of either the adults or the larvae (Westdal et al. 1976). But adult control does not preclude larval control. Thus, timing of insecticide application is critical. Insecticides to control adults must be applied before most of the eggs are laid, whereas for larvae the chemicals must be sprayed after most eggs have hatched. With adult control, even if the application is properly timed, there is still the possibility of reinvasion.

The only study on optimum time of control in relation to the sunflower beetle is that of Neill (1982). He simulated chemical control by manually removing larvae from the plants at intervals during the larval period. Based on his observations, he proposed the mid-point of the second instar as the optimal time for control of larvae, since at that time most eggs will have hatched and little foliar damage will have been caused by the early (first and second) instars. The mid-point in the development of the second larval instar occurred 21 days after first hatch was noted. Practical application of this information would require farmers to check their fields at three to four day intervals to determine the start of hatching. Neill's recommendation is based solely on the insect's phenology. The method does not address the stage of the plant at which insecticides should be applied, nor does it consider the growth stage at the time of infestation.

The effectiveness of chemical control is dependent upon practical and efficient monitoring systems. The recommended procedure for monitoring the sunflower beetle is to sample randomly 100 plants in an "X" pattern starting at least 30 m away from the field margins (McBride et al. 1985b). No information could be located to indicate how this sampling procedure was developed. Further, there are no reports to show the presence of an edge effect; neither is there any information to indicate that the edge effect extends 30 m into the field.

Sampling techniques with greater efficiency could be developed that would enable the grower to decide whether a particular population requires control. Sequential sampling is one technique that could aid in the sound management of the sunflower beetle.

2.3 ECONOMIC THRESHOLD

2.3.1 Definitions

Stern et al. (1959) initially proposed the terms economic injury level (EIL) and economic threshold (ET), and emphasized the importance of accurately relating pest densities to economic losses when making decisions to apply control measures. The EIL was defined as "the lowest population density that will cause economic damage," the economic damage being "the amount of injury which will justify the cost of artificial control measures". The economic threshold was defined as "the density at which control measures should be initiated to prevent an increasing pest population from reaching the economic injury level". The ET is always below the EIL and takes into account the time needed for control measures to be applied before the EIL is reached or surpassed. Thus for the ET to be determined, the EIL and the time when it occurs must be known.

Since the coining of these terms, economic thresholds have been defined in several ways (Edwards and Heath 1964; Beirne 1966; National Academy of Sciences 1969; Headley 1973; Poston et al. 1983a), in an attempt to refine the concept. The most recent definition is that of Pedigo et al. (1986). They defined the ET as "the injury equivalency of a pest population corresponding to the latest possible date for which a given control tactic could be implemented to prevent increasing injury from causing economic damage". The advantage of expressing the ET in injury equivalents is that the density and age structure of a population can be considered when describing a population's injuriousness.

Of the various definitions, only those by Edwards and Heath (1964) and Headley (1973) take into consideration the economics of pest control and offer a direct method of determining the ET. Implicit in the definition is that for any control measures to be justifiable, the value of the yield increase resulting from control measure must be equal to or greater than the cost of control. Thus, the ET is the pest population level at which such yield increases are realized after a control measure is applied.

2.3.2 Determination and Use

The relationship between insect damage and crop yield loss is the most important information needed for developing economic thresholds (Poston et al. 1983a; Walker 1983). Obtaining reliable crop loss data is difficult because the relationship between insect populations and their effects on yield-forming processes is often complex and variable (Bardner and Fletcher 1974). Quantifying yield loss becomes even more difficult with indirect damage (injury to non-harvestable parts of the plant) such as defoliation (Hare 1980; Ferro et al. 1983). Several factors affect the relationship between crop response and damage. These factors have been discussed by Pedigo et al. (1986) in relation to the development of EILs.

Estimations of crop response to damage are most frequently made by measuring yield. Crop response to insect attacks may be assessed by: 1) observing natural populations; 2) modifying natural populations; 3) establishing artificial populations, and 4) simulating damage (Poston et al. 1983a). These methods are described at length by Walker (1983) who also discusses their relative merits.

Whichever method is used to assess crop response, and in turn develop economic thresholds, the aim is to subject the plant to variable densities of the pest and determine the yield at each density. Once this information is obtained a regression model is fitted to describe the relationship between yield and pest density. Such relationships may be non-linear or linear (Pedigo et al. 1986), but often the latter is chosen because of its simplicity (Poston et al. 1983a). Economic thresholds can then be determined by incorporating control costs and crop market value into the model using either the empirical method (Ogunlana and Pedigo 1974), cost-benefit analysis (Ferro et al. 1983) or the deductive approach (Stone and Pedigo 1972). These methods have been reviewed by Maiteki (1985). General formulas for calculating ET and EILs can be found in Onstad (1987).

"Nominal thresholds" are established through past experience and have no experimental basis for their determination. Most of the existing thresholds likely fit into this category (Poston et al. 1983a). Thresholds which are based on experimental estimation of the relationship between the damage potential of the pest, crop market value, control costs and potential crop yield are termed "simple thresholds" (Poston et al. 1983a). These types of thresholds are a step above "nominal thresholds". The ultimate goal and one as yet to be attained is to develop "comprehensive thresholds" which take into account the total production system on the farm and incorporate the variabilities which occur from year to year in economic, weather and stress factors (Poston *et al*. 1983a). The challenge lies in developing indices which take into account several stress factors and in particular the effects of multiple pests (Pedigo *et al*. 1986).

It has long been realized that accurate economic thresholds are a prerequisite to the development of sophisticated pest-control programs (Stern *et al*. 1959; Stern 1973). However, the actual development of economic threshholds continues to challenge applied entomologists (Poston *et al*. 1983a; Pedigo *et al*. 1986) and represents one of the weakest areas of economic entomology (Allen *et al*. 1972). Economic thresholds have proved notoriously difficult to develop because of the need to address several factors, many of which are economic and not readily assessable (National Academy of Sciences 1969; Poston *et al*. 1983a). Even the primary determinants including control costs, crop market value, proportionate injury per individual pest and crop response to injury are not simple constants but complex biological processes and/or economic variables which fluctuate through space and time (Poston *et al*. 1983a). This implies that economic thresholds are not static and emphasizes the need to develop them using data from several seasons.

The complex nature of the parameters and the variability which occurs from year to year has made the determination of an accurate economic threshold a goal yet to be attained and also raises doubts as to their usefulness. Economic thresholds can be extended only rarely into new areas and even then they must first be tested before they are adopted. Thus their use is limited primarily to the specific areas for which they are developed. Despite the limitations both "nominal" and "simple" thresholds have been useful in providing a basis for making control decisions and thus reducing pesticide use (Poston et al. 1983a). Economic thresholds are an essential requisite for developing sequential sampling plans.

2.4 SEQUENTIAL SAMPLING

2.4.1 Development

The successful implementation of a sampling procedure in a pest management program requires that the method be easy to use, provide a reliable estimate of density and minimize the sampler's time and effort. These constraints have been met through the use of sequential sampling schemes (Shepard 1980; Burts and Brunner 1981). Briefly, sequential sampling is a technique in which samples are taken in sequence with decisions made after each sample, based on cumulative information obtained and specified levels of risk (Shepard 1980). Sequential sampling schemes for pest management are based on the premise that practical control programs do not require exact estimates of population density, but rather that the pest population be categorized into density classes (Ruesink and Kogan 1975).

Sequential sampling was developed in the early 1940's (Wald 1945). However, its use as a tool in pest surveys was not realized until almost a decade later (Morris 1954). Forest entomologists were among the pioneers to use sequential sampling in estimating insect populations (Stark 1952; Morris 1954; Stevens and Stark 1962). In agricultural entomology, the first applications of sequential sampling were reported by Sylvester and Cox (1961), Wolfenbarger and Darrock (1965), and Harcourt (1966). Since then, numerous sequential sampling plans have been developed for different insects on a wide array of crops. A literature review of sequential plans for insects has been published (Pieters 1978) and the rationale of sequential sampling with emphasis on its use in pest management has been discussed (Onsager 1976; Boivin and Vincent 1983).

A general discussion on the basic requirements, essential features, applications and advantages of sequential sampling plans in relation to entomological problems is given by Waters (1955) and more recently by Boivin and Vincent (1983). For the development of a sequential model, using Wald's (1945) procedure, there are three fundamental pieces of information that are necessary: 1) the mathematical distribution of the insects or their damage in the field, 2) the economic thresholds or treatment levels, and 3) an acceptable probability of error. If these factors are known, sequential sampling plans can be developed using the appropriate mathematical formulae (Waters 1955; Shepard 1980).

Determination of the spatial distribution is most critical of the various factors in a sequential model. An extensive literature has developed on this controversial subject. Spatial distribution, with particular reference to its assessment and interpretation has recently been reviewed (Taylor 1984). The economic or damage threshold is the second essential component required for developing sequential sampling plans. Without it no precise "class limits" or infestation categories can be set (Shepard 1980). The practicality of developing precise economic thresholds has been addressed (Poston et al. 1983a; Pedigo et al. 1986).

Like any other sampling procedure, there is a risk involved in making a decision based on sequential sampling. Thus, establishing an acceptable level of precision is the third essential component needed for sequential model development (Waters 1955; Onsager 1976; Shepard 1980). In general a 10% precision level is required for intensive population research whereas a 25% precision level is considered adequate for surveys and pest management decision making (Southwood 1978).

Sequential plans that are developed using Wald's (1945) procedure are based upon predetermined fit of sample data to theoretical distribution models. Thus, knowledge of the underlying mathematical distribution is essential in developing these "traditional" sequential sampling schemes. One of the major problems encountered in developing sequential plans using the traditional approach, is the determination of spatial distribution. The actual problem arises when fitting the sample data to the theoretical models. The data may fit one, several or none of the models (Taylor 1965, 1971; Shepard and Carner 1976).

Methods of developing sequential sampling plans independent of knowledge of which theoretical distribution describes sample data have been developed (Kuno 1969; Green 1970; Iwao 1975). The essential feature of this method is that the variance be described as a function of mean density. This relationship can be established using Iwao's (1968) "mean crowding" to mean function (Kuno 1969; Iwao 1975), but Taylor's power law (Taylor 1961) is equally suitable (Bechinski and Pedigo 1983). When developing plans using Iwao's (1975) procedure, it is important that both Taylor's (1961) and Iwao's (1968) analyses are used to determine the most appropriate functional relationship between sample variance and mean density. This is because Iwao's analysis may perform inadequately at low population levels (Buntin and Pedigo 1981; Bechinski et al. 1983).

Traditional sequential sampling plans (Waters 1955; Onsager 1976) classify populations into broad categories only and do not allow precise estimation of the population mean (Shepard 1980). Sequential sampling formulas of Kuno (1969) and Iwao (1975) can be used to develop research-oriented count plans (Bechinski *et al*. 1983) that estimate mean density of a population relative to a fixed coefficient of variation of the mean (Shepard 1980). In general, the development and application of sequential count plans is similar to that of sequential decision plans. The only difference is that in the former method samples are taken to estimate a density with a fixed level of precision whereas in the latter method, samples are taken to make a treatment decision.

2.4.2 Application

In order to understand and visualize the workings of a sequential sampling plan, the operating characteristic (OC) and average sample number (ASN) curves may be developed (Waters 1955; Onsager 1976; Shepard 1980). These curves indicate how risk of a correct decision and the number of samples required to reach a decision relate to population density. The curves, although not essential in the application of the sequential plan, are important in that they indicate how the plan will operate in the field. In addition, they can be used to appraise the plan in advance of field testing (Morris 1954; Onsager 1976; Luna *et al*. 1983). The ASN curves are especially helpful to scouts in that they indicate the sampling requirements at different population densities (Harcourt 1983). Once the plan is appraised, it must be tested in the field.

The plan should be tested with field data collected independently from that used in developing the plan (Onsager 1976; Luna et al. 1983). Although not often followed, validation is still essential not only to determine if the plan will operate but also to determine how efficient it is relative to the conventional sampling method. In validating the plan, it is important to point out the maximum number of samples to be taken (Kirby and Slosser 1981). This is necessary if a plan fails to yield a decision. Thus an alternate course of action must also be given, which may vary from sampling again (Kirby and Slosser 1981) to using conventional methods (Luna et al. 1983). Once field testing is accomplished, the plan is ready for use in an integrated pest management program.

Once the plan has been recommended for field application, the most important question regarding its use is the degree to which it can be extended into new areas or slightly different situations. Sequential plans developed with data collected over a number of years and a variety of fields within a year (Bechinski et al. 1983) are more likely to be extended into new areas (Onsager 1976). However, like economic thresholds, sequential plans must first be tested before they are adopted in new areas.

Sequential decision plans are efficient only when insect populations or infestations are at their extremes (low or high). At intermediate levels sequential plans are unlikely to have an advantage over conventional sampling methods. The efficiency of sequential plans arises largely from a reduction in sample size (number of samples) and consequently a reduction in sampling time which has been shown to be greater than 40% (Kirby and Slosser 1981; Boivin and Vincent 1983; Luna et al. 1983). Sequential sampling is of benefit to insect pest management programs since it may be used to identify treatment needs of individual fields (Harcourt 1983). As entomologists gain familiarity with it, and since decision-making and cost reduction are vital to pest management programs, it is quite likely that its use will become increasingly important (Pieters 1978; Shepard 1980).

CHAPTER 3

EXPERIMENTAL STUDIES

SECTION I

INSECT PESTS OF SUNFLOWER AND THEIR MANAGEMENT BY GROWERS IN MANITOBA

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SECTION I

INSECT PESTS OF SUNFLOWER AND THEIR MANAGEMENT BY GROWERS IN MANITOBA

ABSTRACT

A field survey was conducted in 1983 to determine the type of insect pests that attack sunflower by monitoring twelve commercial fields. Of the various insect pests recorded, the sunflower beetle, sunflower midge, sunflower maggot, banded sunflower moth, and sunflower moth were most prevalent. Each of these pests was found in at least 10 of the 12 fields.

Grower surveys were also conducted in 1983 and 1984 to determine the status of sunflower insect pest management in Manitoba. Pests of primary concern to growers were sunflower beetle, sunflower midge and cutworms. More than 80% of the growers monitored their fields for insect pests, used economic thresholds and considered the threshold values to be an effective decision-making tool. However, data from the field survey on sunflower beetle showed that growers applied insecticides at well below the currently recommended threshold values.

Key words: Sunflower, insect pests, control, management.

INSECT PESTS OF SUNFLOWER AND THEIR MANAGEMENT BY GROWERS IN MANITOBA

INTRODUCTION

Sunflower is an important oil crop native to North America (Heiser 1978). Commercial production of oilseed sunflower began in 1943 in Canada (Geise 1974). Since then the crop has been grown continuously in Manitoba (Putt 1978), which is the leading producer, contributing more than 80% to the total Canadian production (Anonymous 1986). Sunflower is subject to attack by numerous species of insects, many of which are also native to North America (Schulz 1978; Hilgendorf and Goeden 1981).

In Manitoba several species have been noted on commercial plantings (Westdal 1975) and the type of damage caused by a few species has been established (Westdal and Barrett 1955). Pests of economic importance in Manitoba are relatively few (Westdal 1975) when compared to the neighboring state of North Dakota (McBride et al. 1985b), where the hectarage planted is significantly higher (Cobia 1978). The occurrence of various species as well as their economic significance has fluctuated over the years both in Manitoba (Westdal 1975) and North Dakota (Schulz 1978; Schulz and Oseto 1979). Of late, there has been no systematic documentation of the relative importance of the various insect pests that attack sunflower in Manitoba. Such knowledge along with information on how growers perceive and manage the pest problems is necessary for identifying research and extension needs as well as for developing sunflower pest management programs.

This study was initiated to determine the relative importance of the more common insect pests that attack sunflower in Manitoba. An additional objective of the survey was to determine the importance of these pests to growers and identify the control strategies currently used for managing the various pests.

MATERIALS AND METHODS

Two types of surveys were conducted: a field survey and a grower survey. The former was conducted by monitoring commercial fields in 1983, whereas the latter was conducted using questionnaires in 1983 and 1984.

Field survey. Twelve farms were selected (Fig. 1), two from each of six municipalities (Appendix 1). On each farm, two plots, 50 rows by 50 plants, were established. The plots were 100 m apart, and 30 m away from either side of the field margins to avoid any edge effects. Sampling was initiated at V4, the 4 leaf stage (Appendix 2), and continued on a weekly basis until the plants were harvested. Farms were sampled in sequence, 1-4, 5-8, 9-12, and on each sampling date in each plot, 10 randomly selected plants were visually searched for the presence of insect pests. The stage (Schneiter and Miller 1981) and height of the plants were recorded. The stems were dissected lengthwise in the field to check for pests that tunnel in the stalk. The heads (when present) of the selected plants from each plot were cut below the receptacle, placed in separate plastic bags, brought to the laboratory and kept in the cold room at $5 \pm 1\,^{\circ}C$. The heads were examined the following day, and the type and number of head infesting species recorded.

Juveniles were initially identified to species using the key of Oseto (undated). After rearing the larvae to adults, species identification was confirmed using the key of Weinzierl *et al*. (1981). To break the diapause and ensure that the insects could be reared to the adult stage, portions of the plant tissue containing the larvae were first held in the cold room at $5 \pm 1\,^{\circ}C$ for 6 to 8 weeks (Charlet 1983b). Thereafter, the plant parts were placed in styrofoam cups and held in an environmental chamber at $20\,^{\circ}C$, and an 18 h photophase until the adults emerged.

Throughout the study, when observing the pests, emphasis was placed on those species that are of current concern in the neighboring state of North Dakota. Manitoba's sunflower growing region is contiguous with the major sunflower producing areas there (McMullen 1985). Populations were recorded for sunflower beetle, sunflower midge, sunflower maggot, banded sunflower moth and sunflower moth. Since adults of most species were present at low numbers and were relatively mobile, counts of pest species and percent plants infested were based on larval stages, with the exception of the sunflower beetle, for which the egg, adult and larval numbers were recorded. Similar but non-destructive sampling was continued to determine the seasonal abundance of the sunflower beetle in 1984 and 1985. Four plots were established in each of the two fields, in each year. Sampling was initiated at the 2 leaf stage and continued until the insect completed its life cycle or when the grower applied insecticides to control the beetle.

Grower survey. A 20-question questionnaire (Appendix 3), similar in structure to that of Thomas (1979), was developed with the following primary objectives: 1) to determine the insect pest(s) of concern to growers, 2) to determine the type of control strategies used, and 3) to determine if growers monitor their fields and use economic thresholds when managing the pest(s). The questionnaires, including self-addressed, postage paid envelopes, were sent to the growers in mid-September, just prior to harvest. To increase uniformity in response, 15 November was designated as the deadline date for returning the questionnaires. Sunflower is grown primarily on contract basis in Manitoba; to increase the percent response, the questionnaires were sent through the leading contracting agents. In 1983, 350 questionniares were sent to growers through CSP Foods, Altona. A total of 635 questionnaires were dispatched to growers in 1984: 400 through Manitoba Pool Elevators, Winnipeg; 200 through CSP Foods, Altona and 35 through Cargill, Elm Creek.

Data analysis. Data from field survey and seasonal abundance studies were analyzed using nested analysis of variance (SAS 1985). The numbers of larvae per plant were transformed by $\sqrt{x + 0.5}$ before analyzing the data. Data from seasonal abundance studies were analyzed separately for each year.

In each year, and for each question, frequency distributions were generated from the grower surveys. Of the questionnaires that were received, several were incomplete and so the data were expressed as a percentage of total number of responses for a particular aspect of the survey.

RESULTS

Field survey. A total of nine insect pests were observed attacking various parts of cultivated sunflower (Table 1). These pests have close biological association with the genus *Helianthus* (Charlet *et al*. 1987) and are among the sixteen species that have caused or have the potential of causing economic damage to commercial sunflower in the northern Great Plains (Schulz 1978; Charlet *et al*. 1987). *Aphis helianthi* Monell (Homoptera: Aphididae), as well as polyphagous species such as grasshoppers (Orthoptera: Acrididae), crickets (Orthoptera: Gryllidae), cutworms (Lepidoptera: Noctuidae) and thrips (Thysanoptera) were among other pests that were also noted. In North Dakota, both grasshoppers and cutworms have caused severe crop losses in some years (Charlet _et al_. 1987). In this study grasshoppers were observed in all fields, whereas cutworms were noted in two fields (Farm 2 and 3). A soil sampling program was not carried out, so cutworms as well as other soil inhabiting polyphagous species such as wireworms (Coleoptera: Elateridae) and white grubs (Coleoptera: Scarabaeidae) could have been present in one or more of the fields.

The number of insect pests attacking the sunflower over the season ranged from four to eight per field. Of the various pests, the sunflower beetle, sunflower midge, sunflower maggot, banded sunflower moth and sunflower moth were most prevalent and found in at least 10 of the 12 farms (Table 1). Analysis of variance on larval populations of these species showed no significant differences ($P<0.05$) between plots within farms.

The sunflower beetle is the most important defoliating pest of cultivated sunflower (Westdal 1975). It has been a pest of economic importance in North Dakota, Minnesota, and Manitoba (Charlet _et al_. 1987). Both adults and larvae defoliate the plant. Damage assessment studies (Section II) show that adults are less damaging whereas larvae are more damaging than had been reported previously (Westdal _et al_. 1973). In this study mean larval densities of the sunflower beetle ranged from 0.5 per plant for a period of 7 weeks in Farm 11 to a high of 4.4 for a period of 3 weeks in Farm 7 (Table 2). The maximum number of larvae recorded per plant was 21 in Farm 10. Except for Farm 11, which had very few beetles, an average of eight or more out of every 20 plants were infested with this insect. Analysis of variance showed significant difference in the larval populations of this species among municipalities and between farms within municipalities.

Variation among farms in the duration and level of infestation was also noted for sunflower midge (Fig. 2), sunflower maggot, and banded sunflower moth (Fig. 3). The periods and patterns of infestation illustrated in Fig. 2 and 3 are representative of the remaining nine fields. These farms (1, 5 and 9) also represent the slight differences in the dates of sampling for the three groups of farms (1-4, 5-8, 9-12).

The sunflower midge is the first insect that appears in the sunflower capitulum. Sporadic outbreaks of this insect have occurred in the past and damage has been restricted to the Red River Valley of North Dakota, Minnesota and southern Manitoba (Kopp 1983). Severe infestation results in distortion and gnarling of the capitulum, reducing the plants' capacity to produce achenes. In this study mean larval densities per capitulum ranged from 7.2 for a period of six weeks (Farm 10) to a high of 19 for a period of 8 weeks (Farm 5) (Table 2). The maximum number of larvae recorded was 231 in Farm 7. Analysis of variance showed significant differences between municipalities and between farms within municipalities. Except for Farm 7, on average, less than 50% of the plants were infested with this species.

The sunflower midge was not present as far west as McGregor (Farm 4) in 1983. The durations, mean larval densities and mean percent infestations were relatively low in Farms 1 and 2. These areas were located outside the range of the midge (Kopp 1983). On the basis of duration and percent infestation (Fig. 2), it appeared that there were two peaks; one towards the end of July and one towards the end of August. The precise number of generations per year has not been established. In North Dakota a major peak of adult emergence has consistently been recorded during the first week of July. Additional emergence peaks have been observed also in mid-July and again in mid-August (Schulz 1982). Under optimal conditions, the sunflower midge can complete its life cycle in 31-35 days (Samuelson 1976). Thus it is probable that there is a partial second generation of adults in mid-August (Kopp and Busacca 1983) and that the two generations are distinct at low populations (Fig. 2, Farm 1) whereas at high densities the two generations overlap (Fig. 2, Farm 5). Apparently the second generation causes no economic damage because of the maturity of the plant at the time of larval feeding (Kopp and Busacca 1983).

In the northern Plains, the sunflower maggot is the only tephritid species found in the stem of commercial sunflower (Schulz 1978). Damage is caused by larval feeding and ranges from slight tunnelling to complete destruction of the pith (Westdal and Barrett 1960). Apparently maggot injury to the pith of the stalk causes no detrimental effect to yield (Westdal and Barrett 1962). In this study mean larval densities of the sunflower maggot ranged from 0.9 for a period of seven weeks to a high of 2.6 larvae per plant for a period of six weeks (Table 2). Analysis of variance showed significant differences in the larval population of this species among municipalities but not between farms within municipalities. A maximum of 14 larvae were recorded on a plant in Farm 7. On several occasions larvae were found tunnelling in the petioles of the lower leaves and as many as five larvae were noted in a single petiole. The average number of plants infested with this species was relatively uniform and ranged from 54.3-79.2% (Table 2). On several occasions 100% of the plants were found infested with this insect (Fig. 3). Such high infestation levels were reported previously in Manitoba (Westdal and Barrett 1962) and North Dakota (Schulz and Lipp 1969).

The banded sunflower moth is one of the two lepidopteran species that attacks the capitulum of cultivated sunflower. Damage is caused by larval feeding. The early instars feed on pollen and remain in the florets. Later instars tunnel into the achene and consume part or all of the kernel. A single larva may destroy three to five seeds (McBride *et al*. 1985b). In this study mean densities of the banded sunflower moth ranged from 0.5-3.1 larvae per plant (Table 2). Analysis of variance showed significant difference in the larval populations of this species among municipalities and between farms within municipalities. A maximum of 17 larvae were recorded on a single plant in Farm 9. Except for Farm 1, which had a low level of infestation, eight or more out of every 20 plants on average were infested with this insect.

The sunflower moth is the second lepidopteran species that attacks the capitulum of the commercial sunflower. This species is a migratory pest (Arthur and Bauer 1981) and unlike the banded sunflower moth, it cannot successfully overwinter in the northern Great Plains (Charlet *et al*. 1987). Damage is caused by larval feeding and is similar to that caused by the banded sunflower moth. An average of nine achenes may be destroyed by a single larva (Carlson 1967). Serious seed losses could result with a moderate to severe infestation of 12-24 larvae per head. Except for Farm 7, mean larval densities in this study ranged from 0.05 for a period of one week (Farm 12) to 0.20 for a period of five weeks (Farm 1). Farm 7 had the highest mean larval density (0.7 larvae per plant for a period of three weeks). Analysis of variance showed significant differences among municipalities and between farms within municipalities. A maximum of four larvae per plant was recorded in Farm 7. In general less than 20% of the plants on average were infested with this pest. The sunflower moth has been a pest of concern in Saskatchewan (Arthur 1978).

Sunflower bud moth, painted lady butterfly, sunflower seed maggot and red sunflower seed weevil were among the less frequently occurring pests in 1983 (Table 1). The sunflower bud moth is the only lepidopterous species of economic concern that attacks stems of cultivated sunflower (Charlet _et al_. 1987). Larvae of the first generation tunnel the stalk whereas the second generation larvae feed in the receptacle of the capitulum. Economic loss due to this insect has been minimal (McBride _et al_. 1985b).

The painted lady butterfly is the only lepidopteran species that has been a serious defoliating pest of sunflower. This insect breeds in Canada, migrates to the south to overwinter and returns to Manitoba in June (Westdal 1975). Damage by this insect has been severe only in some years, although it may be present every year (Westdal and Barrett 1955).

The sunflower seed maggot is the smallest of the three tephritid species that attack cultivated sunflower. It has two generations per year. First generation larvae feed on florets and a single larva may tunnel through 12 ovaries. Second generation larvae may destroy one to three achenes (McBride _et al_. 1985b). This pest has caused economic damage in the southern United States (Schulz 1978). On occasions it has been a pest of concern in Saskatchewan (A.

Arthur, personal communication).

The red sunflower seed weevil is a key pest of commercial sunflower in North Dakota and Minnesota (Charlet et al. 1987). At high infestations, between 50-80% of the seeds may contain weevil larvae causing severe yield reductions. In the present study only a few late blooming sunflower plants were found infested with this insect. No attempt was made to determine the number of achenes destroyed because of low population levels.

Cursory observations in 1984 and 1985 revealed the presence of most of these species in experimental plots at Glenlea. The black sunflower stem weevil, Apion occidentale Fall (Coleoptera: Curculionidae), and the sunflower stem weevil, Cylindrocopturus adspersus (LeConte) (Coleoptera: Curculionidae) were among the additional pests that were noted. Adult feeding by these species causes minor mechanical injury. The former species has been associated with the transmission of Phoma macdonaldii Boerma, the causal agent of phoma black stem (Gaudet and Schulz 1984). Larvae of the sunflower stem weevil tunnel the stalk and can cause extensive damage. Twenty-eight percent lodging resulted from a mean infestation of 37.5 larvae per plant in North Dakota in 1983 (Charlet et al. 1985).

Because of its importance as a pest of sunflower, additional studies on the seasonal abundance of the sunflower beetle were conducted in 1984 (Fig. 4, Farm A and B) and 1985 (Fig. 4, Farm C and D). For both years analysis of variance showed no significant differences ($P<0.05$) between plots within farms. In 1985, adult, egg and larval densities differed significantly among farms whereas in 1984 only the larval populations were significantly different between the two farms (A and B). In both years peak adult and egg numbers generally coincided and occurred around 25 June when the plants were in the ten to twelve leaf stage (Fig. 4). Although counts of sunflower beetle adults were made in 1983, peak adult activity could not be established because sampling was initiated later in the season (20 June or later). Furthermore, in six of the 12 farms insecticides were applied to control the adults (Fig. 5). In general insecticides were applied below the recommended threshold value of 0.5 adults per plant (Anonymous 1987). The results (Fig. 5) show that the insecticide applications were not effective either because of poor chemical control or most likely because of re-invasion of the field within a short period. In artificial defoliation studies (Section III) insecticides were required on a weekly basis to prevent re-infestation by the adults.

Neither the data from the field survey nor the population data from seasonal abundance studies could be used to establish the peak larval activity. This is because in all but one field (Farm 11) insecticides were applied to control the larvae (Fig. 4, Table 3). Except for Farms 4 and 9 in 1983, Farm A in 1984 and Farm C in 1985, insecticides were applied well below the available economic threshold values of 10-15 larvae per plant (Anonymous 1987). Insecticides were applied throughout the field with the applications being made when the plants were generally in the R2-R3 stage (Schneiter and Miller 1981).

Larval population data from seasonal abundance studies were used to verify Neill's (1982) method of determining the optimum time for larval control. Using Neill's method of 21 days after first hatch, the insecticide should have been applied on 12 July in 1984 (for Farms A and B) and 13 July in 1985 (for Farm C and D). These estimates are based on the assumption that the first date of egg hatch occurred at the mid-point, between the date prior to and the date at which first larvae were observed. This assumption is justifiable since eggs can hatch in about 3 days under optimal conditions. Using the threshold values of 10-15 larvae per plant, Neill's (1982) method would have necessitated re-sampling of the fields with low populations (Fig. 4, Farms B and D), to determine if the larvae exceeded the economic thresholds at a later date. However, using the new thresholds (5-10 larvae, Section II), a decision could have been made even at low population and it would not have been necessary to sample again. From these empirical observations it would appear that Neill's (1982) method of determining the optimal time of control is compatible with the new thresholds (Section II).

Grower survey. The questionnaires were sent to approximately 34% of the growers in 1983 and 50% of the growers in 1984. A total of 131 growers in 1983 and 138 growers in 1984 responded to the survey. Thus the respondents comprised about 13% and 11% of the survey population for 1983 and 1984, respectively. There was an inherent bias in the survey, since the responses were from growers who contracted their crop. It is unlikely that the pest problems for these growers would be different than for those growers who do not contract their crop. However, the management skills of the growers who contract their crop may be higher as this is demanded of them by the contracting agents (D. Watson, CSP Foods, Altona, personnal communication).

In both years, more than 60% of the growers ranked sunflower beetle as the most important insect pest of concern (Table 4). A small proportion of growers considered sunflower midge and cutworms as pests of primary concern. The sunflower beetle was also considered as the second most important insect pest in 1983; however, in 1984 the cutworms were ranked as the second most important pests. A relatively large proportion of growers ranked the cutworms as the third most important insect pest of cultivated sunflower in both years.

Over the years, the sunflower beetle has become increasingly important to growers (Fig. 6). At the same time the importance of cutworms has generally declined. The sunflower midge became of concern to growers in 1981, the year during which it first caused economic damage in

Manitoba. Its importance increased over the next two years and then decreased in 1984 (Fig. 6). This is partly due to the decline in sunflower production (Anonymous 1986) and partly because production shifted to areas outside the range of the midge (D. Watson, CSP Foods, Altona, personal communication).

In both 1983 and 1984, more than 96% of the growers indicated that they check their fields for insect pest problems. Of the growers that monitored their fields, 39.4±8.5% in 1983 and 29.6±7.7% in 1984 checked their fields on a monthly basis or occasionally. The remaining proportion was equally divided between those that monitor twice a week and those that monitor once a week. Most growers monitored their fields for sunflower beetle, cutworms and sunflower midge (Fig. 7). The sunflower maggot, sunflower moth, stem weevil and painted lady butterfly were among other pests that were monitored by a comparatively small proportion of the growers. The effectiveness of monitoring for these latter pests including the sunflower midge is questionable since there are no practical methods for detecting these pests before the damage is done. Furthermore, with the exception of painted lady butterfly, there are no control recommendations for these pests in Manitoba (Anonymous 1987).

Only a small proportion of the growers, 10.7±5.3% in 1983 and 20.4±6.7% in 1984, adjusted their planting date to avoid a pest or to reduce its impact (Table 5). Most of these growers delayed planting to avoid midge infestation or reduce the impact of cutworms. Early planting to avoid sunflower midge, cutworms and sunflower beetle is unlikely to be useful and there is no literature available to indicate that such a strategy will be effective against these pests. Delayed planting is likely to be effective against the dingy cutworm, Feltia ducens (Walker) (Lepidoptera: Noctuidae) (G. Ayre, Agriculture Canada Research Station, Winnipeg, personal communication). But whether growers can distinguish this pest from the redbacked cutworm, Euxoa ochrogaster (Guenee) (Lepidoptera: Noctuidae), is doubtful. Ten of the 14 growers who adjusted planting date in 1983 and all such growers in 1984 had to use insecticides to control other pests.

In both 1983 and 1984, more than 80% of the growers had insect problems in their fields and more than 75% of these growers had to use insecticides (Fig. 8). The number of growers applying one or two treatments was generally similar but in 1983 a small percentage of the growers (less than 10%) made three applications (Fig. 8).

Insecticides were applied primarily to control sunflower beetle and cutworms (Fig. 9). This is reflected in the type of insecticides used by the growers (Fig. 10). A small proportion of growers indicated that they applied Furadan for the control of sunflower maggot and sunflower moth in 1983. There are no control recommendations for these pests in Manitoba (Anonymous 1987). From the type of insecticide used it is probable that the insect in question was sunflower beetle. In both 1983 and 1984 a small proportion of growers indicated that they used malathion to control sunflower beetle, an insecticide which is not recommended for the control of sunflower beetle in Manitoba (Anonymous 1987). In both years more than 70% of insecticide applications were made aerially and in all instances the entire fields were treated. For all treatments and in both years, the effectiveness of the insecticide was rated as good.

In both 1983 and 1984 more than 85% of the growers indicated that they were aware of economic thresholds (Table 6). More than 80% of these growers indicated that they used the thresholds when making a control decision. Of the growers that applied the thresholds more than 90% considered the thresholds as a useful tool for making pest management decisions. However, in both years approximately half of the growers that applied the thresholds rated them as only partly effective (Table 6). It is difficult to follow the reasoning behind such disparate responses.

DISCUSSION

Data from the field survey revealed that sunflower beetle, sunflower midge, sunflower maggot and sunflower moth were the most frequently occurring insect pests in cultivated sunflower. The larval populations of these species were generally low and most likely underestimated. For example, all fields were treated with insecticides and so larval populations of the sunflower beetle did not attain their natural peaks. Larvae of the sunflower midge are relatively easy to detect and count when present in the area between the bracts and the developing inflorescence. But with progressive development of the insect and the sunflower capitulum, they migrate into the head and become increasingly difficult to detect. All the larvae of the sunflower maggot might not have been exposed when the stalks were dissected. Further, it was later observed that the maggots were also present in the petioles of the lower leaves. Early instars of the banded sunflower moth and sunflower moth are difficult to detect, partly because of their size and partly because of their feeding behaviour. This is also true of the sunflower maggot and is reflected in some fields where abrupt peaks in percent infestation occurred (Fig. 2,3). Nonetheless, the data do provide an indication of the relative abundance of these species.

Larval densities of the banded sunflower moth were higher than those of the sunflower moth. The duration of infestation and percent infestation was also high for the former species. Lipp (1972) also noted that in North Dakota the banded sunflower moth, *C. hospes*, occurred more frequently and more extensively than the sunflower moth, *H. ellectellum*. In the northern Great Plains, economic damage due to the banded sunflower moth has been on the increase in recent years (McBride *et al*. 1985a). With increased area planted to sunflower, *C. hospes* could cause severe yield losses in Manitoba. Larval populations of the sunflower moth were extremely low, probably a reflection of its inability to overwinter locally. It is unlikely that control for this insect will be required.

High infestation rates of the sunflower maggot were recorded in most fields. Although it appears to cause no detrimental effect on sunflower yield (Westdal and Barrett 1962), it is likely to cause stem breakage in sunflower plantings. Experience with Manitoba sunflower growers has shown that dessicants may be used to enhance ripening and avoid stem breakage in the field. This insect has the potential of causing indirect economic damage especially if high winds and drought are to occur at or near harvest. Lodging is likely to be confounded if the populations of the sunflower stem weevil increase.

Responses from the grower surveys were generally low in both years. Getting an adequate yet representative response from mail oriented surveys has always been a problem. One major assumption of the survey is that the survey sample reflects an accurate cross section of the survey population. Clearly this assumption could not be met. However, responses for the two years were very similar and do show consistancy in the results.

Although the relative position of the species varied slightly, data from the grower surveys clearly showed that pests of primary concern to growers were sunflower beetle, sunflower midge and cutworms. When compared to the field survey it would appear that growers were concerned and aware of those species that cause conspicuous damage. Notably, these pests also occurred early in the season. Field surveys did not reveal cutworms as one of the more prevelent pests. This is because soil sampling was not carried out. Furthermore, cutworms occur much earlier (early June) than when sampling was initiated (late June).

Few growers adjusted their planting dates to avoid a pest problem. Although the proportion of growers that adjusted their planting dates doubled in 1984, this technique was not used as a major strategy for the management of sunflower insect pests. This is surprising since for the management of sunflower midge, the only practical method is to delay planting possibly after 25 May (Schulz 1982). Only 12.8% of the growers in 1983 and 8.5% of the growers in 1984 planted sunflower later than 25 May. It could not be established as to why delayed planting was not used by a greater proportion of growers. Whether the growers were not aware of this strategy or whether it was not practical to adjust the planting date remains uncertain. This is especially so for 1983 where a larger proportion of growers considered the midge to be a serious problem. Delayed planting would also reduce the impact of other pests such as banded sunflower moth, sunflower moth and the red sunflower seed weevil.

The present results revealed that growers rely heavily on insecticides for the management of sunflower insect pests. The bulk of these insecticides are used in controlling the sunflower beetle. Although a large proportion of growers indicated that they use economic thresholds when making a treatment decision, data from the field survey on sunflower beetle showed that growers applied insecticides at well below the established threshold values. Similar observations were made in spatial distribution studies (Section IV) where 6 out of 8 growers applied insecticides at well below the threshold values. Thus the use of economic thresholds by growers is highly suspect.

Data from seasonal abundance studies showed that adult control is probably not effective because of re-invasion. In each instance the entire field was treated. Border treatments for the control of adults could prove useful and should be investigated. Such a strategy would reduce control costs as well as the pesticide load. In 1983 six fields were treated for adult control (Fig. 5). Control for adults would not have been necessary in any of these fields if the new thresholds of 2-3 adults per plant were applied (Section II). On the contrary, 7 fields (instead of 2 fields according to the old thresholds) would have had to be treated for larval control. But actually, eleven fields were treated for larval control (Table 3). Thus it would appear that growers have been unintentionally using the new threshold values of 5-10 larvae per plant.

ACKNOWLEDGEMENT

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Table 1: Occurrence of sunflower insect pests in twelve farms in Manitoba, 1983.

Insect Order[a]	Insect Family	Pest Species	Common name	Farm[b,c] 1	2	3	4	5	6	7	8	9	10	11	12
			STEM												
LEP	Tortricidae	*Suleima helianthana* (Riley)	Sunflower bud moth	+	–	–	–	–	+	–	–	+	–	+	–
DIP	Tephritidae	*Strauzia longipennis* (Wied.)	Sunflower maggot	+	+	+	+	+	+	+	+	+	+	+	+
			FOLIAGE												
LEP	Nymphalidae	*Vanessa cardui* (L.)	Painted lady	–	+	+	+	–	–	–	–	+	–	–	–
COL	Chrysomelidae	*Zygogramma exclamationis* (F.)	Sunflower beetle	+	+	+	+	+	+	+	+	+	+	+	+
			CAPITULUM												
LEP	Cochylidae	*Cochylis hospes* (Wlshm.)	Banded sunflower moth	+	+	+	+	+	+	+	+	+	+	+	+
	Pyralidae	*Homoeosoma electellum* (Hulst.)	Sunflower moth	+	+	+	+	+	–	+	–	+	+	+	+
DIP	Cecidomyiidae	*Contarinia schulzi* Gagne	Sunflower midge	+	+	–	–	+	+	+	+	+	+	+	+
	Tephritidae	*Neotephritis finalis* (Loew)	Sunflower seed maggot	–	–	–	+	–	–	+	–	–	–	+	+
COL	Curculionidae	*Smicronyx fulvus* LeConte	Red sunflower seed weevil	–	–	–	–	+	+	–	–	–	–	+	+

[a]Order code: LEP = Lepidoptera, DIP = Diptera, and COL = Coleoptera
[b]+ = present, – = absent [c]See Fig. 1 for location of farms.

Table 2: Duration, mean densities, and mean percent infestation of four sunflower insect pests in twelve farms in Manitoba, 1983.

Farm	Sunflower Beetle			Sunflower Midge			Sunflower Maggot			Banded S. Moth		
	N[a]	Mean Density[b]	Percent Infest.[c]	N	Mean Density	Percent Infest.	N	Mean Density	Percent Infest.	N	Mean Density	Percent Infest.
1	5	2.8	60.0	3	7.6	25.0	7	0.9	54.3	5	0.5	22.0
2	5	3.9	77.0	2	7.8	17.5	7	0.9	55.0	6	2.2	57.5
3	5	1.8	47.0	0	0	0	7	1.2	61.6	6	2.5	71.7
4	6	3.3	54.2	0	0	0	7	1.1	60.0	6	2.2	63.3
5	5	1.8	69.0	8	19.0	46.9	7	1.0	60.7	7	1.8	57.1
6	6	2.4	71.7	7	15.0	42.9	7	0.8	55.7	7	0.3	40.0
7	3	4.4	93.3	8	14.7	48.8	6	2.6	79.2	6	1.6	55.8
8	3	3.1	86.7	7	13.0	52.8	6	2.6	75.8	5	1.7	62.0
9	8	3.3	40.0	6	7.9	30.0	6	2.0	69.2	5	3.1	74.0
10	7	1.8	40.7	6	7.2	25.0	7	1.3	63.6	7	0.8	40.0
11	7	0.5	29.3	7	9.8	37.1	7	1.3	63.6	7	2.1	57.0
12	5	3.8	61.0	4	8.7	37.5	7	1.3	64.3	6	0.7	40.0

[a]Period of infestation in weeks. [b]Mean number of larvae per plant per week.
[c]Mean infestation per week.

Table 3: Dates and density at which insecticides were applied to control sunflower beetle larvae in eleven farms in Manitoba, 1983.

Farm	Date of Spraying	Density[a,b]
1	13 July	6.9 ± 0.7
2	19 July	5.0 ± 0.8
3	15 July	5.8 ± 0.6
4	30 July	9.7 ± 1.0
5	14 July	3.6 ± 0.4
6	29 July	4.1 ± 0.5
7	17 July	5.7 ± 0.9
8	18 July	2.7 ± 0.4
9	16 July	12.9 ± 0.6
10	21 July	3.3 ± 0.7
12	15 July	7.7 ± 0.8

[a] Mean($\pm$S.E.) number of larvae per plant; n = 20

[b] Fields sampled 1-5 days prior to date of treatment.

Table 4: Sunflower insect pests, in order of importance to growers in Manitoba, 1983-1984.

Order of Importance	n	% Response (±C.L.)[a] Sunflower beetle	Sunflower midge	Cutworms
		1983		
First	112	67.0± 8.7	15.2± 6.6	8.9± 5.3
Second	72	35.5±11.2	30.6±10.8	9.7± 6.8
Third	28	17.9±14.2	17.9±14.2	32.0±17.3
		1984		
First	133	76.7± 7.2	3.0± 2.9	12.8± 8.3
Second	78	24.4± 9.5	20.5± 9.0	28.2±10.0
Third	23	8.7±11.5	13.3±13.7	17.4±15.5

[a] % response with 95% confidence limits

Table 5: Adjustment of planting time, for the management of sunflower insect pests, by growers in Manitoba, 1983-1984.

Type of Pest	Adjustment of planting date	Grower Response 1983	Grower Response 1984
Sunflower midge	early	3	0
	late	7	11
Cutworms	early	1	3
	late	3	4
Sunflower beetle	early	-	3
	late	-	2
Sunflower moth	early	-	0
	late	-	3
Sunflower budworm	early	-	0
	late	-	2
	Total	14 (10.7)[a]	28 (20.4)

[a]% response

Table 6: Awareness, use, and effectiveness of economic thresholds to sunflower growers in Manitoba, 1983-1984.

Economic Thresholds	Grower Response 1983	Grower Response 1984
Awareness		
Aware	114 (88.4)[a]	123 (89.8)
Not aware	15	14
Application		
Apply	96 (85.0)	119 (96.7)
Do not apply	17	4
Usefulness		
Useful	106 (98.1)	114 (92.7)
Not useful	2	9
Effectiveness		
Very effective	57 (53.8)	61 (53.5)
Partly effective	49	53

[a]% response

Fig. 1. Location of sites for field survey and seasonal abundance studies. Sites are numbered according to the sequence in which they were sampled. WPG = Winnipeg.

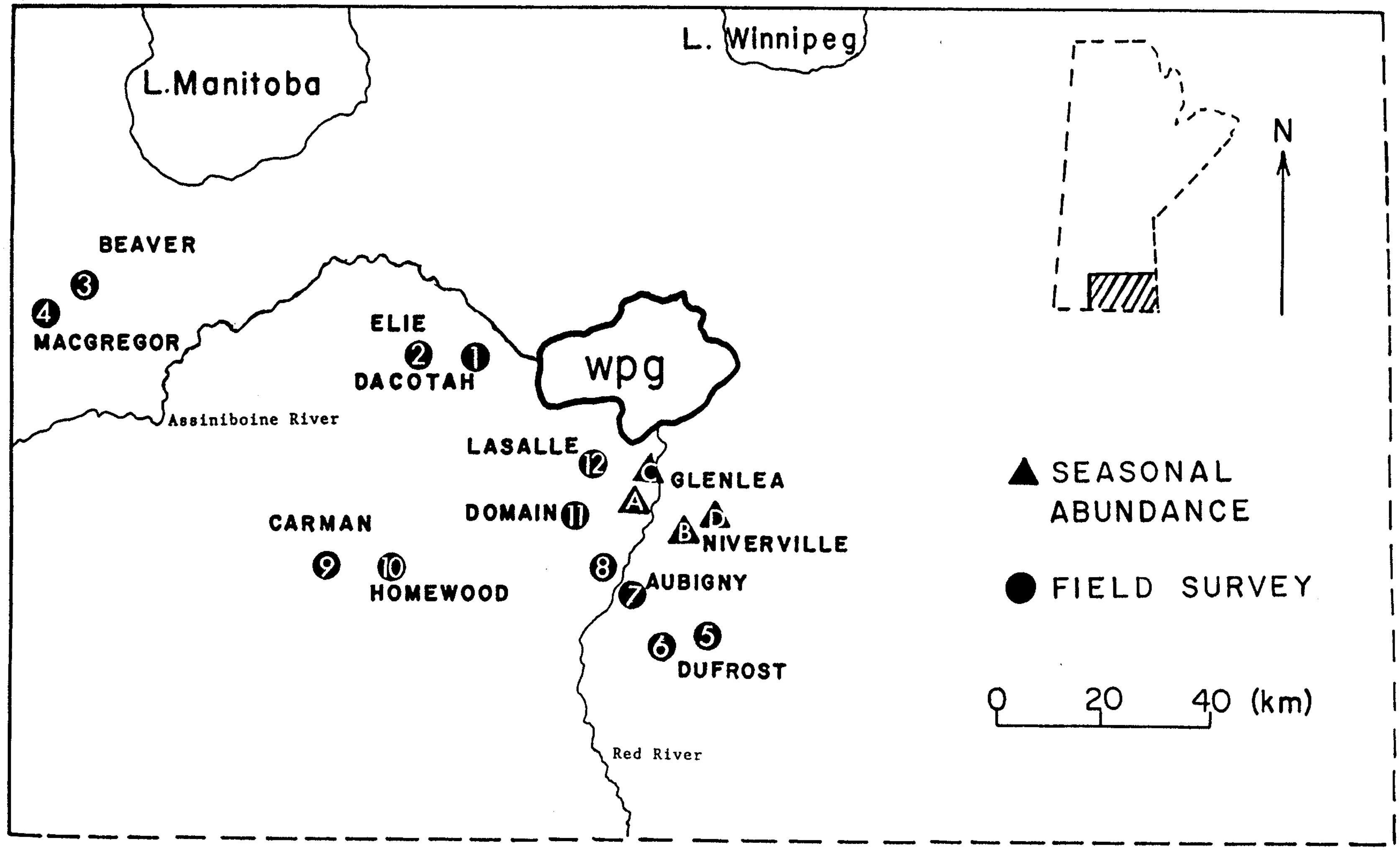

L.Manitoba
L. Winnipeg
N
BEAVER
MACGREGOR
ELIE
DACOTAH
wpg
Assiniboine River
LASALLE
GLENLEA
DOMAIN
CARMAN
NIVERVILLE
HOMEWOOD
AUBIGNY
DUFROST
Red River
SEASONAL ABUNDANCE
FIELD SURVEY
0 20 40 (km)

Fig. 2. Duration and percent infestation of sunflower beetle and sunflower midge in three farms in Manitoba, 1983. See Fig. 1 for location of farms. n = 20.

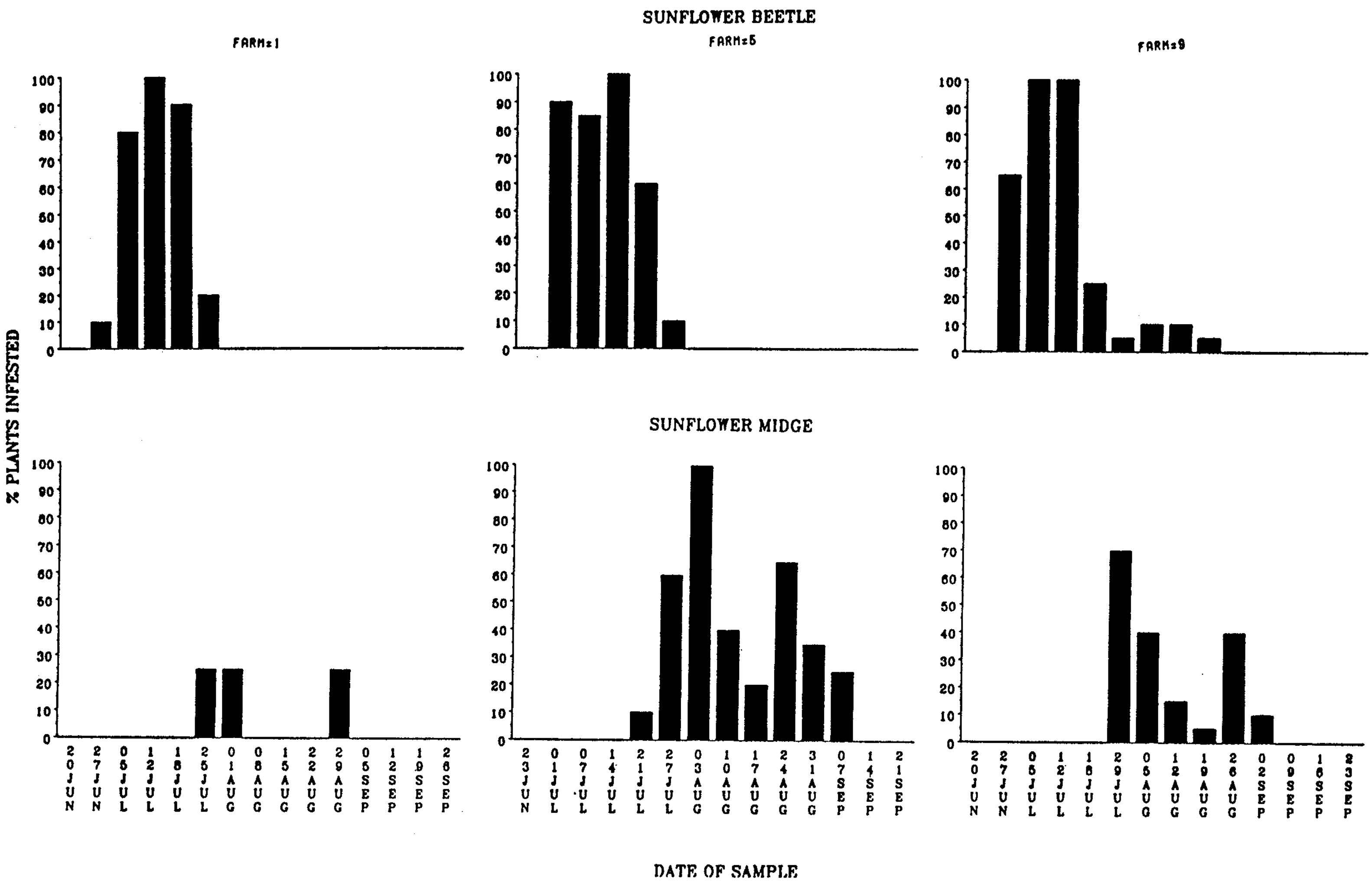

SUNFLOWER BEETLE
FARM=1
FARM=5
FARM=9
SUNFLOWER MIDGE
% PLANTS INFESTED
0 10 20 30 40 50 60 70 80 90 100
20JUN 27JUN 05JUL 12JUL 18JUL 25JUL 01AUG 08AUG 15AUG 22AUG 29AUG 05SEP 12SEP 19SEP 26SEP
23JUN 01JUL 07JUL 14JUL 21JUL 27JUL 03AUG 10AUG 17AUG 24AUG 31AUG 07SEP 14SEP 21SEP
20JUN 27JUN 05JUL 12JUL 18JUL 29JUL 05AUG 12AUG 19AUG 26AUG 02SEP 09SEP 16SEP 23SEP
DATE OF SAMPLE

Fig. 3. Duration and percent infestation of sunflower maggot and banded sunflower moth in three farms in Manitoba, 1983. See Fig. 1 for location of farms. n = 20.

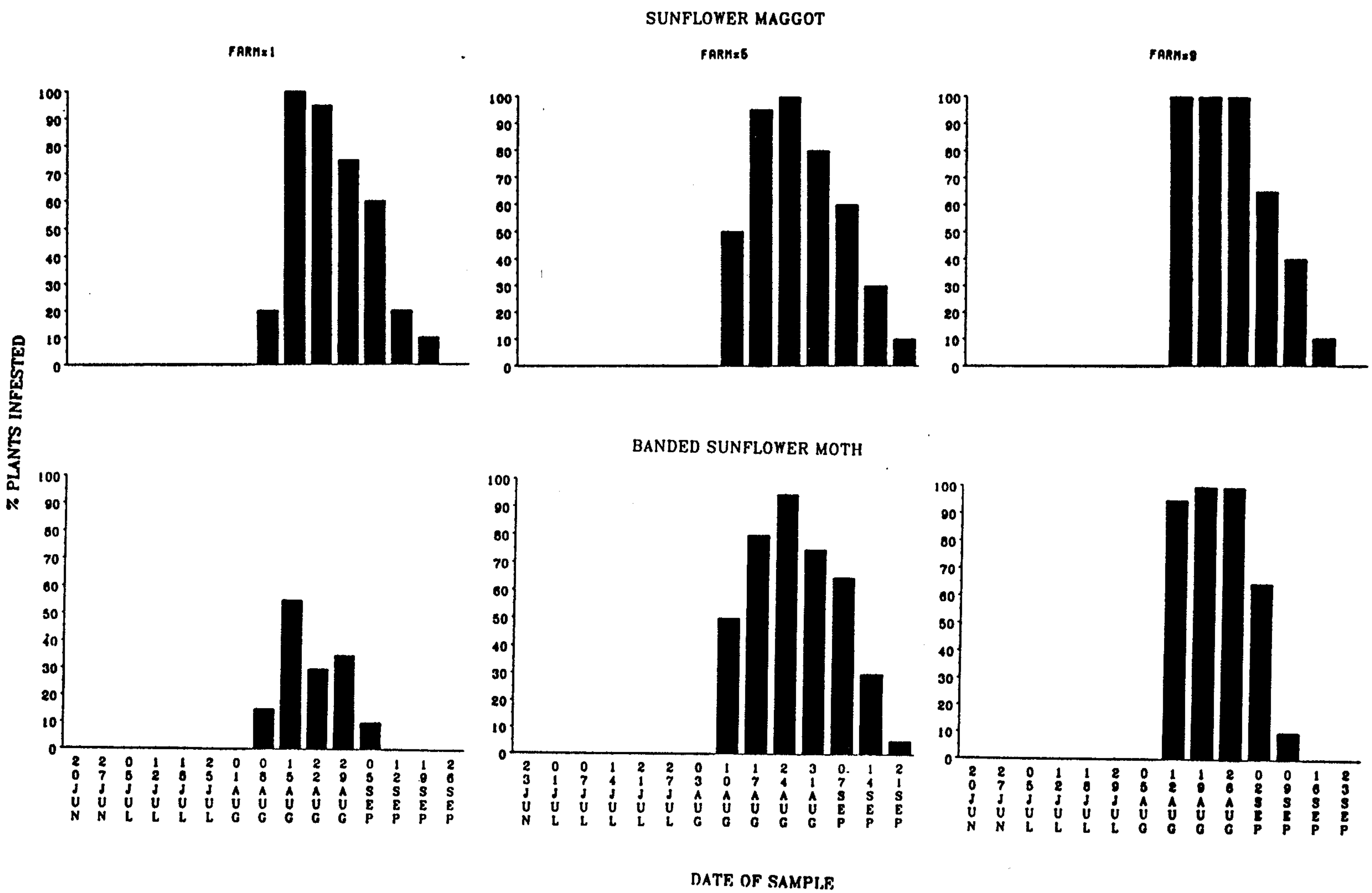

SUNFLOWER MAGGOT
FARM=1
FARM=5
FARM=9
BANDED SUNFLOWER MOTH
% PLANTS INFESTED
DATE OF SAMPLE

Fig. 4. Mean ($\pm$S.E.) number of sunflower beetles per plant in four farms in Manitoba, 1984-1985. Arrows indicate application of insecticides. See Fig. 1 for location of farms. DP = Date of planting. n = 40.

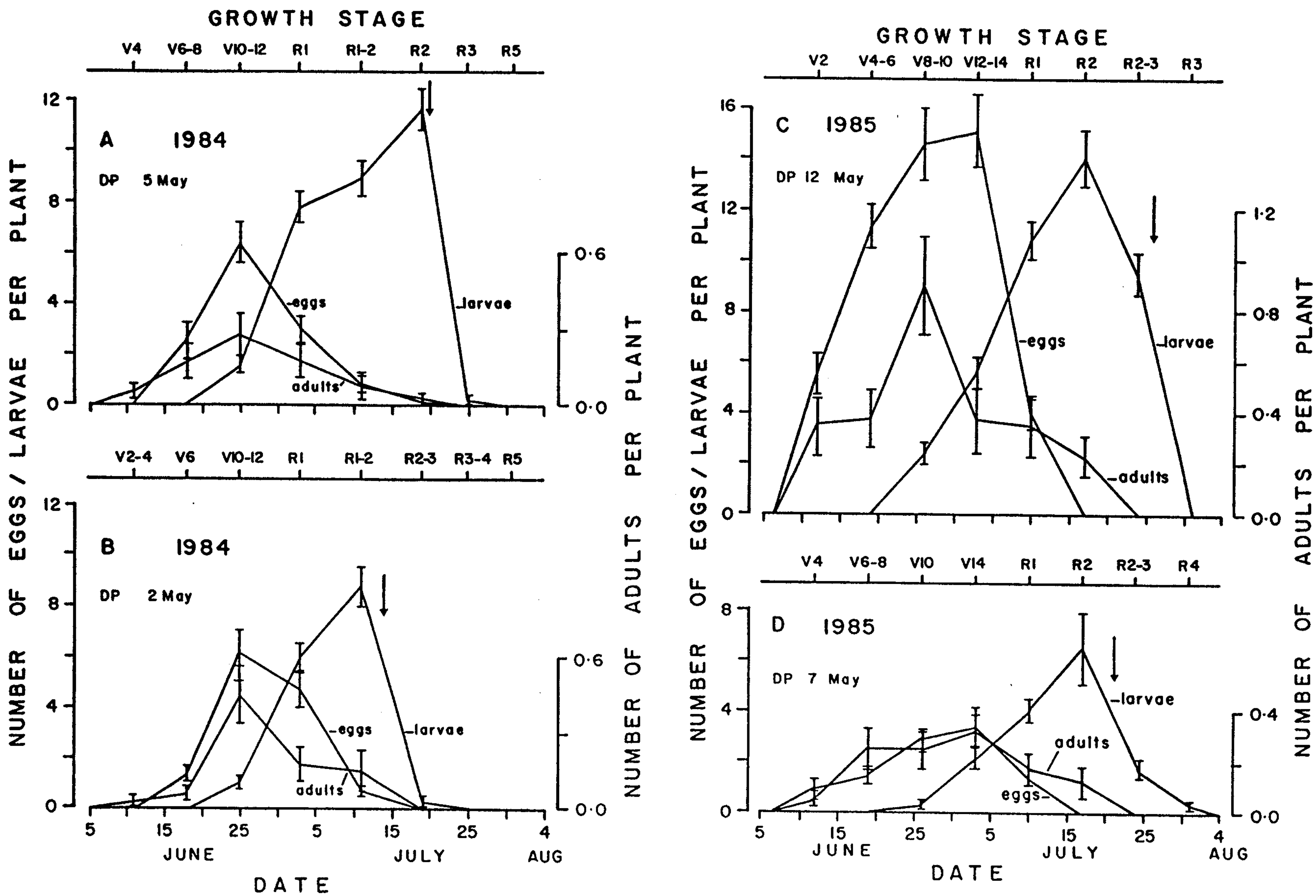
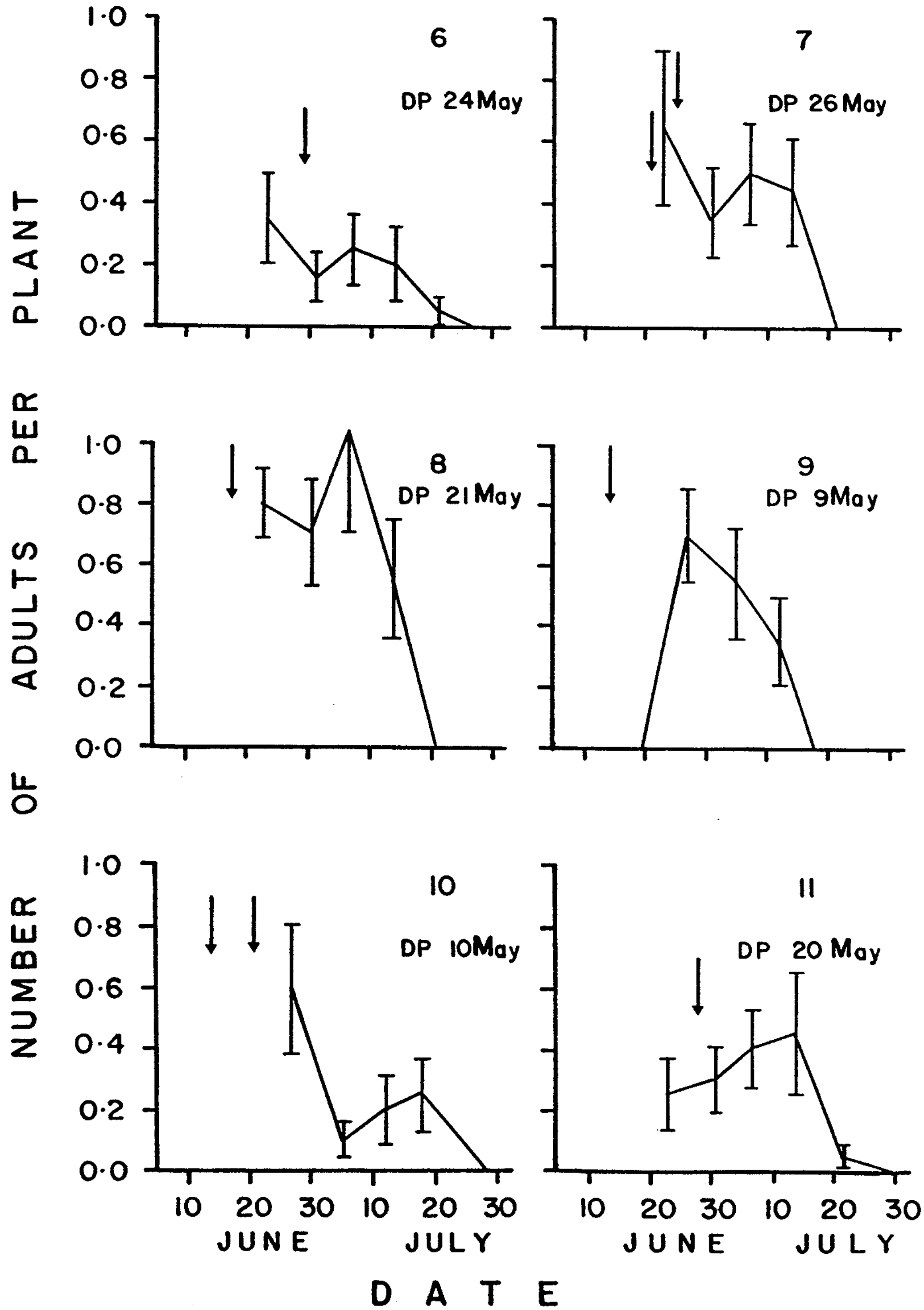

GROWTH STAGE
V4 V6-8 V10-12 R1 R1-2 R2 R3 R5
A 1984
DP 5 May
eggs
larvae
adults
V2-4 V6 V10-12 R1 R1-2 R2-3 R3-4 R5
B 1984
DP 2 May
eggs
larvae
adults
NUMBER OF EGGS / LARVAE PER PLANT
NUMBER OF ADULTS PER PLANT
5 15 25 5 15 25 4
JUNE JULY AUG
DATE
GROWTH STAGE
V2 V4-6 V8-10 V12-14 R1 R2 R2-3 R3
C 1985
DP 12 May
eggs
larvae
adults
V4 V6-8 V10 V14 R1 R2 R2-3 R4
D 1985
DP 7 May
larvae
adults
eggs
NUMBER OF EGGS / LARVAE PER PLANT
NUMBER OF ADULTS PER PLANT
5 15 25 5 15 25 4
JUNE JULY AUG
DATE

Fig. 5. Mean ($\pm$S.E.) number of sunflower beetle adults per plant in six farms in Manitoba, 1983. Arrows indicate application of insecticides. See Fig. 1 for location of farms. DP = Date of planting. n = 20.



NUMBER OF ADULTS PER PLANT
1·0
0·8
0·6
0·4
0·2
0·0
6
DP 24May
7
DP 26May
8
DP 21May
9
DP 9May
10
DP 10May
11
DP 20 May
10 20 30 10 20 30
JUNE JULY
DATE

Fig. 6. Insect pests of concern to sunflower growers in Manitoba, 1980-1984. SFB = sunflower beetle, CWS = cutworms, SMG = sunflower midge, SMA = sunflower maggot, SMO = sunflower moth, STW = stem weevil, PLD = painted lady, and OTH = others. Bars on histograms represent 95% confidence limits.

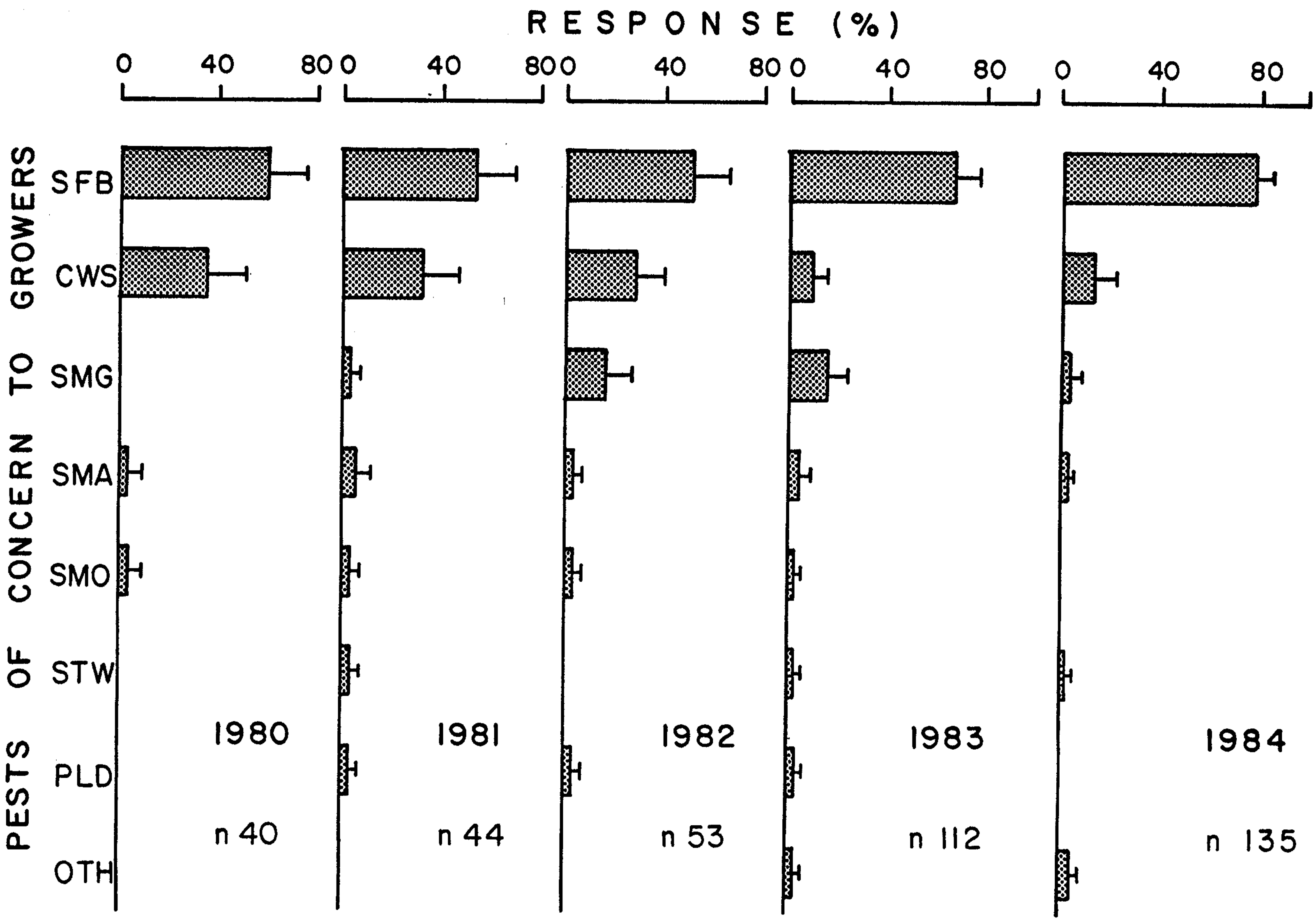

RESPONSE (%)
0 40 80
PESTS OF CONCERN TO GROWERS
SFB
CWS
SMG
SMA
SMO
STW
PLD
OTH
1980
n 40
1981
n 44
1982
n 53
1983
n 112
1984
n 135

Fig. 7. Type of insect pests monitored by sunflower growers in Manitoba, 1983-1984. SFB = sunflower beetle, CWS = cutworms, SMG = sunflower midge, SMA = sunflower maggot, SMO = sunflower moth, STW = stem weevil, and PLD = painted lady. Bars on histograms represent 95% confidence limits.

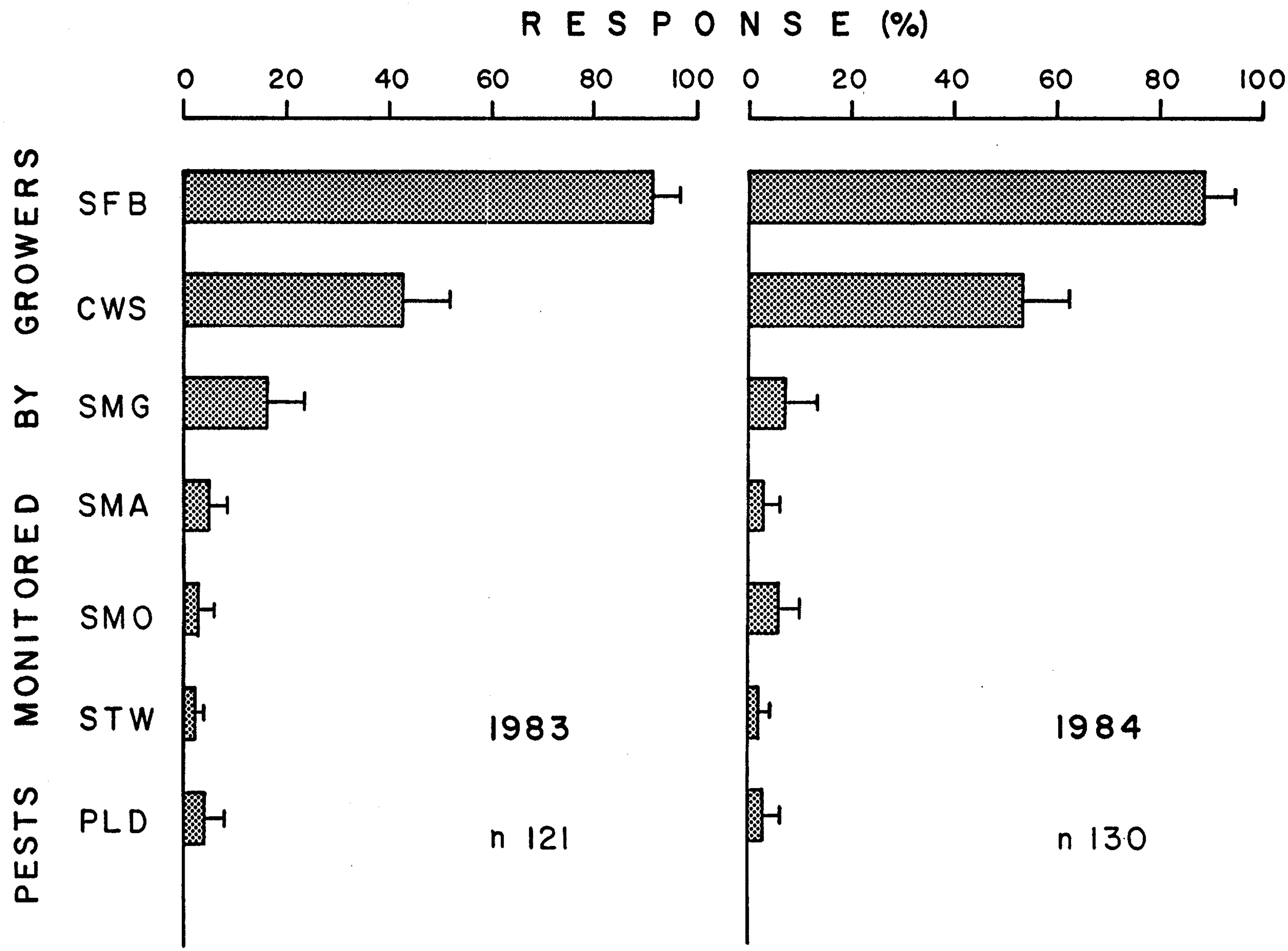

RESPONSE (%)
0 20 40 60 80 100
0 20 40 60 80 100
PESTS MONITORED BY GROWERS
SFB
CWS
SMG
SMA
SMO
STW
PLD
1983
n 121
1984
n 130

Fig. 8. Use of insecticides and frequency of treatment for the control of sunflower insects, by growers in Manitoba, 1983-1984. Bars on histograms represent 95% confidence limits.

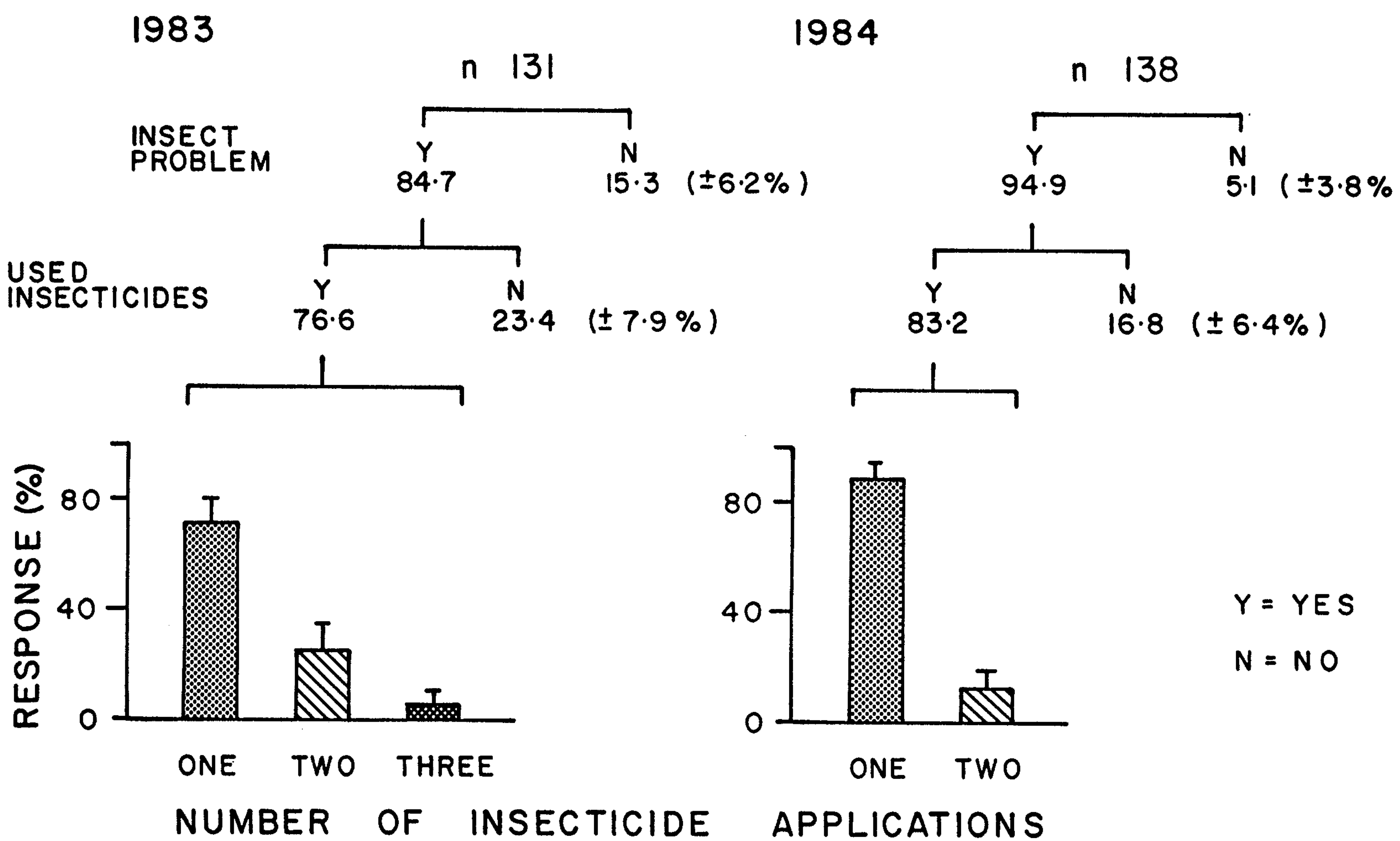
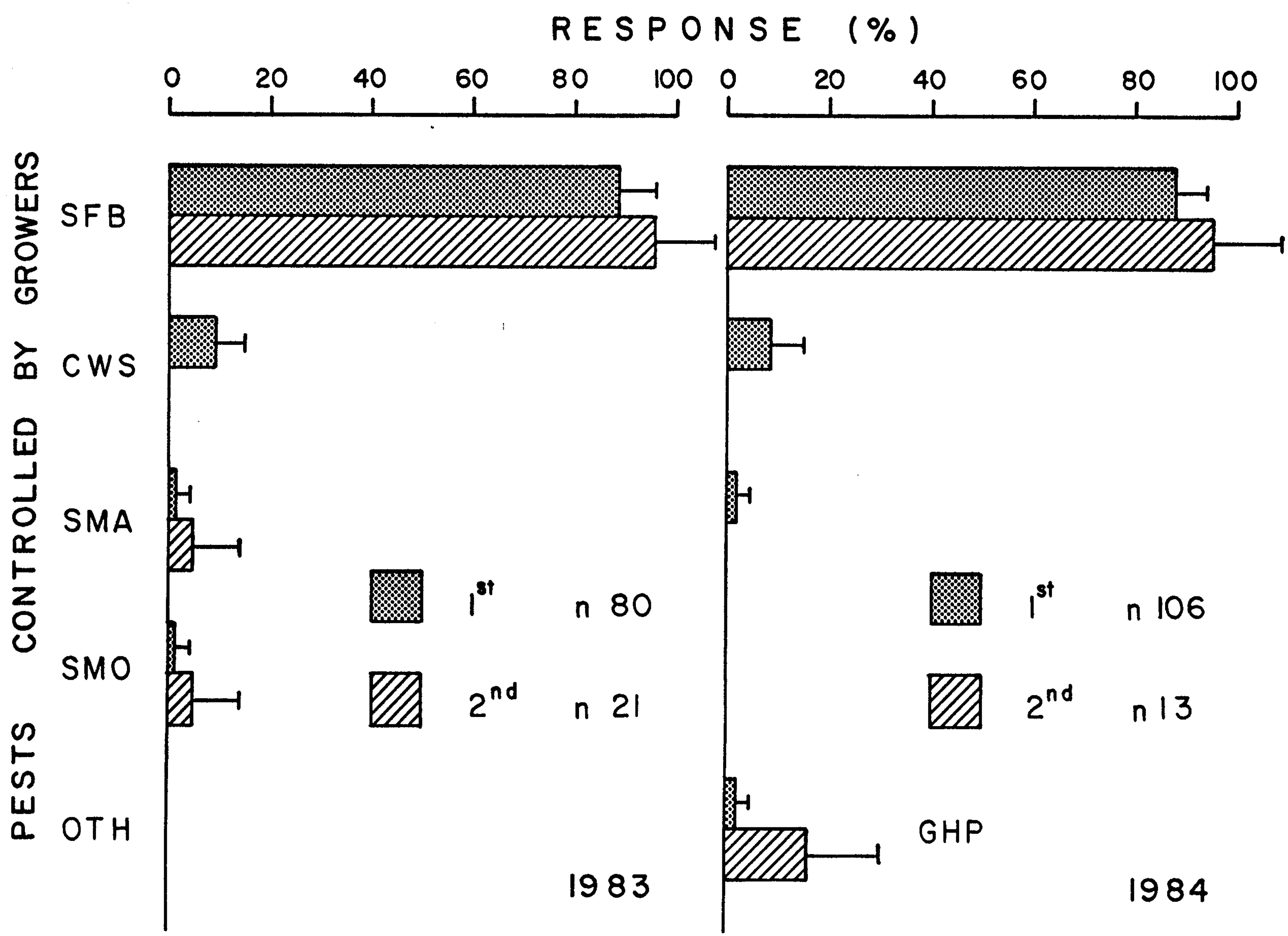
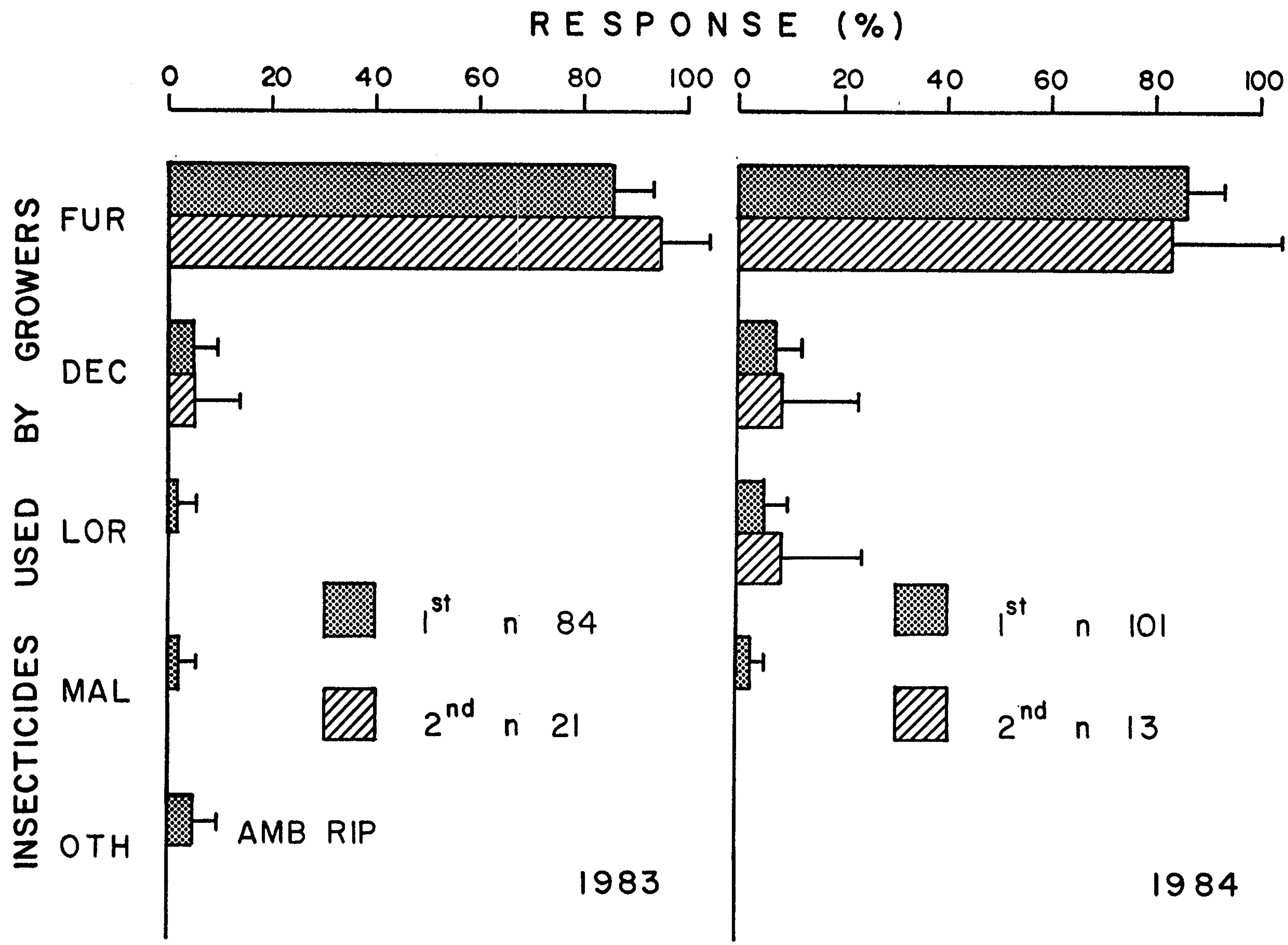

1983
n 131
INSECT PROBLEM
Y
84·7
N
15·3 (±6·2%)
USED INSECTICIDES
Y
76·6
N
23·4 (± 7·9 %)
RESPONSE (%)
80
40
0
ONE
TWO
THREE
1984
n 138
Y
94·9
N
5·1 (±3·8%)
Y
83·2
N
16·8 (± 6·4%)
80
40
0
ONE
TWO
Y = YES
N = NO
NUMBER OF INSECTICIDE APPLICATIONS

Fig. 9. Type of insect pests controlled by sunflower growers in Manitoba, 1983-1984. SFB = sunflower beetle, CWS = cutworms, SMA = sunflower maggot, SMO = sunflower moth, OTH = others and GHP = grasshoppers. 1st = First application. 2nd = Second application. Bars on histograms represent 95% confidence limits.



RESPONSE (%)
0
20
40
60
80
100
0
20
40
60
80
100
PESTS CONTROLLED BY GROWERS
SFB
CWS
SMA
SMO
OTH
1st
n 80
2nd
n 21
1983
1st
n 106
2nd
n 13
GHP
1984

Fig. 10. Type of insecticides used by growers to control sunflower insect pests in Manitoba, 1983-1984. FUR = Furadan, DEC = Decis, LOR = Lorsban, MAL = Malathion, OTH = Others, RIP = Ripcord and AMB = Ambush. 1st = First application. 2nd = Second application. Bars on histograms represent 95% confidence limits.


RESPONSE (%)
0
20
40
60
80
100
INSECTICIDES USED BY GROWERS
FUR
DEC
LOR
MAL
OTH
AMB RIP
1st n 84
2nd n 21
1983
1st n 101
2nd n 13
1984

SECTION II

DAMAGE ASSESSMENT AND ECONOMIC THRESHOLDS OF THE SUNFLOWER BEETLE, *ZYGOGRAMMA EXCLAMATIONIS* (COLEOPTERA: CHRYSOMELIDAE), ON SUNFLOWER IN MANITOBA

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SECTION II

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ABSTRACT

The effect of defoliation of sunflower by sunflower beetle, Zygogramma exclamationis (Fabricius), was quantified from experimental field plots in 1984 and 1985. Separate assessment studies were conducted to determine the effect of adult and larval defoliation, by manipulating the densities on individual plants using caged and open studies. Defoliation by adults or larvae did not significantly affect plant height. Head diameter, yield and seed weight decreased, whereas oil content increased with increasing sunflower beetle density. The relationship between pest density and percent yield was curvilinear for adults ($Y = 100 - 0.37X - 0.43X^2$) and larvae ($Y = 100 - 0.28X - 0.02X^2$) in both years. These quadratic polynomial regressions were used to estimate the economic thresholds which ranged from 2-3 adults and 5-10 larvae per plant over the two years.

Key words: Zygogramma exclamationis, sunflower, damage assessment, economic thresholds.

DAMAGE ASSESSMENT AND ECONOMIC THRESHOLDS OF THE SUNFLOWER BEETLE, *ZYGOGRAMMA EXCLAMATIONIS* (COLEOPTERA: CHRYSOMELIDAE), ON SUNFLOWER IN MANITOBA

INTRODUCTION

The sunflower beetle, *Zygogramma exclamationis* (Fabricius), is the predominant defoliating pest of commercial sunflower in Manitoba (Westdal and Barrett 1955; Westdal 1975) and North Dakota (Schulz and Lipp 1969; Schulz 1978). Both adults and larvae defoliate the plant. The beetle occurs every year and chemical control is the only method currently used to suppress the populations. Experience with Manitoba growers has shown that two to three applications may be made to control the sunflower beetle (Section I). Insecticides are frequently applied to control this insect probably because of the conspicuous damage it causes.

Economic thresholds for adults and larvae have been available for some time. However, the threshold values of Manitoba (Westdal *et al*. 1976) are lower than those of North Dakota (McBride *et al*. 1985b). No information is available to account for the difference in these thresholds; neither is there any published information on how the thresholds were developed. Economic thresholds are not static and must be refined over time. The importance of developing thresholds using experimental data on the relationship between damage potential of the pest, crop market value, control costs and potential crop yield has been addressed (Poston *et al*. 1983a).

The purpose of this study was to quantify the effect of defoliation by the sunflower beetle, and develop economic thresholds on the basis of experimental evidence of economic damage.

MATERIALS AND METHODS

Two plots, each 50 x 50 m were established at Glenlea, Manitoba and sown with hybrid sunflower 7101(IS) on 30 May 1984, and 24 May 1985. In each year, the two fields were separated by 50 m of fallow land. The plots were fertilized with 37-17-0 (N:P:K) at recommended rates. Fertilizer was side-banded at seeding time. Seeds (size #4) were planted at a depth of 5 cm, in rows spaced at 90 cm, with a seeding rate of 40,000 plants/ha. Plots were cultivated once, approximately three weeks after planting. Two types of studies were conducted, one in each plot: caged and open. A completely randomized design was used for all experiments. Plants of the same stage (Schneiter and Miller 1981) and approximately the same height were randomly selected from every fourth row and tagged. Two plants on either side of the experimental unit were removed a day prior to infestation. Plants were artificially infested at the 4 and

8 leaf stages (V4 and V8), with adults and larvae, respectively. Unless otherwise stated, all experimental units were examined twice a week, when the number of insects per plant was recorded and where necessary new introductions were made to maintain a fixed density. Weeds in the vicinity of the experimental units were removed by hand each time the plants were examined. Plant stage (Schneiter and Miller 1981) and height were recorded once per week.

Caged studies. Plastic-screen cages (1 m^3) were placed over individual plants, a day prior to the infestation. To determine the effect of adult defoliation, 0, 1, 2, 3 and 4 newly emerged females were introduced into the cages. These densities were doubled in 1985. Plants were infested on 21 June 1984 and 24 June 1985, and the treatments replicated 6 and 10 times, in 1984 and 1985, respectively. Eggs found on the plant were destroyed each time the cages were examined. On occasion the eggs hatched and the first instar larvae were removed.

Initial and subsequent introductions of adults were made from a laboratory colony. Adults were collected from a sunflower field in Carman and Bothwell, Manitoba, on 24 August 1983 and 28 August 1984 and reared according to the methods of Neill (1982). Once diapause was broken, the adults were maintained in an environmental chamber at 20°C with 16:8(L:D) and fed on excised leaves from sunflower (hybrid 7101) grown in a plant growth room. Only those females that had mated and begun ovipositing were selected for the experiments.

To determine the effect of larval defoliation, 0, 10, 20, 30 and 40 first instar larvae were introduced into the cages on 28 June 1984, and 2 July 1985. The treatments were replicated 6 and 10 times, in 1984 and 1985, respectively. Plants were initially infested with larvae obtained primarily from eggs that hatched in the laboratory. Additional larvae for subsequent infestations were obtained from a sunflower field in Niverville in 1984 and in Warren, Manitoba in 1985. Field collections were made on each day that the cages were examined. To follow the phenology of the insect, larvae were collected from the same site within each field in each year.

Open studies. Two types of experiments were conducted. In the first type, plants were infested and the initial densities were maintained at fixed levels by making subsequent additions of larvae. In the second type no further additions were made after the initial infestations and densities were therefore variable. In the absence of cages, plants became infested with sunflower midge, for which there are no practical control methods. To account for the midge damage, plants were rated at maturity using a six-point rating scale as follows: 0 = no midge damage, 1 = only bracts damaged, 2 = head slightly distorted, 3 = head severely distorted, 4 = head beginning to cup and 5 = head severely cupped (Appendix 4).

The fixed density studies were conducted to determine the effects of larval defoliation in the absence of cages and to confirm if damage assessment could be performed without the use of cages. The treatments were similar to those used in caged studies and replicated 10 times in each of 1984 and 1985. Plants were infested on 29 June 1984, and 4 July 1985. The larvae were allowed to feed for a period of about 25 days.

The variable density experiments, in which no subsequent additions of larvae were made after the initial infestations, were performed to determine the effect of early season defoliation and the rate of decline of larvae. Plants were infested on 29 June 1984, and 4 July 1985, and the treatments, similar to those used in caged studies, were replicated 10 times in each year. Plants were examined once a week in 1984 and twice a week in 1985, and the number of larvae remaining on each plant recorded.

All experimental units in both caged and open studies were tagged and the cages as well as the insects removed from the plants on 23 July 1984, and 29 July 1985. Heads of all plants were bagged after ray flowers wilted (R6) to prevent seed loss to birds. Plant height and head diameter were recorded just before harvesting. Plants were harvested by hand at maturity (R9). Heads were individually bagged, dried for 2 weeks at room temperature and threshed mechanically. Seeds were cleaned using a mechanical separator and dried in an oven for 24 hours at $50 \pm 1^{\circ}C$.

Weight per head (yield) as well as 250-seed weight and oil content were determined.

Data were analyzed by analysis of variance and multiple regression (SAS 1985). Separate analyses were performed on data for each year. Linear regression ($y = a + bx$) of plant parameters (y) against sunflower beetle densities (x) was conducted for each type of study. A significance level of $P \leq 0.05$ was used unless otherwise stated.

The economic threshold was calculated using the method of Ogunlana and Pedigo (1974). To calculate the thresholds, the following values for yield from commercial fields, crop price, and control costs (Canadian dollars) were used (Anonymous 1986; J. Dean, Manitoba Department of Agriculture, Winnipeg, personal communication). Yield from commercial fields was 1150 kg/ha in 1984, and 1190 kg/ha in 1985. Crop price was $0.388/kg and $0.236/kg in 1984 and 1985, respectively. Costs of insecticide (Furadan 480F) depended on the rate of application and ranged from $2.59 to $5.18/ha in 1984, and from $3.01 to $6.02/ha in 1985. Application costs using tractor mounted equipment was estimated at $6.00/ha for the two years. Aerial application cost was $7.41/ha in 1984 and $8.03/ha in 1985.

RESULTS AND DISCUSSION

Except for oil content, growth and yield components generally decreased with increasing insect densities. Over the two years, in all but three studies, there was no significant linear relationship between sunflower beetle density and plant height (Table 1). Defoliation by adults with densities up to 8 per plant did not significantly affect plant height. These results are contrary to those of Westdal et al. (1973). They observed that defoliation over a two week period with densities of 2 adults per plant substantially reduced plant height. However, the field in which their caged tests were performed became heavily infected with Sclerotinia wilt and this may have contributed to the observed effect. Although a significant linear relationship was obtained between larval density and plant height, the regressions accounted for less than 20% of the variation and there was no consistent trend in the direction of the slopes.

In all studies, there was a reduction in head diameter and seed weight with increasing sunflower beetle density (Table 1). The relationship between sunflower beetle density and head diameter was significant in all but the variable density studies. The variation accounted for by the regressions ranged from 18 to 62%. The relationship between larval density and seed weight was significant in all studies except for the variable density study conducted in 1984.

Oil content tended to increase with increasing sunflower beetle densities in all studies. Adult feeding affected oil content but only when densities were doubled in 1985. The relationship between larval density and oil content was consistently significant in studies with constant densities. However, the regressions accounted for no more than 22% of the variation. Charlet (1983a) also observed a slight increase in oil content in North Dakota with densities of up to 4 adults per plant but noted that this increase was not significantly different from the effects of 8 adults per plant. A significant reduction in oil content occurred at densities of 16 adults per plant. The physiology of oil production in sunflower is complex and poorly understood; however, when seed size decreases oil content tends to increase (W. Dedio, personal communication). This may explain in part the observed increase in oil content.

There was a reduction in yield with increasing sunflower beetle density in all studies (Table 2). This trend was more apparent in studies with constant densities. Yields in 1985 were generally lower than in 1984 probably because of the relatively wet field season in that year. In both years, the mean yields per plant of controls were higher in caged studies when compared to open studies. To account for these differences, yields of treatments in all studies were expressed as a percentage of controls before multiple regression was used to establish the relationship between sunflower beetle density and yield.

There was a nonlinear relationship between density of sunflower beetle adults and percent yield reduction both in 1984 ($Y = -0.17 + 1.36X + 0.65X^2$, $F = 3.2$, df = 2,27) and 1985 ($Y = 0.27 - 2.00X + 0.74X^2$, $F = 20.1$, df = 2,46). Analysis of covariance based on quadratic polynomial regression showed that the slopes for the yield parameters did not differ significantly between years. A significant quadratic polynomial relationship ($F = 40.1$, df = 2, 77, $P<0.0001$) was obtained from the analysis of the pooled data (Fig. 1A). The regression accounted for 95.3% of the variation among treatments. Comparison of the control against each treatment (orthogonal contrasts) showed a significant reduction in yield at 6 and 8 adults per plant. Charlet (1983a) found, in North Dakota, that population infestation of only 2 adults per plant can result in a significant yield loss of over 20%. However, the yield loss was a combined effect of adult and larval feeding since eggs and larvae produced by the adults were not removed as in the present study. Thus, the apparent discrepancy may be due to the difference in the method of damage assessment.

A similar curvilinear relationship between larval density and percent yield reduction was obtained in caged and open studies with fixed density. In caged studies the relationship between larval density and percent yield reduction was significant in both 1984 ($Y = -0.08 + 0.62X + 0.01X^2$, $F = 9.8$, df = 2, 27) and 1985 ($Y = 1.02 + 0.05X + 0.02X^2$, $F = 16.1$, df = 2, 47). Analysis of covariance showed that the slopes for the yield parameters were not significantly different between years. The regression from the analysis of the pooled data, relating larval density to percent yield ($Y = 100 - 0.31X - 0.02X^2$, $F = 63.4$, $df = 2, 78$) accounted for 93.5% of the among treatment variation.

Damage assessment in open studies with fixed and variable densities was confounded by sunflower midge. However, in both types of study and in both years, analysis of variance showed that there was no significant interaction between the treatments and midge damage, indicating that the effect of midge on sunflower yield is probably additive. In fixed density studies, the sunflower midge affected the yield in 1984 but the significance level was marginal ($F = 2.4$, $df = 5, 38$, $P<0.0517$). In studies with variable density, the sunflower midge significantly affected the yield in 1985 ($F = 4.4$, $df = 5, 36$, $P<0.0033$). In both types of study, analysis of covariance showed that the slopes for the yield parameters were not significantly different between years. Thus, although the sunflower midge reduced the yield, the slopes were not affected and so their effect was not considered when relating larval density to yield.

In fixed density studies and in the absence of the effect of midge, the regression from the analysis of the pooled data, relating larval density to percent yield ($Y = 100 - 0.31X - 0.02X^2$, $F = 80.8$, $df = 2, 94$), accounted for 86.5% of the among treatment variation. Analysis of covariance also showed that the slopes for the yield parameters did not differ significantly between caged and open studies over the two years. A significant quadratic polynomial relationship (F = 80.8, df = 2, 174, $P<0.0001$) was obtained from the analysis of the pooled data (Fig. 1B). The regression accounted for 96.6% of the among treatment variation. Over the two years, in both caged and open studies, comparison of the control against each treatment (orthogonal contrast) showed a significant reduction in yield at 30 and 40 larvae per plant. These results are in agreement with Charlet (1981), who reported that the sunflower plant can tolerate up to 20 larvae per plant. Westdal et al. (1973) studied the effect of larval defoliation over one field season in Manitoba and concluded that larval densities of 25 or more per plant could result in yield reductions of 30%. The field in which the test was conducted became heavily infected with Sclerotinia wilt. Thus, the yield losses also could have been due at least in part to the disease.

In studies with variable density, the relationship between sunflower beetle larvae and percent yield was nonlinear but not significant both in 1984 (F = 0.5, df = 2, 47, $P<0.6345$) and 1985 (F = 2.7, df = 2, 43, $P<0.0799$). Comparison of the control against each treatment showed a significant reduction in yield only in 1985 and only when the plants were infested at an initial density of 40 larvae per plant. From the initial infestations of 10, 20, 30 and 40 larvae per plant, the densities declined substantially.

The mean densities over the season for the respective treatments were 6.4, 9.2, 10.6 and 12.5 in 1984 (Table 3) and 4.2, 6.5, 8.6 and 8.9 in 1985 (Table 4). In comparison to fixed density studies, the results show that defoliation early in the season, even with initial densities as high as 40 larvae per plant, may not significantly reduce the yield. It appears that the effect of larval defoliation is less apparent when densities decline over the season and that yields are markedly affected by relatively constant densities even at low populations. This is probably because of the continuous defoliation over the growing season.

Larval numbers also declined in fixed density studies. This is despite an attempt to maintain constant densities by making additions on a semi-weekly basis. In both years the decline of larval densities in cages was similar to open studies (Table 3,4) and unexpected. Apparently, the cages did not serve the purpose for which they were intended. One reason for the decline in larval numbers could have been predation, especially early in the season. On several occasions, larvae of *Chrysopa* sp. (Neuroptera: Chrysopidae) were found feeding on the sunflower beetle larvae in the cages. In open studies *Collops vittatus* Say (Coleoptera: Melyridae) and *Lebia atriventris* Say (Coleoptera: Carabidae) were among other species that were frequently observed feeding on the sunflower beetle larvae. Predation by these species was confirmed in force feeding trials in the laboratory. In both years and in all larval studies the decline in the number of larvae appeared to be density related. That is at higher densities, the decline was proportionately greater.

In a survey of predators of the sunflower beetle, Neill (1982) recorded eight insect species that were found feeding on one or more stages of the beetle. He noted that the melyrid beetle, C. vittatus, was common, but only observed it feeding on sunflower beetle eggs. Neill (1982) considered the carabid, L. atriventris, to be a rare predator. This species was not found feeding on any of the stages of the sunflower beetle in the field. Westdal (1975) considered L. atriventris as an important natural control agent of the sunflower beetle larvae. Both Neill (1982) and Westdal (1975) concluded that natural enemies (parasites and predators) played an important role in suppressing the beetle populations in Manitoba. Thus other predators as well as factors such as disease could also have caused the larval densities to decline in this study.

In open studies the decline of larvae later in the season could also have been due to inter-plant movement. This is especially true at relatively high densities. Experience (sampling 24 fields over three years) has shown that it is unusual to find densities exceeding 40 larvae per plant even at relatively high population levels.

The regressions from the analyses of the pooled data of fixed density studies were used to calculate the economic threshold for adults (Fig. 1A) and larvae (Fig. 1B). To calculate the threshold, the amount of loss in yield that constitutes minimum economic damage or "gain threshold" must be known (Ogunlana and Pedigo 1974). The formula used for calculating the gain threshold was:

$$\text{Gain threshold kg/ha} = \frac{\text{cost of pest control/ha}}{\text{market price of crop/kg}}$$

The gain threshold was expressed as a proportion of the average yield for commercial field:

$$\frac{\text{Gain threshold kg/ha}}{\text{Average yield of commercial field kg/ha}} \times 100 = Z$$

Chemical control is justified for any reduction in yield above Z. The economic threshold is obtained by substituting Z in the density-related regressions and solving the quadratic equations for X, where X represents the lowest population density that will cause economic damage. In this study we have equated the economic threshold to the economic injury level. This is justifiable since with chemical control there is usually no time delay in the control operation.

The economic thresholds, based on a single insecticide application varied depending on control costs including the method of application and ranged from 2-3 adults and 5-10 larvae per plant over the two years (Table 5). These threshold values are applicable to areas not affected by the sunflower midge. The thresholds for the sunflower beetle will be higher in areas where the midge occurs since damage caused by the midge is additive. With an estimated yield loss of 30% (D. Watson, CSP Foods, Altona, personal communication) the threshold values for the beetle will range from 3-4 adults and 9-13 larvae per plant. We recommend that these higher thresholds be adopted in areas severely affected by the sunflower midge.

In the calculation of these thresholds no consideration was given to depreciation costs associated with spraying equipment. Addition of these costs would increase the overall control costs and raise the thresholds. This is only one of the many difficulties encountered when attempting to establish realistic, precise thresholds (Poston *et al*. 1983a; Maiteki and Lamb 1985). The economic threshold is neither constant nor a single value. It is a dynamic parameter that varies depending on market price, control costs and potential yield (Pedigo *et al*. 1986). A revised threshold can be calculated readily from the regressions if substantial changes in crop price or control costs occur.

The proposed thresholds for adults are substantially higher than the guidelines presently available for Manitoba (Westdal *et al*. 1976) and North Dakota (McBride *et al*. 1985b). On the contrary, the larval thresholds are slightly lower. They were expected to be higher since damage assessment was conducted separately for adults and larvae. The lower values are probably because of maintaining constant densities over the entire larval period. The present experimental results indicate that adults are less damaging whereas the larvae are more damaging than has been previously reported (Westdal *et al*. 1973).

The proposed thresholds represent a substantial improvement over the guidelines presently available. This is because the values are based on experimental evidence of economic damage. Since the thresholds are based on separate effects of adults and larvae, the use of larval thresholds can be questioned. Experience (based on sampling 16 fields over a period of 3 years) has shown that densities rarely exceed 1 adult per plant (Section I). Thus, the proposed larval thresholds should be applicable unless there is a severe outbreak of the sunflower beetle where the adults may cause extensive damage to the seedlings. In this situation additional damage by larvae would have a lesser effect on percent yield reduction.

The thresholds will provide growers with a basis for making an economically sound decision on whether to apply insecticides to control sunflower beetle populations on sunflower. These values will also be useful in evaluating the performance of a control program. Since the present study was conducted over a period of two years, the threshold values may not be accurate for all growing conditions in Manitoba. Furthermore, it is unlikely that these data can be used for other hybrids or for areas where there is a marked difference between the relative phenology of the plant and the sunflower beetle.

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Table 1: Regression coefficients for the relationship between plant components (y) and sunflower beetle density (x) in Manitoba, 1984-1985.

COMPONENT	1984			1985		
	a	b	r^2	a	b	r^2
ADULTS (CAGED)[a]						
Plant height (cm)	159.15	1.75	0.02	141.01	0.40	0.01
Head diameter (cm)	27.97	-1.08	0.18*	30.44	-0.54	0.32*
250 seed weight (g)	14.44	-0.44	0.11	14.07	-0.17	0.05
Oil content (%)	40.72	0.50	0.06	38.11	0.44	0.12*
LARVAE (CAGED)[a]						
Plant height (cm)	172.11	1.18	0.02	143.47	-3.08	0.13*
Head diameter (cm)	30.05	-1.68	0.35*	28.69	-1.92	0.49*
250 seed weight (g)	15.12	-0.82	0.23*	14.84	-1.25	0.41*
Oil content (%)	41.00	0.90	0.22*	41.49	1.01	0.21*
LARVAE (OPEN)[a]						
Plant height (cm)	172.47	0.58	0.01	141.02	1.76	0.18*
Head diameter (cm)	26.32	-1.24	0.44*	26.45	-1.82	0.62*
250 seed weight (g)	14.82	-0.98	0.39*	9.93	-0.79	0.51*
Oil content (%)	41.43	0.97	0.18*	42.54	0.59	0.15*
LARVAE (OPEN)[b]						
Plant height (cm)	182.79	-0.18	0.14*	137.68	-0.18	0.04
Head diameter (cm)	24.18	-0.04	0.06	23.60	-0.05	0.15
250 seed weight (g)	14.14	-0.02	0.02	11.91	-0.05	0.14*
Oil content (%)	42.35	0.10	0.17*	41.42	0.05	0.06

[b]Variable density [a]Fixed density *$P \leq 0.05$

Table 2: Effect of four densities of sunflower beetle on sunflower yield in Manitoba, 1984-1985.

1984		1985	
Density	Mean (±S.E.) yield per plant (g)	Density	Mean (±S.E.) yield per plant (g)
	ADULTS (CAGED)[a]		
0	123.43± 5.51	0	123.87± 6.09
1	120.95± 5.09	2	123.21± 4.44
2	118.97± 8.49	4	121.10± 2.48
3	109.13± 5.84	6	103.60± 7.63
4	104.98± 6.51	8	84.94± 4.97
	LARVAE (CAGED)[a]		
0	142.18± 8.61	0	115.81± 6.45
10	131.68± 7.26	10	108.93± 9.50
20	121.40±13.16	20	102.03± 5.75
30	101.45±12.95	30	90.01± 5.43
40	86.27± 9.78	40	65.87± 7.15
	LARVAE (OPEN)[a]		
0	105.08± 7.08	0	82.69± 6.01
10	99.19± 7.29	10	79.56± 5.59
20	93.28± 5.20	20	71.11± 3.77
30	79.31± 5.28	30	56.08± 4.63
40	62.34± 6.60	40	46.03± 3.40
	LARVAE (OPEN)[b]		
0	114.06± 5.93	0	81.81± 5.93
10	108.78±10.01	10	69.39± 3.48
20	108.85± 9.58	20	66.82± 7.63
30	106.55± 6.43	30	66.68± 7.01
40	103.98± 4.44	40	62.43± 5.30

[a]Fixed density [b]Variable density

Table 3: Rate of decline of sunflower beetle larvae in three studies at Glenlea, Manitoba, 1984.

Date	Initial Density 10	20	30	40
	CAGED (FIXED DENSITY)			
4 July	10.0±0.0*	18.0±0.7	24.5±0.6	32.5±1.4
9 July	8.3±1.3	17.7±0.6	22.3±1.3	27.3±1.2
13 July	6.7±0.8	11.0±1.3	15.5±2.7	21.7±2.1
16 July	7.3±1.2	9.8±1.0	14.0±1.2	22.3±1.3
20 July	6.0±0.9	10.2±1.4	14.5±1.9	20.2±1.1
23 July	9.5±0.3	14.8±1.2	24.5±1.9	32.7±1.1
Overall Mean	8.0	13.6	19.2	26.1
	OPEN (FIXED DENSITY)			
4 July	9.2±0.4	18.7±0.4	22.7±0.4	28.1±1.1
9 July	8.1±0.6	15.9±0.5	16.7±2.2	20.9±1.2
13 July	7.5±0.7	14.5±0.9	15.5±2.1	21.1±1.6
16 July	6.6±0.7	9.5±0.8	16.9±1.6	21.7±1.6
20 July	7.9±0.5	13.5±0.9	16.5±1.8	15.7±1.7
23 July	7.6±0.4	11.7±1.5	13.1±2.1	14.9±1.8
Overall Mean	7.8	14.0	16.9	20.4
	OPEN (VARIABLE DENSITY)			
5 July	9.2±0.5	15.1±0.9	20.0±1.6	23.0±1.4
10 July	6.9±0.9	11.8±1.2	14.7±1.7	14.7±1.9
17 July	5.2±0.9	5.5±0.9	4.0±0.7	7.5±1.1
24 July	4.2±0.7	4.2±0.4	3.8±0.6	4.6±0.4
Overall Mean	6.4	9.2	10.6	12.5

*Mean(±S.E.) number of larvae per plant

Table 4: Rate of decline of sunflower beetle larvae in three studies at Glenlea, Manitoba, 1985.

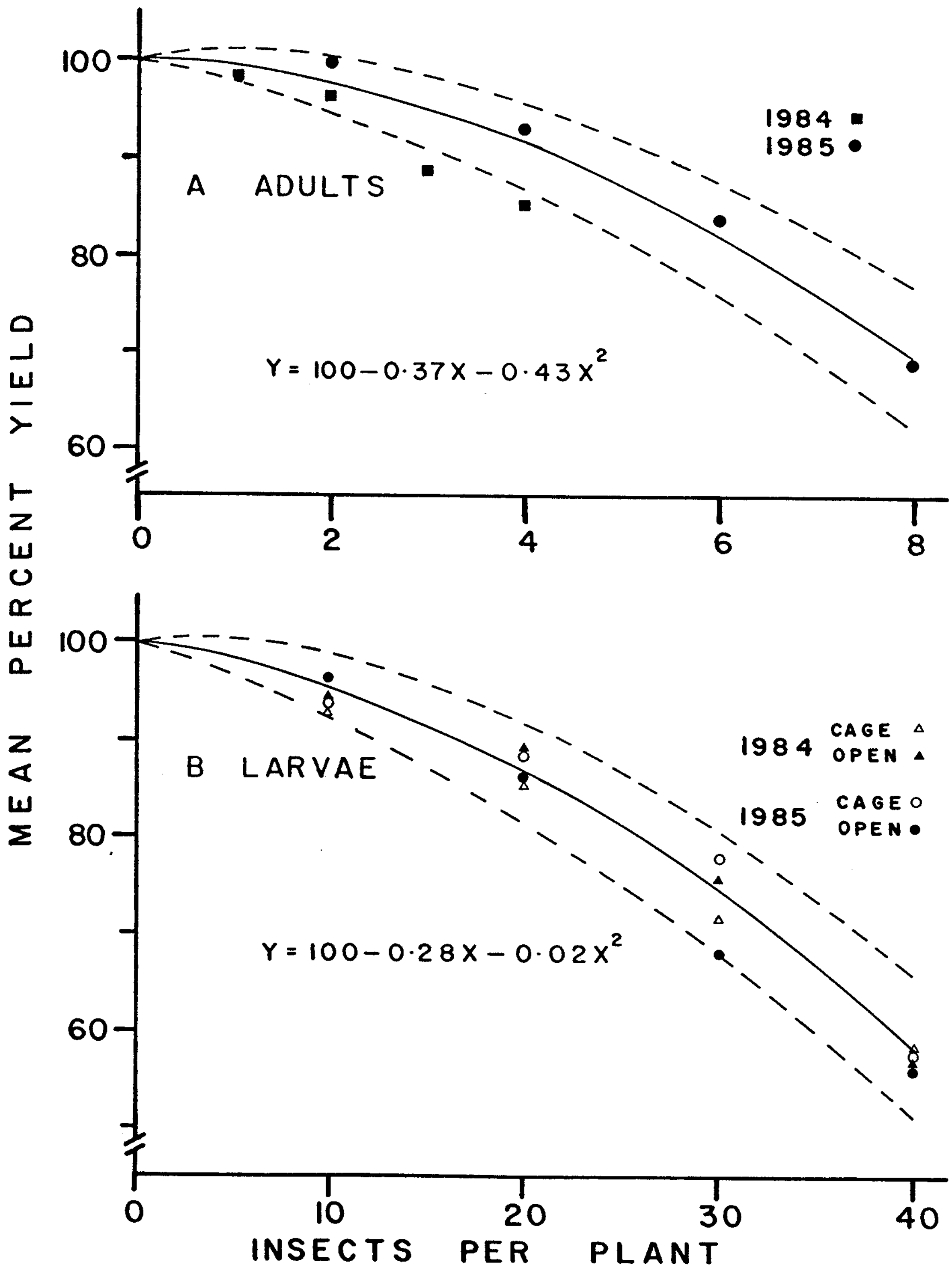
	Initial Density			
Date	10	20	30	40
		CAGED (FIXED DENSITY)		
5 July	8.4±0.3*	15.2±0.4	19.6±0.4	23.9±0.8
9 July	8.7±0.3	15.3±0.4	22.9±1.0	25.0±0.5
12 July	9.0±0.2	13.8±0.7	23.5±0.7	23.8±0.9
16 July	5.7±0.6	11.0±1.1	19.1±0.8	19.1±0.7
19 July	8.2±0.2	13.5±0.9	18.9±0.6	21.3±1.1
22 July	7.9±0.4	13.8±0.8	16.6±1.0	21.7±0.9
26 July	6.5±0.8	12.1±0.9	14.0±0.5	17.4±0.9
Overall Mean	7.8	13.5	19.2	21.6
		OPEN (FIXED DENSITY)		
8 July	6.6±0.5	9.8±1.7	14.0±1.2	16.0±1.3
11 July	8.0±0.7	12.5±1.2	18.5±1.0	25.9±0.8
15 July	8.8±0.4	14.2±0.6	18.5±0.7	23.8±0.7
18 July	6.6±0.6	12.4±1.0	15.6±0.9	21.0±1.2
22 July	5.2±0.8	14.1±0.6	14.3±1.0	16.8±1.0
25 July	7.3±0.4	14.9±0.6	12.9±1.3	15.3±1.3
29 July	6.2±0.5	9.8±0.5	12.5±0.8	16.3±1.2
Overall Mean	7.0	12.5	15.2	19.3
		OPEN (VARIABLE DENSITY)		
8 July	7.4±0.5	11.6±1.1	17.1±0.8	16.8±1.4
11 July	5.7±0.6	8.8±1.1	11.9±0.7	12.7±1.1
15 July	5.1±0.7	8.3±1.0	10.8±0.5	11.1±1.1
18 July	4.4±0.5	7.0±0.8	8.1±0.6	8.6±0.7
22 July	3.0±0.5	4.0±0.8	5.3±0.5	5.8±0.6
25 July	2.1±0.3	3.0±0.5	3.9±0.6	3.8±0.6
29 July	2.0±0.4	2.5±0.3	3.0±0.5	3.8±0.6
Overall Mean	4.2	6.5	8.6	8.9

*Mean(±S.E.) number of larvae per plant

Table 5: Method of insecticide spraying and economic thresholds for the sunflower beetle in Manitoba, 1984-1985.

Method of insecticide application	Range of economic thresholds	
	1984	1985
	ADULTS	
Ground	1.7 - 2.0	2.3 - 2.8
Aerial	1.9 - 2.2	2.6 - 3.0
	LARVAE	
Ground	5.1 - 6.2	7.5 - 9.2
Aerial	5.7 - 6.8	8.7 - 10.3

Figure 1: Relationship of yield, as a percentage of control yield and sunflower beetle density, with 95% confidence limits of the estimated mean yield, 1984-1985. A: Adults. B: Larvae.



A ADULTS
1984 ■
1985 ●
Y = 100−0·37X − 0·43X²
B LARVAE
1984 CAGE △ OPEN ▲
1985 CAGE ○ OPEN ●
Y = 100−0·28X − 0·02X²
MEAN PERCENT YIELD
INSECTS PER PLANT

SECTION III

IMPACT OF ARTIFICIAL DEFOLIATION ON YIELD OF SUNFLOWER

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SECTION III

IMPACT OF ARTIFICIAL DEFOLIATION ON YIELD OF SUNFLOWER

ABSTRACT

Sunflower plants were artificially defoliated at five growth stages using four levels of defoliation to simulate time of damage and time of insecticide application in relation to the sunflower beetle, *Zygogramma exclamationis* (Fabricius) (Coleoptera: Chrysomelidae). Plant height, head diameter, yield, seed weight and oil content generally decreased with increasing levels of defoliation at all growth stages. Plants showed compensation at low levels (25%) of defoliation. Yield response to defoliation varied, depending on the growth stage at which injury was initiated (occurred) or the plant stage at which damage was terminated (controlled). Depending on the duration of defoliation, a linear or quadratic relationship between yield and defoliation was obtained. These relationships were used to calculate defoliation thresholds for individual growth stages.

Key words: Sunflower, artificial defoliation, damage, control, defoliation thresholds.

IMPACT OF ARTIFICIAL DEFOLIATION ON YIELD OF SUNFLOWER

INTRODUCTION

The sunflower beetle, *Zygogramma exclamationis* (Fabricius) (Coleoptera: Chrysomelidae), is an important annual pest of cultivated sunflower in Manitoba (Westdal 1975). Both adults and larvae defoliate the plant. Damage caused by the sunflower beetle is conspicuous and growers frequently apply insecticides with little knowledge of pest numbers (Section I) or the plant growth stages and the defoliation levels at which economic damage occurs. The indirect nature of yield loss caused by insect defoliators makes quantitative assessment of yield reduction difficult (Ferro *et al*. 1983). Plants differ in susceptibility to insect defoliation and yield effects are influenced primarily by the growth stage of the plant and the extent of defoliation at the time of injury (Hare 1980; Shields and Wyman 1984). An understanding of the critical stage of plant growth and defoliation level at which damage occurs is essential for developing and implementing pest management strategies. There is no published information to indicate the critical stage of plant growth in relation to the sunflower beetle in Manitoba; neither are there any reports to indicate the stage of crop development at which insecticides should be applied to minimize damage.

The purpose of this study was two-fold. First, to determine the effects of defoliation at five different growth stages and four defoliation levels simulating damage by the sunflower beetle. Second, to simulate insecticide application and identify the stage of plant growth and defoliation level at which control measures should be applied to minimize damage.

MATERIALS AND METHODS

Two plots each 50 m by 50 m were established at Glenlea, Manitoba and sown with hybrid sunflower 7101(IS) on 27 May 1985. The two fields were separated by 50 m of fallow land and fertilized with 35-17-0 (N:P:K) at recommended rates. Fertilizer was side-banded at seeding time and each plot was cultivated once on 3 July 1985. Seeds (size #4) were planted at a depth of 5 cm in rows spaced at 90 cm, with a seeding rate of 40,000 plants/ha. Furadan 480F at 0.134 kg (AI)/ha was applied using a knapsack sprayer at weekly intervals to prevent defoliation by the sunflower beetle.

A factorial experiment with completely randomized design was used for each of the two types of studies. Plants of the same stage (Schneiter and Miller 1981) and approximately the same height were randomly selected from every third row and tagged. When plants reached the stage slated for defoliation, 0, 25, 50 or 75% of the foliage was removed by defoliating portions of the leaves from the entire plant. Thereafter, plants were defoliated as the new leaves developed. Defoliation levels were obtained by removing the distal end of the leaves using a pair of scissors. In all cases, foliage was removed without destroying the midrib. This type of leaf removal is more comparable to that caused by insect injury (Poston et al. 1976). The treatments were replicated 10 times. Treatments with zero level of defoliation served as checks for each stage of plant growth and were handled similarly to plants that were defoliated except that no foliage was removed. To determine the critical stage of plant growth, plants were initially defoliated at V4, V8, V12, R1 and R2 stage with defoliation being continued sequentially up to the R3 stage (Schneiter and Miller 1981). To identify the stage of plant development at which control measures should be applied to minimize damage, defoliation was initiated at the V4 stage, continued sequentially and terminated at the V8, V12, R1, R2 and R3 stage (Fig. 1). Weeds in the vicinity of the experimental unit were removed by hand each time defoliation was performed. Heads of the plants were bagged after ray flowers wilted (R6) to prevent loss of seeds to birds.

Both fields became infested with sunflower midge, for which there are no control recommendations. To account for the midge damage a six-point rating scale was used: 0 = no midge damage, 1 = only bracts damaged, 2 = head slightly distorted, 3 = head severely distorted, 4 = head beginning to cup, and 5 = head severely cupped (Appendix 4). Plants were rated at maturity (R9) on 5 September, 1985.

Plant height and head diameter were recorded prior to harvesting. Plants were harvested by hand on 31 October 1985. Heads were individually bagged, dried for 2 weeks at room temperature and threshed mechanically. Seeds were cleaned using a mechanical separator and dried in an oven for 24 hours and $50 \pm 1\,^{\circ}C$. Weight per head (yield) as well as 250 seed weight and oil content were determined.

Data were analyzed by analysis of variance and multiple regression (SAS 1985). Linear regression ($y = a + bx$) of growth and yield components (y) against defoliation levels (x) was conducted separately for each plant stage. Unless otherwise indicated, a significance level of $P \leq 0.05$ was adopted.

Defoliation thresholds were calculated for each plant stage using the method of Ogunlana and Pedigo (1974). To calculate the thresholds, the following values for yield from commercial fields, crop price, and control costs (Canadian dollars) were used (Anonymous 1986; J. Dean, Manitoba Department of Agriculture, Winnipeg, personal communication). Yield from commercial fields was 1190 kg/ha in 1985. Crop price was $0.236/kg. Cost of insecticide application (Furadan 480F), depending on rate of application, ranged from $3.01 to $6.02/ha. Application cost using tractor mounted equipment was estimated at $6.0/ha. Aerial application cost was $8.03/ha.

RESULTS

For both types of studies, analysis of variance showed no significant interaction between growth stage and defoliation. However, for the purposes of clarity, data for each plant stage are presented separately.

<u>Damage simulation</u>. In general, both growth and yield components of sunflower decreased with increasing levels of defoliation at all growth stages. The relationship between plant height and defoliation was significant only when defoliation was initiated at V4 stage. Although significant, the regression accounted for less than 20% of the variation (Table 1). Comparison of the control against each treatment (orthogonal contrast) showed a significant reduction in plant height at 75% defoliation only.

The relationship between percent defoliation and head diameter as well as percent defoliation and seed weight was significant at all growth stages. The variation accounted for by the regressions ranged from 46-75% and 36-71% for head diameter and seed weight, respectively. Comparison of the controls against each treatment showed a significant reduction in head diameter and seed weight at all levels of defoliation when defoliation was initiated at V4 and V8 stage. At later growth stages, head diameter and seed weight were significantly reduced but only at 50 and 75% defoliation.

Oil content decreased with increasing levels of defoliation at all growth stages. However, the relationship between oil content and percent defoliation was significant only when defoliation was initiated at the vegetative stages (Table 1). Comparison of the controls against each treatment (for V4 - V12 stages) showed a significant reduction in oil content at 75% defoliation only.

At all growth stages, there was a reduction in yield with increasing levels of defoliation (Table 2). The results show that the proportion of yield reduction at 50% defoliation, when defoliation is initiated early in the season (V4 - V8 stages) is similar to 75% defoliation, when defoliation is initiated later in the season (V12 - R2 stages). It would appear that the plants can tolerate greater amounts of defoliation later in their development.

The effect of defoliation on sunflower yield was confounded by sunflower midge. However, for all growth stages, analysis of variance showed that there was no significant interaction between defoliation and midge damage, indicating that the effect of midge on sunflower yield is probably additive. The present findings are similar to the observations made in the previous study on the effect of defoliation by the sunflower beetle (Section II). Sunflower midge affected the yield but only when defoliation was initiated at V4 stage. However, the significance level was marginal ($F = 2.5$; $df = 4, 29$; $P<0.0656$).

Yields of the controls varied slightly among the various growth stages (Table 2). To account for these differences, yields of the treatments for all growth stages were expressed as a percentage of controls before regression analysis was used to relate yield reduction to percent defoliation. The relationship between percent defoliation and yield varied depending on the growth stage at which defoliation was initiated (Fig. 2).

A significant ($P<0.0001$) linear relationship between percent yield and defoliation was obtained when defoliation was initiated at V4 ($Y = 100 - 1.1701X$, $F = 406.6$, df = 1, 36) and V8 ($Y = 100 - 1.1389X$, $F = 344.7$, df = 1,37) stages. The regressions accounted for 99.5 and 98.7% of the among treatment variation for the two growth stages, respectively. Comparison of the controls against each treatment showed a significant yield reduction at all levels of defoliation.

A significant ($P<0.001$) curvilinear relationship between percent yield and defoliation was obtained when defoliation was initiated at V12 ($Y = 100 - 0.0134X^2$, $F = 80.9$, df = 1, 36), R1 ($Y = 100 - 0.0129X^2$, $F = 85.4$, df = 1, 37) and R2 ($Y = 100 - 0.0109X^2$, $F = 69.7$, df =1, 37) stages. The regressions accounted for 87.4, 93.0 and 96.3% of the among treatment variation for the three growth stages, respectively. Comparison of the controls against each treatment showed a significant reduction in yield at 50 and 75% defoliation only. The results indicate that the plants can tolerate up to 25% defoliation at later growth stages (V12 - R2).

The regressions (Fig. 2) were used to calculate defoliation thresholds for individual growth stages. To calculate the threshold, the amount of loss in yield that constitutes mimimum economic damage or "gain threshold" must be known (Ogunlana and Pedigo 1974). The formula used for calculating the gain threshold was:

$$\text{Gain threshold kg/ha} = \frac{\text{cost of pest control/ha}}{\text{market price of crop/kg}}$$

The gain threshold was expressed as a proportion of the average yield for commercial field:

$$\frac{\text{Gain threshold kg/ha}}{\text{Average yield of commercial field kg/ha}} \times 100 = Z$$

Chemical control is justified for any reduction in yield above Z. The defoliation threshold is obtained by substituting Z in the defoliation - related regressions and solving the equations for X, where X represents the lowest level of defoliation that will cause economic damage. In this study the thresholds have been equated to economic injury levels. This is justifiable since with chemical control there is usually no time delay in the control operation.

As expected, the defoliation thresholds, based on a single application varied, depending on the growth stage when defoliation was initiated. The defoliation thresholds ranged from 3.2-3.8 and 3.3-3.9% when defoliation was initiated at V4 and V8 stages, respectively. The threshold values were substantially higher when defoliation was initiated at V12, R1 and R2 stages. The respective defoliation thresholds for the three growth stages ranged from 16.7-18.2, 17.0-18.6, and 18.5-20.2%.

Simulation of insecticide application. Plant height, head diameter, yield, 250 seed weight and oil content tended to decrease with increasing levels of defoliation at all growth stages. The relationship between plant height and defoliation was significant only when defoliation was terminated at R3 stage. Although significant, the regression accounted for only 21% of the variation (Table 3). Comparison of the control against each treatment showed a significant reduction in plant height at 75% defoliation only.

The relationship between percent defoliation and head diameter as well as percent defoliation and seed weight was significant for all growth stages, even when defoliation was terminated early in the season (V8 and V12 stages). The variation accounted for by the regressions ranged from 34-64% and 12-47% for head diameter and seed weight, respectively (Table 3). For all growth stages, comparison of the controls against each treatment showed a significant reduction in head diameter at all levels of defoliation. Seed weight was significantly reduced at 75% defoliation, when defoliation was terminated at V8 and V12 stages. At later growth stages (R1 - R3), both 50 and 75% defoliation significantly reduced seed weight.

There was a decrease in oil content with increasing levels of defoliation. In general, the relationship between oil content and percent defoliation was significant whether defoliation was terminated early or late in the season. The variation accounted for by the regressions ranged from 12-25% (Table 3). Comparison of the controls against each treatment showed a significant reduction in oil content at 75% defoliation.

Yields generally decreased with increasing levels of defoliation. The plants showed considerable compensation at low levels of defoliation (25%), when defoliation was terminated at V8 and V12 stages (Table 4). The proportion of yield reduction at 50% defoliation when defoliation is terminated at V8 and V12 stages is similar to 25% defoliation, when defoliation is terminated at R2 and R3 stages. Likewise, 75% defoliation when defoliation is terminated at the vegetative stages (V8 and V12) has a similar effect on yield loss as 50% defoliation, when defoliation is terminated at the reproductive stages (R1 and R2). Thus, for the same proportion of yield reduction, a greater amount of leaf loss must occur when defoliation is terminated at the vegetative stages.

As in damage simulation studies, the effect of sunflower yield was confounded by sunflower midge. However, for all growth stages, analysis of variance showed no significant interaction between defoliation and midge damage. These results confirm those of the damage simulation studies indicating that the effect of midge damage is most likely additive. Sunflower midge significantly affected the yield when defoliation was terminated at V8 ($F = 4.4$, df = 3, 29, $P<0.0114$) and R1 ($F = 3.8$, df = 5, 31, $P<0.0083$) stages. The significance level was marginal when defoliation was terminated at R2 ($F = 2.3$, df = 4, 32, $P<0.0792$) and R3 ($F = 2.4$, df = 3, 32, $P<0.0836$) stages.

Yields of the controls for the various growth stages varied slightly (Table 4). To account for these differences, yields of the treatments for all growth stages were expressed as a percentage of controls before regression analysis was used to relate yield to defoliation. The relationship between percent yield and defoliation varied depending on the growth stage at which defoliation was terminated (Fig. 3).

A significant ($P<0.0001$) quadratic relationship between yield and percent defoliation was obtained when defoliation was terminated at V8 ($Y = 100 - 0.0064X^2$, $F = 27.1$, df = 1, 35), V12 ($Y = 100 - 0.0068X^2$, $F = 59.6$, df = 1, 38), and R1 ($Y = 100 - 0.0117X^2$, $F = 137.7$, df = 1, 39) stages. The regressions accounted for 97.0, 98.3 and 98.6% of the among treatment variation for the three growth stages, respectively. Comparison of the controls against each treatment showed a significant reduction in yield at 75% defoliation when defoliation was terminated at V8 stage. When damage was terminated at later growth stages (V12 and R1), 50 and 75% defoliation significantly reduced the yield.

The relationship between percent yield and defoliation was linear when defoliation was terminated at R2 ($Y = 100 - 0.9336X$, $F = 141.0$, $df = 1, 39$, $P<0.0001$) and R3 ($Y = 100 - 1.0663X$, $F = 164.6$, $df = 1, 38$, $P<0.0001$) stages. The regressions accounted for 97.4 and 99.7% of the among treatment variation for the two growth stages, respectively. Comparison of the control against each treatment showed a significant reduction in yield at 50 and 75% defoliation, when defoliation was terminated at R2 stage. At R3 stage, all levels of defoliation significantly reduced the yield.

As in the damage simulation studies the regressions (Fig. 3) were used to calculate defoliation thresholds for individual growth stages. The threshold values varied depending on the growth stage when defoliation was terminated. The defoliation thresholds ranged from 24.1-26.4, 23.4-25.6 and 17.9-19.5%, when defoliation was terminated at V8, V12 and R1 stages, respectively. The threshold values were substantially lower when defoliation was terminated at R2 and R3 stages. The respective defoliation thresholds for the two growth stages ranged from 4.0-4.8 and 3.5-4.2%.

DISCUSSION

The effect of artificial defoliation at various stages of plant development on sunflower growth and yield components has been quantified by other researchers

(Sackston 1959; Johnson 1972; Schneiter _et al_. 1983). However, results from these studies are not directly comparable to the present experimental data. For example, in disease simulation studies (Sackston 1959), the technique employed to simulate damage was similar to the present study; however, defoliation was conducted once only and at three stages of plant development, that is, at seedling, flowering and maturing stages. In studies simulating the effect of damage by hail (Schneiter _et al_. 1983) plants were defoliated at nine stages of sunflower development. Although the levels of defoliation were similar to the present study, defoliation was conducted by excising whole leaves at a single time. Despite the differences in the method and sequence of defoliation, the results from those studies are similar to the present study in that plant height, head diameter, yield, seed weight and oil content generally decreased with increasing levels of defoliation. But, the response of these variables was dependent upon the stage at which injury or defoliation occurred.

In the present study, high levels of defoliation (75%) significantly reduced plant height but only when defoliation was continued from V4 to R3 stage. Sackston (1959) also noted a significant reduction in plant height when seedlings of the hybrid variety Advance were completely (100%) defoliated. Partial defoliation of the seedlings (25 and 50%) did not affect plant height. Thus a considerable amount of stress (defoliation) must be imposed before plant height is significantly reduced.

In both damage simulation and simulation of insecticide application studies, head diameter and seed weight decreased with increasing levels of defoliation. The relationship between these variables and defoliation was significant irrespective of the growth stage at which injury occurred or the plant stage at which damage was terminated. In both types of studies and with both components, the amount of variation accounted for by the linear regressions increased as the duration of defoliation increased (Table 1 and 3).

From the two types of studies, it would appear that the effect of defoliation on oil content was dependent upon the stage of the plant at which damage was initiatied rather than the duration of defoliation. Oil content was significantly reduced at high levels of defoliation when defoliation was initiated at the vegetative stages of the plant development. Sackston (1959) also noted that oil content was significantly reduced only when sunflower seedlings were completely (100%) defoliated.

The present findings on oil content contradict observations made on the effects of defoliation of sunflower by sunflower beetle (Section II) where oil content generally increased with increasing insect densities. The apparent differences are difficult to harmonize. It is likely that other factors, such as plant response to insect saliva as well as the pattern of defoliation (shape and size of holes and edge indentations) may also be involved in the differential response of oil content to defoliation. It is also possible that oil content may increase with moderate defoliation and then decrease with severe defoliation. Nonetheless, the present data serve to emphasize that not all responses to insect feeding may be reflected by damage simulation studies.

Although yields generally decreased with increasing levels of defoliation, sunflower plants showed a considerable amount of compensation at low levels of defoliation. This was particularly so when damage occurred later in their development or when injury was terminated early in the vegetative stages of the plant. In the latter case, plants also showed some degree of overcompensation (Pedigo et al. 1986). Schneiter et al. (1983) also noted slight yield increases with 25% defoliation at the V6-9 and V10-14 stages. The present studies revealed that sunflower yields are markedly affected by continuous defoliation. It would appear that plants are less able to compensate when defoliation is continuous. The studies also show that yield response to defoliation will vary depending on the growth stage at which injury occurs or the plant stage at which damage is terminated. It would seem that this differential response is determined primarily by the duration of defoliation.

Data from damage simulation studies show that defoliation during the early growth stages (V4 and V8) have the greatest inpact on yield. This is reflected in the threshold values for these stages. The low threshold values are probably a result of continuous defoliation over an extended duration. The amount of defoliation that warrants insecticide application is about 4-5 times higher when damage begins later in the development of the plant. Studies on simulation of insecticide application revealed that defoliation thresholds will be higher if control is intended early in the season. This is a likely situation, if control for sunflower beetle adults is desired. Delaying control until plants are well into their reproductive stages will lower the thresholds by 5-6 fold. This is only logical since damage will have continued for a longer duration.

These theoretical thresholds were developed in relation to the sunflower beetle and on the assumption that a single application of insecticide will be effective in controlling the insect. Furthermore, the thresholds were calculated without considering the effect of sunflower midge. Since damage caused by the sunflower midge is additive, new thresholds for midge affected areas can readily be calculated from the regressions (Figs. 2 and 3) by adjusting the average yield for the amount of loss likely to be caused by the midge.

Since the present study was conducted over one field season and with one hybrid, the threshold values may not be accurate for all growing conditions in Manitoba or for other hybrids. It is unlikely that these defoliation thresholds can be used solely as a basis for making management decisions on whether or not to control the sunflower beetle. The threshold values cannot be recommended for pest management programs until the fidelity of surrogate damage is tested against actual insect feeding. This will require developing leaf consumption models that quantitatively relate insect feeding and growth (Hammond and Pedigo 1982). For the present, the defoliation thresholds should be considered as guidelines and used only in conjunction with the proposed thresholds for the sunflower beetle (Section II). The present experimental results show how sunflower responds to defoliation. These data will aid in limiting the growth stages that need to be considered for further experimental studies on the effect of defoliation by the sunflower beetle.

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Table 1: Regression coefficients relating percent defoliation (x) to growth and yield components of sunflower (y), for five growth stages, simulating time of damage.

Regression Coefficients	Initiation of Defoliation[a]				
	V4	V8	V12	R1	R2
			PLANT HEIGHT (cm)		
a	145.89	144.48	144.20	142.12	147.42
b	-0.15	-0.02	-0.09	0.01	-0.06
r^2	0.17*	0.00	0.04	0.00	0.03
			HEAD DIAMETER (cm)		
a	22.09	22.12	22.86	22.87	22.90
b	-0.16	-0.15	-0.13	-0.12	-0.12
r^2	0.74*	0.75*	0.46*	0.64*	0.48*
			250 SEED WEIGHT (g)		
a	9.57	9.84	9.98	10.40	10.08
b	-0.06	-0.07	-0.05	-0.05	-0.04
r^2	0.71*	0.71*	0.43*	0.36*	0.43*
			OIL CONTENT (%)		
a	43.05	41.53	41.72	40.72	41.63
b	-0.08	-0.06	-0.04	-0.01	-0.01
r^2	0.33*	0.14*	0.12*	0.02	0.02

[a]Defoliation terminated at R3 stage

* $P \leq 0.05$

Table 2: Effect of four levels of defoliation at five growth stages, simulating time of damage, on yield of sunflower.

Initiation[a] of Defoliation	Percent Defoliation			
	0	25	50	75
V4	57.68±3.32*	40.82±4.08	21.84±2.18	8.80±2.28
V8	58.87±4.53	41.19±3.17	21.71±2.86	11.07±3.24
V12	59.14±5.49	52.02±5.35	29.51±4.74	20.44±3.88
R1	59.63±7.45	53.83±5.05	31.81±3.05	19.85±4.62
R2	57.20±5.50	52.75±3.72	36.69±5.80	24.24±3.53

[a] Defoliation terminated at R3 stage

*Mean(±S.E.) yield per plant (g)

Table 3: Regression coefficients relating percent defoliation (x) to growth and yield components of sunflower (y), for five growth stages, simulating time of insecticide application.

Regression Coefficients	Termination of Defoliation[a]				
	V8	V12	R1	R2	R3
			PLANT HEIGHT (cm)		
a	142.46	140.76	143.15	148.06	140.62
b	0.02	0.01	-0.07	-0.03	-0.19
r^2	0.00	0.00	0.02	0.01	0.21*
			HEAD DIAMETER (cm)		
a	22.37	22.23	21.75	22.43	22.15
b	-0.08	-0.08	-0.10	-0.13	-0.14
r^2	0.34*	0.42*	0.41*	0.60*	0.64*
			250 SEED WEIGHT (g)		
a	10.37	10.25	9.43	9.67	9.80
b	-0.03	-0.03	-0.04	-0.05	-0.06
r^2	0.12*	0.15*	0.33*	0.37*	0.47*
			OIL CONTENT (%)		
a	44.07	43.45	41.80	43.01	43.96
b	-0.04	-0.04	-0.03	-0.06	-0.07
r^2	0.15*	0.12*	0.04	0.20*	0.25*

[a] Defoliation initiated at V4 stage
*$P \leq 0.05$

Table 4: Effect of four levels of defoliation at five growth stages, simulating time of insecticide application, on yield of sunflower.

Termination[a] of Defoliation	Percent Defoliation			
	0	25	50	75
V8	74.66±7.22*	76.70±5.48	62.24±5.73	47.56±6.42
V12	72.16±3.27	73.16±4.76	60.09±5.41	43.85±2.51
R1	72.11±4.20	65.87±6.42	46.92±2.81	26.80±3.98
R2	73.11±3.09	63.50±6.98	39.74±7.30	18.93±2.56
R3	72.69±8.28	51.55±6.16	32.65±3.51	16.17±2.87

[a]Defoliation initiated at V4 stage

*Mean(±S.E.) yield per plant (g)

Fig. 1. Dates and durations of artificial defoliation of sunflower. A. Defoliation initiated at various growth stages simulating time of damage. B. Defoliation terminated at various growth stages simulating time of insecticide application. Arrows indicate treatment for sunflower beetle control.

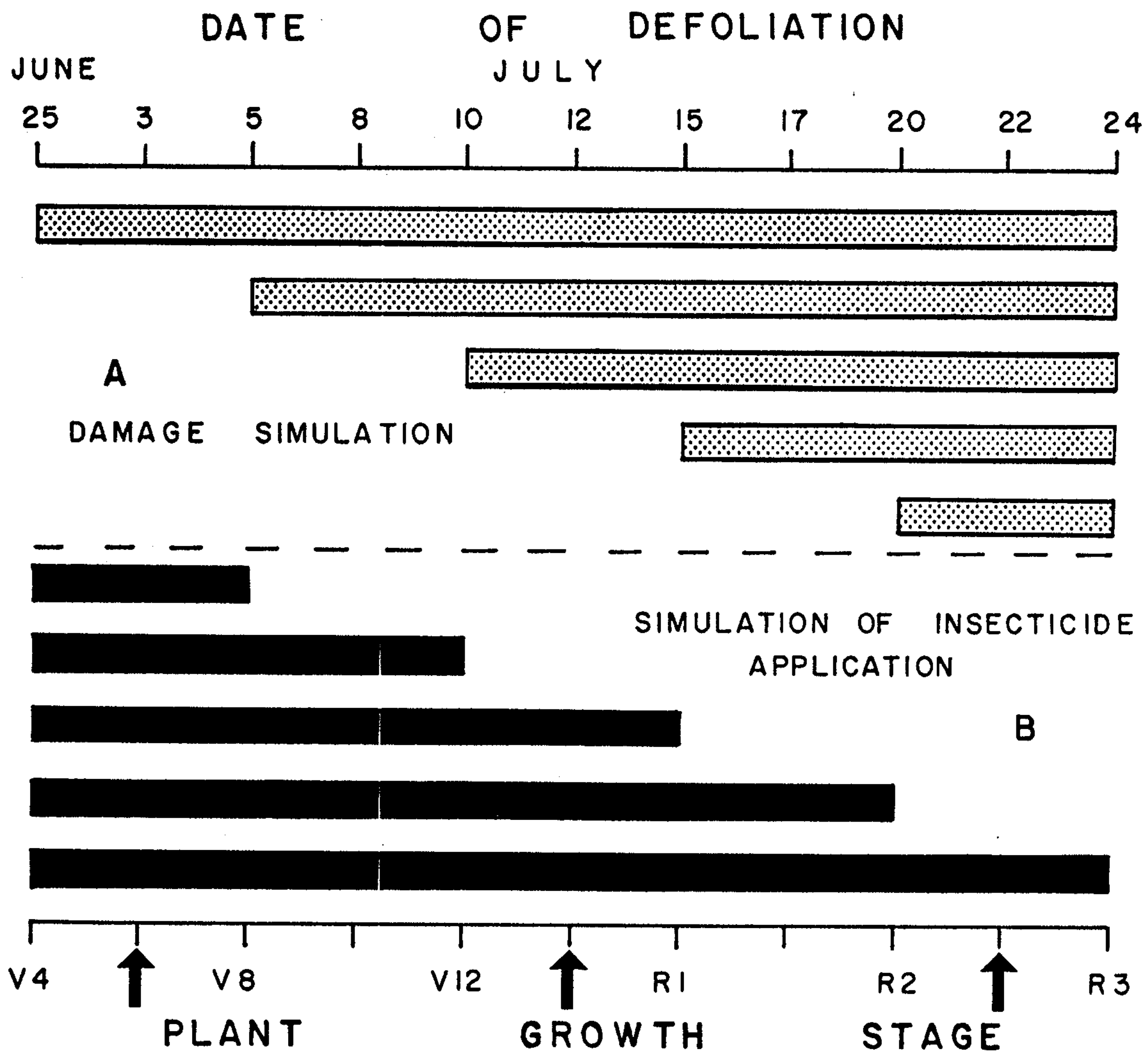
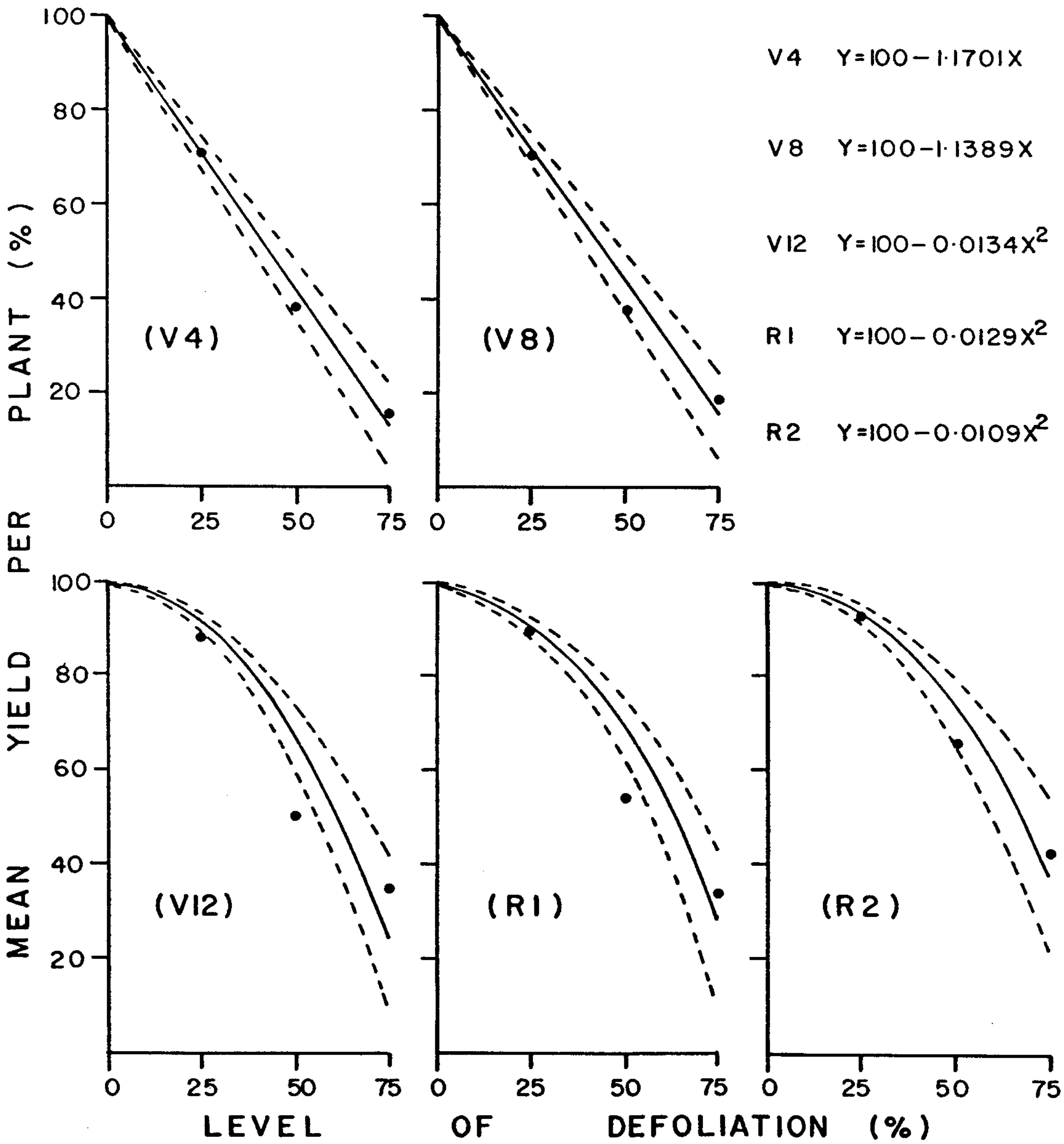
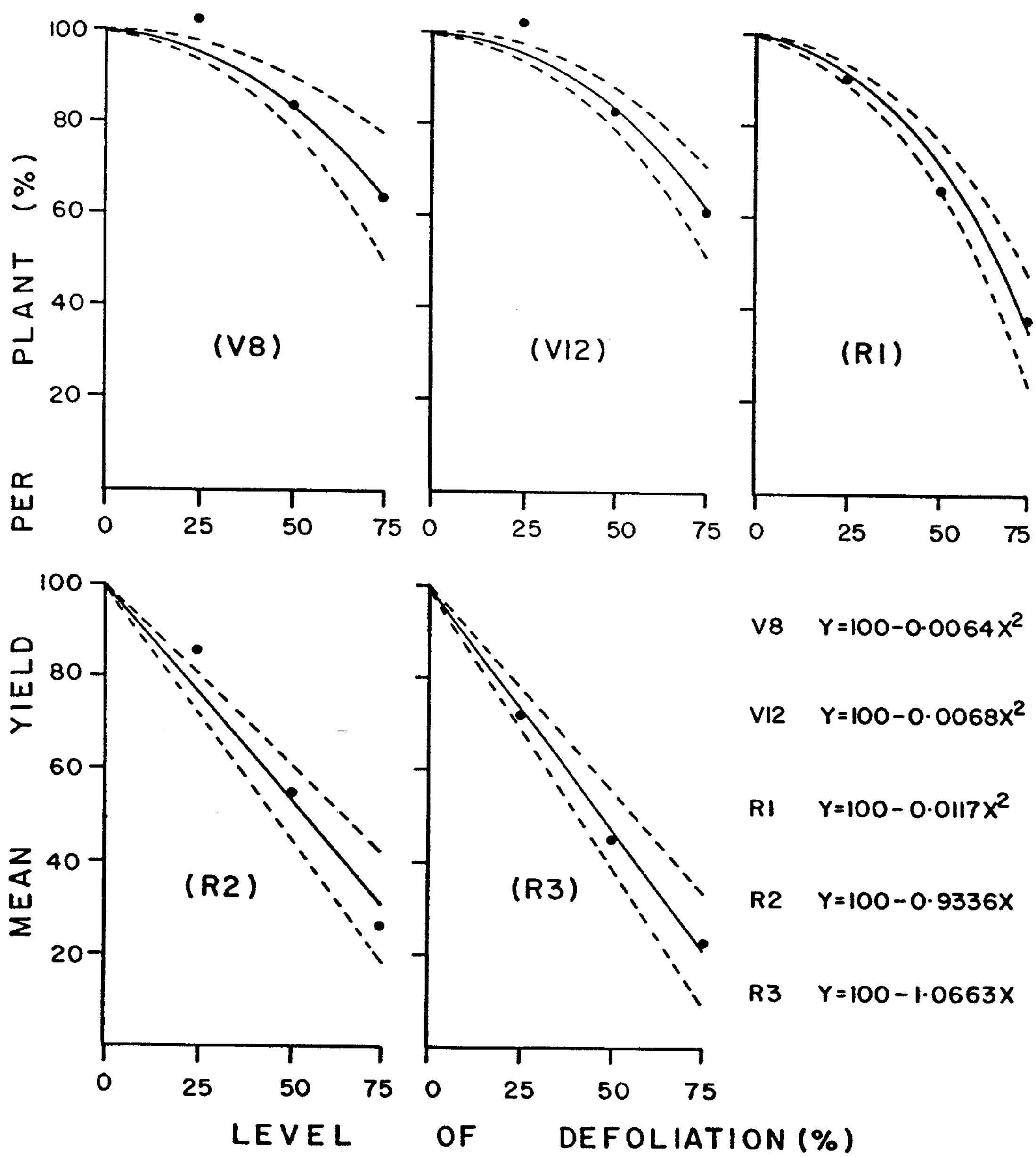

DATE OF DEFOLIATION
JUNE
JULY
25
3
5
8
10
12
15
17
20
22
24
A
DAMAGE SIMULATION
SIMULATION OF INSECTICIDE APPLICATION
B
V4
V8
V12
R1
R2
R3
PLANT GROWTH STAGE

Fig. 2. Relationship between yield and percent defoliation, with 95% confidence limits of the estimated mean yield for five growth stages of sunflower, simulating time of damage. Growth stages shown in parentheses.



MEAN YIELD PER PLANT (%)
LEVEL OF DEFOLIATION (%)
(V4)
(V8)
(V12)
(R1)
(R2)
V4 Y=100−1·1701X
V8 Y=100−1·1389X
V12 Y=100−0·0134X²
R1 Y=100−0·0129X²
R2 Y=100−0·0109X²

Fig. 3. Relationship between yield and percent defoliation, with 95% confidence limits of the estimated mean yield for five growth stages of sunflower, simulating time of insecticide application. Growth stages shown in parentheses.


MEAN YIELD PER PLANT (%)
100
80
60
40
20
(V8)
(V12)
(R1)
(R2)
(R3)
0
25
50
75
V8 Y=100-0·0064X^2
V12 Y=100-0·0068X^2
R1 Y=100-0·0117X^2
R2 Y=100-0·9336X
R3 Y=100-1·0663X
LEVEL OF DEFOLIATION (%)

SECTION IV

SPATIAL DISPERSION AND SEQUENTIAL SAMPLING PLAN FOR LARVAE OF SUNFLOWER BEETLE, *ZYGOGRAMMA EXCLAMATIONIS* (COLEOPTERA: CHRYSOMELIDAE).

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SECTION IV

SPATIAL DISPERSION AND SEQUENTIAL SAMPLING PLAN FOR LARVAE OF SUNFLOWER BEETLE, ZYGOGRAMMA EXCLAMATIONIS (COLEOPTERA: CHRYSOMELIDAE).

ABSTRACT

To minimize sampling efforts, a sequential decision plan for the control of *Zygogramma exclamationis* (F.) larvae was developed. The plan was derived from studies of larval dispersion in grower's fields at five locations over two years in Manitoba. Larval dispersion patterns were analyzed using Taylor's power law and Iwao's regression technique. Both methods detected similar dispersion patterns. Iwao's patchiness regression was used as a basis for the sequential model since it provided a consistently good fit to the data.

Key words: *Zygogramma exclamationis*, sunflower, sequential sampling.

SPATIAL DISPERSION AND SEQUENTIAL SAMPLING PLAN FOR LARVAE OF SUNFLOWER BEETLE, ZYGOGRAMMA EXCLAMATIONIS (COLEOPTERA: CHRYSOMELIDAE).

INTRODUCTION

The sunflower beetle, *Zygogramma exclamationis* (Fabricius), is an important economic pest of cultivated sunflower in Manitoba (Westdal 1975) and the northern sunflower-growing regions of the U.S.A. (Schulz 1978). The beetle occurs annually and both adults and larvae defoliate the plant. Economic thresholds have been established for this insect (Section II); however, their application is dependent upon statistically reliable sampling methods. No such sampling technique has been developed for the sunflower beetle.

What growers need is a rapid and efficient method of classifying populations on the basis of whether or not they require control. Such a task can be accomplished using the technique of sequential sampling (Waters 1955; Onsager 1976). Sequential plans that are developed using Wald's (1945) procedure are based upon predetermined fit of sample data to theoretical distribution models. One major problem encountered in developing sequential plans using this approach is that the sample data may fit each of several of the theoretical models (Shepard and Carner 1976). Methods of developing sequential sampling plans independent of knowing which theoretical distribution describes sample data have been developed (Kuno 1969; Green 1970; Iwao 1975). The essential feature of the latter method is that the variance be described as a function of mean density. This relationship can be established using Iwao's (1968) "mean crowding" to mean function, but Taylor's power law (1961) is equally suitable (Bechenski and Pedigo 1983).

The purpose of this study was two-fold: 1) to determine the spatial dispersion of the sunflower beetle larvae and establish whether there are any edge effects, and 2) to develop a sequential sampling scheme for sunflower beetle larvae.

MATERIALS AND METHODS

Ten commercial sunflower fields were selected, five each in 1984 and 1985. To maintain uniformity only fields with row spacing of 75 cm and plant to plant distance of 25 cm were chosen. The fields ranged in size from approximately 10 to 121 hectares (Table 1). For each field, the location of the nearest sunflower field was recorded for the current and previous year. The presence of hedge rows along the field margins was also noted. The entire field was sampled once about 1-5 days before growers applied insecticides for larval control. Fields were sampled between 6 and 19 July in 1984 and between 14 and 28 July in

1985 (Table 1). The growth stage of the plants ranged from R1 to R3 (Schneiter and Miller 1981).

Sampling procedure: To determine the larval dispersion pattern, systematic sampling was conducted by establishing 8 transects in each field (Fig. 1). Plants were sampled along each transect as follows: going across the field (rows), every plant was sampled for the first 20 rows, every alternate plant for the next 60 rows, every fifth plant for the next 200 rows and every 10th plant for the remaining rows until reaching the mid-point of the field. To maintain the same distance, plants along rows were sampled as follows: every third plant for the first 20 samples, every 6th plant for the next 30 samples, every 15th plant for the next 40 samples and every 30th plant for the remaining row length until reaching the centre. The entire plant was examined and the number of larvae recorded. The time taken to sample the field as well as the plant stage were noted.

Statistical analyses. The number of larvae per plant were transformed by $\sqrt{X + 0.5}$ before analyzing the data. Orthogonal contrasts were used separately for each year to test if orientation and location of transects affected larval counts. Analysis of variance (SAS 1985) was performed to determine if larval densities differed among farms and among transects within farms. The extent of the edge effect was established by comparing means within different regions of the transects. Means were separated using Duncan's multiple range test (Steel and Torrie 1980).

Unless otherwise stated a significance level of $P \leq 0.05$ was used.

Both Iwao's (1968) regression and Taylor's (1961) power law analyses were used to examine larval dispersion and to establish the most appropriate functional relationship between sampling variance (s^2) and mean larval density ($\bar{x}$). Iwao's regression method required calculating Lloyd's (1967) mean crowding index ($\overset{*}{m}$):

$$\overset{*}{m} = \bar{x} + [(s^2 \div \bar{x}) - 1] \qquad (1)$$

Estimates of α and β were then computed by linearly regressing mean crowding indices on mean density: $\overset{*}{m} = \alpha + \beta\bar{x}$. The regression constants of Taylor's power law ($s^2 = a\,\bar{x}^b$) were estimated from the linear regression of $\log_{10} s^2$ on $\log_{10} \bar{x}$. Both dispersion analyses were calculated for each farm in each year. The slope coefficients (b and β terms) from these analyses are indices of aggregation that are constant for the species in a given habitat. In general, the dispersion pattern of a population is identified as being uniform (slope<1), random (slope=1) or aggregated (slope>1).

Mean densities and variances were based on larval counts from the first 120 rows (exterior portion of the field), so that all variances had equal sample sizes. To increase the number of variance to mean functions, each transect was divided into three areas of equal sample size. Thus, a single transect provided three data points, each based on a mean of 15 samples for the regression model.

RESULTS AND DISCUSSION

Sampling pattern. Orientation of the transects significantly affected larval counts in 1985 but only when the exterior portion of the field (first 120 rows) was considered. In general, transects oriented along the field had lower counts of larvae than transects oriented across the field in all farms over the two years. This is probably in part due to a reduction in sampling efficiency since sampling across rows was easier and required less time than sampling along rows. In consideration of these apparent differences and for practical purposes, only data from transects oriented across rows were used in developing the sequential model.

In some fields transects located nearest to the field margins (E and H) had significantly higher densities when compared to adjacent transects (C and D); however, no consistent trends were observed. Larval counts were significantly different with respect to the position of transects relative to the previous sunflower field. Transects located in close proximity and adjacent to the previous sunflower field but separated by a fence row had consistently lower densities when compared to the distal transects of the same field. This trend was reversed (and consistent irrespective of the distance between the two fields; i.e., from 180 to 800 m) in those fields that were not separated by a fence row. These differences were more apparent in the first 30 m of the field than in the next 60 m of the field.

Field Density. Larval densities differed significantly among farms and among transects within farms; however, no consistent trends were noted over the two years. Densities were significantly different in the first 10 m of the field when compared to the next 80 m (Fig. 2) in all farms. Since these differences were consistent over the two years, data from the first 10 m (13 rows) were deleted from all transects when establishing the variance to mean relationship for the sequential model.

Mean larval densities in the first 90 m (exterior portion) of the field ranged from 2.27 ± 0.13 to 14.14 ± 0.40 (Table 1) and were not significantly different (t-test) from the remaining portions (interior) of the field. In two fields (Farm 4 and 6) the mean larval densities exceeded the recommended threshold of 10 to 12 larvae per plant (Westdal et al. 1976) and required control. However, all but farm 8 and 9 were treated with insecticide by the growers within 5 days from the date of count. Application of border treatments to minimize control costs is desirable; however, this strategy is unlikely to be useful for the management of the sunflower beetle since larvae are present throughout the field (Fig. 3).

Larval dispersion. In all farms the slope coefficients from Taylor's and Iwao's analyses were not significantly different from one (Table 1), indicating that a random dispersion pattern would probably be adequate for describing the larval populations. However, both procedures detected aggregation when the data were pooled over the years and locations. The degree of aggregation was similar. The slope coefficients, although significant, were not substantially greater than 1 (i.e., mean b value = 1.17, mean β value = 1.07), indicating a low level of aggregation. Dispersion can change with population density, such that dispersion tends to become random at lower densities, and aggregation is apparent only at higher densities (Southwood 1978). The results of this study show that a slightly aggregated pattern probably is more accurate for describing the larval dispersion of the sunflower beetle over the entire range of observed densities. The degree of aggregation, although low, cannot be ignored in sampling plan design (Bechinski *et al*. 1983).

Sampling plan development. Since covariance analysis showed that slopes and intercepts of the regression ($\overset{*}{m} = \alpha + \beta \bar{x}$) were not significantly different among years and to ensure that the count plans would be applicable to a broad range of field conditions, data were pooled from all years and locations to calculate a common intercept and slope. The slope coefficients did not differ significantly when data from the interior of the field were included using either Taylor's power law or Iwao's regression technique. Similar results were obtained with and without subdividing the transects on the basis of equal distance or sample size. However, both methods substantially improved the fit to the data when transects were divided into equal sample sizes.

Iwao's (1968) analysis was selected as the measure of dispersion for developing the sampling plan because the r^2 value (Table 1) showed that it accounted for a greater proportion of the variability observed between sampling variance and mean density than did Taylor's power law. The sequential decision plan (Table 2) was developed using Iwao's (1975) formula:

$$T_o = qm_o \pm t\sqrt{q\,[(\alpha+1)m_o + (\beta-1)m_o^2\,]} \qquad (2)$$

where T_o = the upper or lower limit (i.e., cumulative total for the number of plants sampled); q = the number of samples taken; m_o = the critical density (i.e., the economic threshold); t = students' t-statistic at the desired level; α(0.92) and β(1.07) are the intercept and slope of the regression model. The critical density (m_o) was set at 7.5, the mid-point for the range reported for the sunflower beetle (Section II). The t-statistic was selected appropriately for each sample at a precision level of P=0.10 (Iwao 1975).

To use the decision plan, plants are sampled and the cumulative total for the larvae tabulated. If the observed total for the number of plants sampled is less than or greater than the values in Table 2, a decision whether or not to treat is made. Sampling is continued if the total falls within the range.

When using the sequential plan, the accumulated count may lie between upper and lower limits over a long sequence of sample units especially if the population density($\bar{x}$) is close to the critical density (m_0). This is a weak point innate to sequential sampling. However, the maximum number of samples required to show that the population density is not significantly different from the critical density can be calculated (Iwao 1975). In this study, 198 and 94 plants were required at a precision level of 0.10 and 0.20, respectively, to show that the mean density is 7.5$\pm$0.5 larvae per plant.

Sample size and sampling precision. Sample number (q) curves can be plotted and used to appraise the sequential plan in advance of field testing. They are helpful to pest-control advisers in that they show the number of sampling units needed to reach a decision at various larval densities. Sample number curves for various population densities (Fig. 4) were calculated using the formula (Iwao and Kuno 1968):

$$q = \frac{t^2}{D^2}\left(\frac{\alpha + 1}{\bar{x}} + \beta - 1\right) \qquad (3)$$

where t is the student's t at infinite degrees of freedom (1.96) and D is the desired level of precision; all other variables are as defined earlier. The precision levels for error were set at 10 and 25% as suggested for intensive and extensive sampling programs, respectively (Southwood 1978).

The precision of the density estimate can decline considerably depending on the level of population being estimated as well as the sample size. The appropriate sample size was derived by calculating the precision response curve (Poston et al. 1983b) after setting q and solving equation 3 for D:

$$D = t\sqrt{\frac{1}{q}\left(\frac{\alpha + 1}{\bar{x}} + \beta - 1\right)} \qquad (4)$$

In this study a sample size of 20 and 30 will be adequate for estimating population means ≥ 7.5 and ≥ 4.5 larvae per plant, respectively, at the desired level of precision ($D \leq 0.25$). The precision of the density estimate will decline substantially ($D > 0.30$) when estimating populations densities below 5 and 2 larvae per plant for the two sample sizes, respectively. Although in principle a decision can be reached using the sequential plan after taking one sample we suggest that farmers or pest-control advisers should not base their decisions on fewer than 30 samples. A sample size of 30 will be adequate to cover the lower ranges of densities observed in the field.

Application. The implementation of this sequential sampling plan is similar to that of traditional sequential sampling programs (Boivin and Vincent 1983). Until a suitable sampling pattern is developed we suggest that the user sequentially sample 5 consecutive plants from each of the 6 transects (Fig. 1) for a total of 30 samples. This is in consideration of the observed differences among transects within farms. If a decision is not reached, then 5 additional samples should be taken along another transect. For practicality, the number of samples in the sequential plan is presented in multiples of 5. Fields should be sampled about mid-July when the plants are at R1 to R3 stage. Sampling should be initiated at least 10 m (13-15 rows) away from the field edge and not 30 m as has been previously recommended (McBride _et al_. 1985b), to avoid possible bias due to the observed edge effect. This sequential decision plan will require less effort than one based on a fixed sample of 100 plants and enable growers to make sound management decisions since the economic threshold data is inherent to the sampling program. The sampling plan is more likely to be acceptable by pest-control advisers and growers since it is not necessary to follow the "X" pattern (McBride _et al_. 1985b) and hence cross the entire field as with the conventional method.

ACKNOWLEDGEMENT

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Table 1: Sampling dates, location and size of field sites, mean densities and dispersion indices for sunflower beetle larvae in Manitoba, 1984-1985.

Sampling		Location			Larval	Variance to mean function [c]					
						Taylor's analysis			Iwao's analysis		
Year	Date	Farm	Area	Size [a]	density [b] (mean±SE)	log a	b	r^2	α	β	r^2
1984	6 July	1	Glenlea	60.8	6.35±0.21	-0.14	1.55	0.47	-0.15	1.29	0.70
1984	11 July	2	Niverville	10.1	4.99±0.18	0.41	1.24	0.57	0.76	1.11	0.80
1984	12 July	3	La Salle	120.8	3.75±0.14	0.60 *	0.91	0.59	0.95 *	0.94	0.91
1984	18 July	4	Warren	61.2	12.52±0.28	-2.12	2.17	0.21	-1.19	1.22	0.62
1984	19 July	5	Steinbach	10.0	5.88±0.16	-0.67	1.64	0.16	0.47	1.07	0.61
1985	14 July	6	Warren	12.3	14.14±0.40	-0.12	1.39	0.73	0.67	1.06	0.98
1985	20 July	7	Glenlea	32.4	9.06±0.30	-0.15	1.55	0.71	0.41	1.18	0.92
1985	21 July	8	Aubiny	48.9	5.32±0.18	-1.43	2.21	0.40	-0.91	1.35	0.73
1985	24 July	9	Niverville	32.4	2.27±0.13	0.64 *	1.16	0.54	0.84	1.23	0.60
1985	28 July	10	Sanford	64.9	7.84±0.30	0.11	1.49	0.31	0.76	1.20	0.60
1984-1985		Pooled				0.45 *	1.17 *	0.70	0.92 *	1.07 *	0.94

[a] Field size in hectares.
[b] Mean larval density in the first 90 m of the field; each mean based on 464 samples.
[c] 18 data points in regression; each based on 15 plants.
* Probability of $t<0.05$ for Ho: a, $\alpha = 0$ or Ho: b, $\beta = 1$. Ho: intercept = 0 or Ho: slope = 1.

Table 2: Sequential decision plan for the management of sunflower beetle larvae in sunflower.

n[a]		Cumulative Number of Larvae			
		<[b]		>[c]	
30		185		265	
35		220		305	
40	DO	254		346	
45		289		386	APPLY
50		324	CONTINUE	426	
55	NOT	359		466	
60		395		505	
65		430		545	
70		465		585	TREATMENT
75	TREAT	501	SAMPLING	624	
80		536		664	
85		572		703	
90		608		742	
95		643		782	

[a]Number of plants sampled
[b]Lower limit
[c]Upper limit

Figure 1: Sampling pattern used for establishing the distribution of sunflower beetle larvae in grower's fields.

Transects A and B oriented along the field; remaining transects oriented across the field.

Transects A, B, C and D located in the centre of the field; E and H, and F and G located one-sixth and one-third away from the nearest field margin, respectively.

——— - - -> Sampling continued up to the middle of the field.

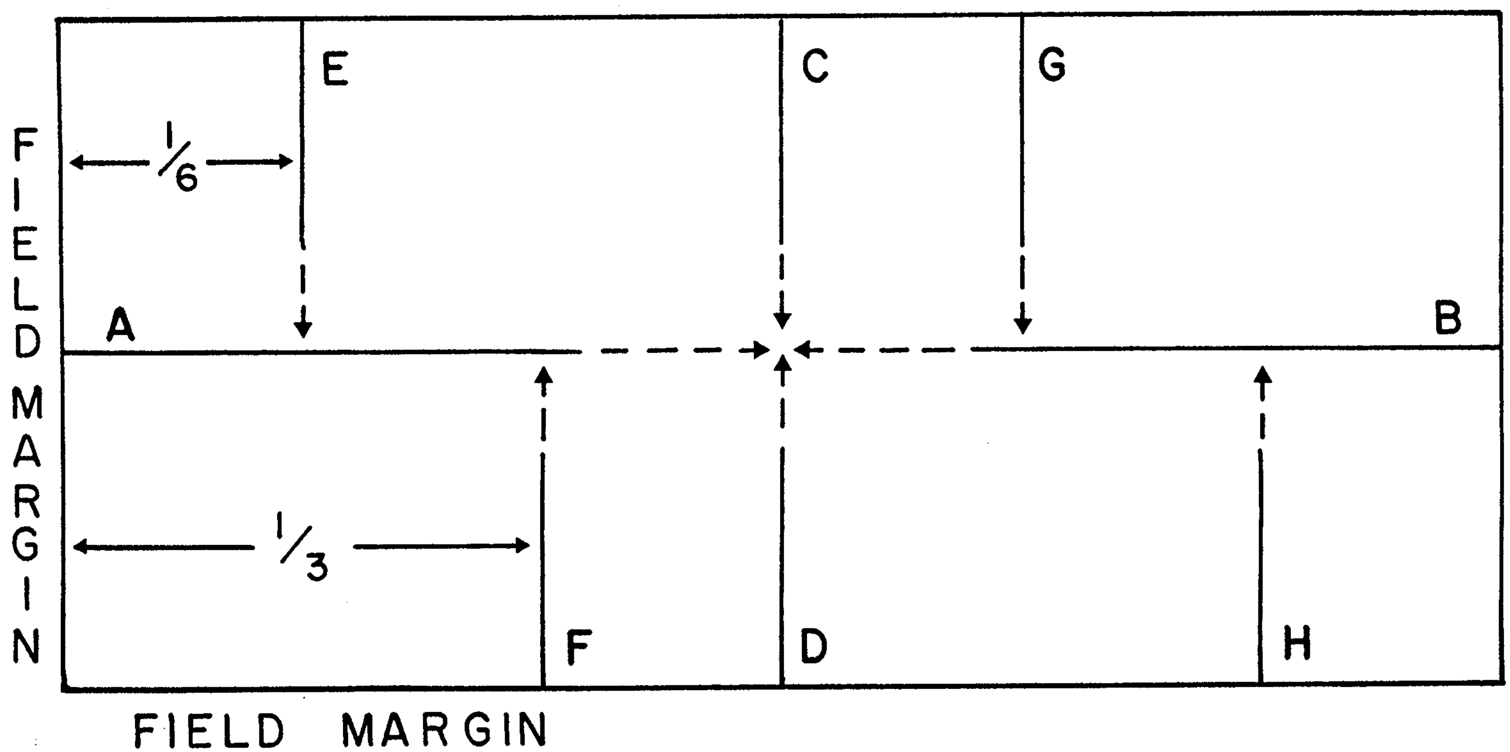
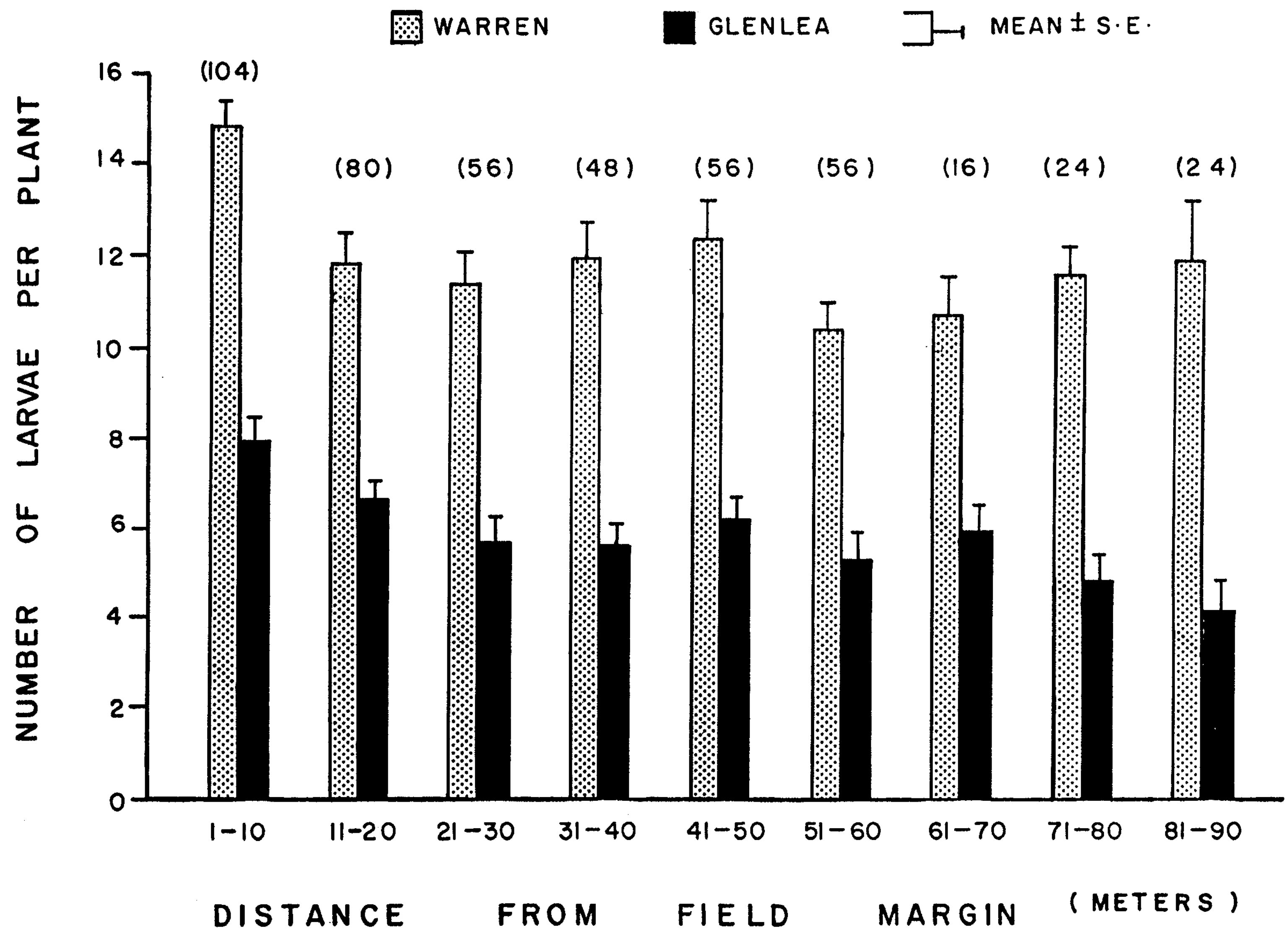
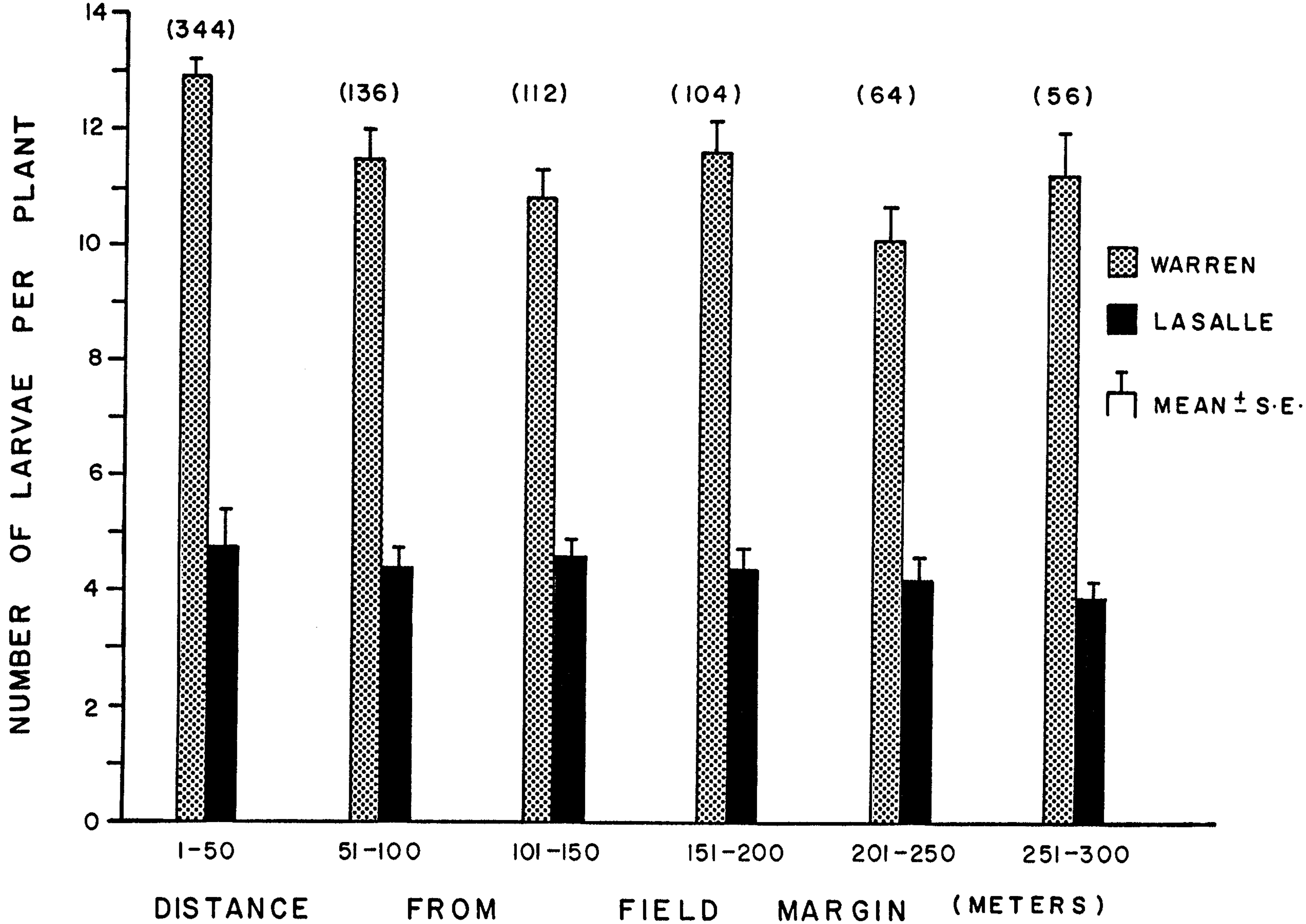

E
C
G
1/6
A
B
1/3
F
D
H
FIELD MARGIN
FIELD MARGIN

Figure 2: Distribution of sunflower beetle larvae in the first 90 m of the field at two locations, Warren and Glenlea, Manitoba, 1984. Sample size is indicated by numbers above bars.



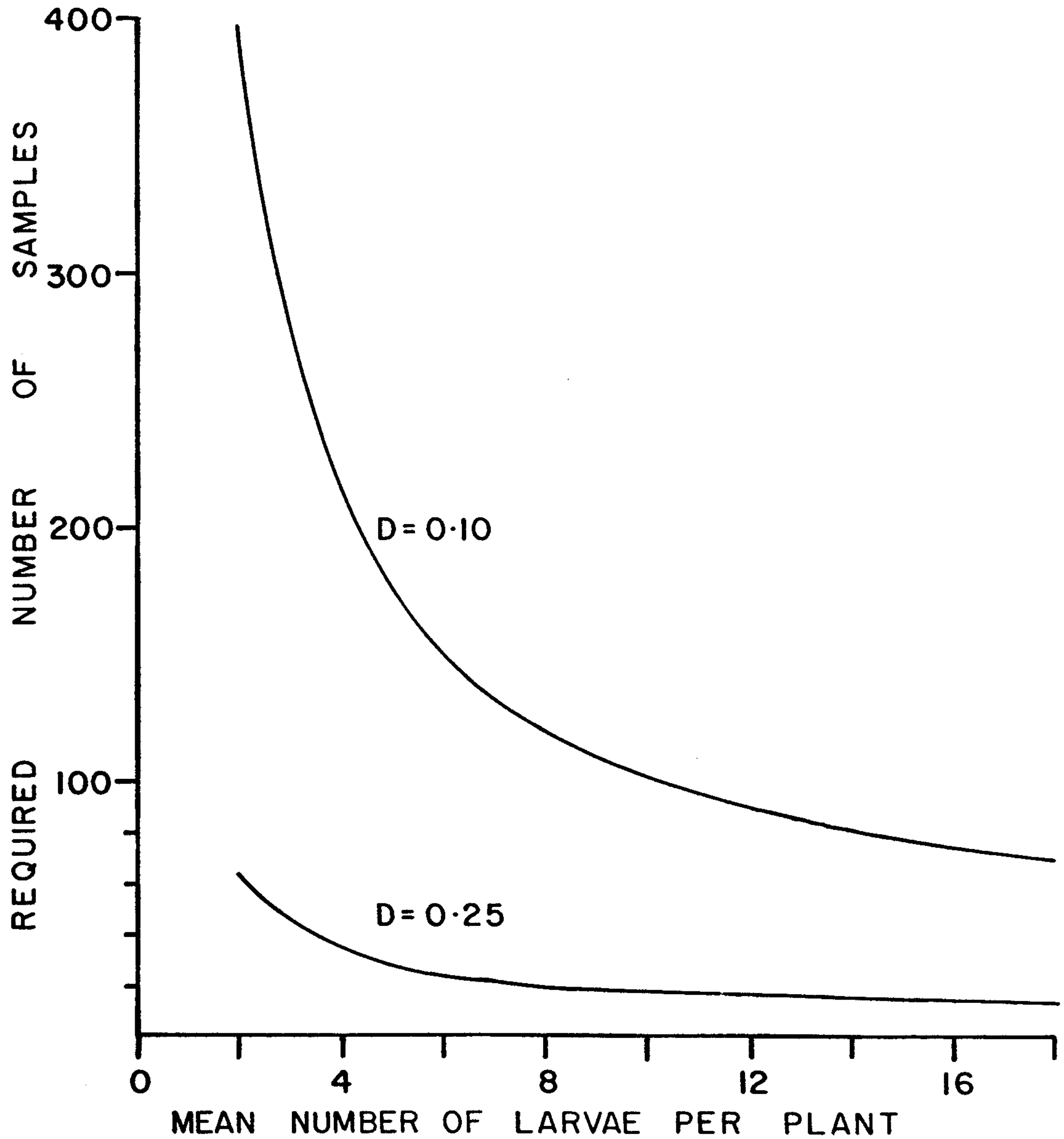
WARREN
GLENLEA
MEAN ± S·E·
NUMBER OF LARVAE PER PLANT
0
2
4
6
8
10
12
14
16
(104)
(80)
(56)
(48)
(56)
(56)
(16)
(24)
(24)
1–10
11–20
21–30
31–40
41–50
51–60
61–70
71–80
81–90
DISTANCE FROM FIELD MARGIN (METERS)

Figure 3: Distribution of sunflower beetle larvae up to the centre of the field at two locations, Warren and LaSalle, Manitoba, 1984. Numbers above the histograms represent sample size.



NUMBER OF LARVAE PER PLANT
14
12
10
8
6
4
2
0
(344)
(136)
(112)
(104)
(64)
(56)
WARREN
LASALLE
MEAN ± S·E·
1-50
51-100
101-150
151-200
201-250
251-300
DISTANCE FROM FIELD MARGIN (METERS)

Figure 4: Required number of samples for various densities of sunflower beetle larvae at two precision levels.


400
300
200
100
REQUIRED NUMBER OF SAMPLES
D = 0·10
D = 0·25
0
4
8
12
16
MEAN NUMBER OF LARVAE PER PLANT

CHAPTER 4

GENERAL DISCUSSION

Commercial sunflower is subject to attack by several species of insects. The occurrence as well as economic significance of these pests has fluctuated from year to year (Westdal 1975). The present study was conducted in part, to determine the current insect-pest complex on cultivated sunflower as well as their management by growers in Manitoba. Of the various species recorded, the sunflower beetle, sunflower midge, sunflower maggot, banded sunflower moth and sunflower moth were most common. However, larval populations of these species based on an average over one season, were generally low. Comparison of this study to earlier reports (Westdal and Barrett 1955; Westdal 1975) shows that there appears to have been little change in the pest status except for the sunflower midge which has caused economic damage in recent years (Schulz 1982). At present, the number of insect pests attacking sunflower in Manitoba is relatively small when compared to the neighboring region of North Dakota (McBride et al. 1985b). Manitoba's cooler climate and relatively low hectarages may partly account for these differences.

Of the various pests that attack sunflower, the sunflower beetle, sunflower midge and cutworms were perceived as pests of primary concern by growers. These pests occur relatively early in the season and the type of damage they cause is readily noticed. Growers showed little concern for sunflower maggot, banded sunflower moth and sunflower moth. Since the initial reports (Westdal and Barrett 1955), these latter pests have not caused economic damage in Manitoba (Westdal 1975) and so the growers' lack of concern is justified. But, from the type of insect pests monitored by growers, it would seem that they are not aware of the presence of these pests. These latter pests occur relatively late in the season. Also, the larval stages of these species are concealed and difficult to detect. Thus, even if growers monitored their fields throughout the season, it is likely that they would be unable to detect these insects. However, the possibility of growers monitoring their fields early in the season only, when the plants are young, cannot be ruled out.

Delayed planting, as a method of cultural control did not play an important role in the management of the various insect pests. This was surprising since delayed planting could aid in reducing the impact of several pests simultaneously. Whether growers were unaware of this strategy or whether it was not practical to delay planting was not ascertained. This question can only be resolved with a follow-up study. Extension efforts should be increased if indeed growers are unaware of this useful strategy.

Chemical control was the primary strategy used by growers for managing the sunflower insect pests.

Insecticides were applied mainly to control sunflower beetle and cutworms. Although growers indicated that they used economic thresholds, data from field surveys (Section I) and spatial dispersion studies (Section IV) on sunflower beetle revealed that growers applied insecticides at well below the recommended threshold values. Thus it is doubtful whether growers actually apply the thresholds when making treatment decisions.

Based on previous findings (Section I) and other considerations, intensive studies were conducted to determine the effect of defoliation of sunflower by the sunflower beetle. Damage simulation studies were also conducted to identify the plant stage most sensitive to defoliation and the growth stage at which insecticides should be applied. Damage assessment studies revealed that adults were less damaging and larvae more damaging than previously reported (Westdal et al. 1973). Growth and yield components generally decreased with increasing insect densities. Similar results were obtained in damage simulation studies with increasing levels of defoliation. Yield reductions were more dramatic when insect densities were held relatively constant or when artificial defoliation was continued for a longer duration. Substantial yield reductions as a result of both insect damage and artificial damage were not surprising because of the continuous stress imposed on the plant. Other researchers have also demonstrated that continuous defoliation over the season results in greater yield loss and that plants can tolerate higher amounts of defoliation early in the season without significant yield reductions (Cranshaw and Radcliffe 1980; Wellik et al. 1981). Continuous defoliation, especially of the newly developing leaves is likely to have a greater impact on yield. Studies have shown that the top 8-12 leaves of the sunflower plant are more physiologically active (Johnson 1972). Removal of such relatively young and photosynthetically active leaves results in greater yield loss than removal of the same proportion of less efficient lower leaves (Sackston 1959).

Damage assessment studies revealed an increase in oil content with increasing insect densities. On the contrary, artificial defoliation studies showed a decrease in oil content with increasing levels of defoliation. These differences are difficult to harmonize. The role of insect saliva as well as the nature of damage (shape or size of holes and edge indentations) as possible factors in the differential response of oil content to insect damage and artificial damage are only speculative. Other researchers have also found that not all responses to insect feeding may be reflected by damage simulation studies (Capinera and Roltsch 1980; Fick 1982; Olfert and Mukerji 1982). For example, Olfert and Mukerji (1982) found that the relative growth rate of wheat was lower when the plants were defoliated by grasshoppers than when defoliated to an equal level by manual clipping. The factor causing impaired regrowth was thought to be of salivary origin (Dyer and Bokhari 1976).

Data from damage assessment studies were used to calculate economic thresholds for the sunflower beetle. When compared to previous reports (Westdal et al. 1976; McBride et al. 1985b), the economic thresholds reported in the present study are substantially higher for adults and lower for larvae. These thresholds were based on separate effects of adult and larval feeding. But adult and larval defoliation can occur on the same plant. Whether the present larval thresholds will differ as a result of the additional defoliation due to the adults needs further investigation. However, on the basis of the damage potential of the adults (Section II), the plants' ability to tolerate defoliation early in the season (Section III) and the observed densities in the field (Section I), it is unlikely that the present larval thresholds will differ markedly from those based on the combined effect of adult and larval feeding. When developing the thresholds, no consideration was given to the possible benefits likely to accrue from the increase in oil content. This is because at present, sunflower premiums are based on yield per se (D. Watson, CSP Foods, Altona, personal communication). These thresholds will have to be re-calculated to include the benefits from increased oil content, but only if the oil content becomes an important price determinant for the growers.

Westdal et al. (1976) stated that a single insecticide application, if properly timed, should be adequate for the control of sunflower beetle adults. However, observations (Section I) indicate that adult control is not effective probably because of the difficulty of timing the application and/or immigration of new adults. Using the new thresholds and on the basis of observed densities (Section I) it is unlikely that adult control will be required. This knowledge should benefit the growers by reducing the overall control costs and also help in preserving the natural enemies of the sunflower beetle. This is especially so for *Myiophorus* sp. which overwinters in the adult and emerges approximately one month later than the sunflower beetle adults (Neill 1982). Avoiding treatment for adult control would also increase the survival of the egg parasite *Erixestus winnemana* Crawford, since adults of this parasite are present in sunflower fields during early June (Neill 1982). Although the impact of predators was not assessed in the present study or by Neill (1982), observations indicate (Section II) that they play a role in reducing the larval populations. Sunflower beetle larvae are also parasitized by *Doryphorophaga macella* Reinhard. This parasite is present throughout most of the larval period and there appears to be no practical way of controlling sunflower beetle larvae without destroying the parasite (Neill 1982). Clearly, the potential impact of insecticides on these and other natural enemies of the sunflower beetle will have to be considered and should be assessed quantitatively, as has been suggested by Neill (1982).

Artificial defoliation studies revealed that plants were most sensitive to prolonged defoliation initiated in their early vegetative stage. Plants showed compensation at low levels of defoliation especially when damage occurred later in their development or when injury was terminated early in the vegetative stages of the plant. The defoliation thresholds presented in this study should only be used as guidelines for various reasons. For example, leaf consumption models that quantitatively relate insect feeding and growth (Hammond and Pedigo 1982) are lacking for the sunflower beetle and so damage inflicted was based on percentage defoliation rather than on specific insect population levels. Furthermore, damage was inflicted uniformly on all the leaves of the plant. Insect feeding damage is discontinuous and composed of many irregular portions and indentations. Also insects do not remove the same proportion of each leaf, nor do they feed on all leaves of the plant. Despite these apparent differences between insect feeding damage and artificial defoliation, data from damage simulation studies do show how sunflower responds to defoliation and should aid in further experimental studies in relation to the sunflower beetle. The fidelity of surrogate damage will have to be tested against actual insect feeding before these defoliation thresholds are recommended for use in pest management programs. This is because insect defoliation is generally less debilitating than artificial defoliation (Cranshaw and Radcliffe 1980; Hare 1980; Wellik et al. 1981; Ferro et al. 1983).

Damage assessment studies using insects (Section II) and artificial defoliation (Section III) showed a marked difference in the threshold values when compared to the significance level for damage. For example, statistical analysis showed a significant reduction in yield at 30 and 40 larvae per plant whereas the threshold values were estimated at 5-10 larvae per plant (Section II). These observations serve to emphasize the need to differentiate statistical significance from biological reality.

Studies were also conducted to determine the spatial dispersion of the sunflower beetle larvae. From these studies a sequential sampling plan was developed for the control of sunflower beetle larvae. In practice, sequential sampling schemes must first be tested before they are recommended for field use (Onsager 1976). In the present study it was deemed unnecessary to test the plan since data were collected from growers' fields. Furthermore, the entire fields were sampled. Testing becomes imperative when the plans are developed using data from experimental plots (Luna et al. 1983). The sequential plan should aid growers in making reliable treatment decisions for the control of sunflower beetle larvae. As a further step to the efficient use of this plan, the most appropriate pattern of sampling will have to be established. An important aspect regarding the use of the plan is the time of sampling. Although no attempt was made to determine the time at which sampling should be initiated, observations (Section I) indicate that sampling should be initiated around mid-July (2nd week). Empirical observations also indicate that Neill's (1982) method of determining the optimal time of control could prove useful, if the new thresholds are applied. Overall, these data should provide Manitoba sunflower growers with a sound basis of managing the sunflower beetle. The data should also prove useful to extension personnel as well as sunflower entomologists.

CHAPTER 5

CONCLUSIONS

This study indicates that the sunflower beetle, sunflower midge, sunflower maggot, banded sunflower moth and sunflower moth are the five most common insect pests that attack cultivated sunflower in Manitoba. The first two of these species as well as cutworms are pests of primary concern to growers. Growers rely heavily on chemical control. Delayed planting as a method of cultural control does not play a major role in the management of these or other sunflower insect pests. Although growers are aware of and attempt to use economic thresholds when available, it is doubtful whether they actually apply the thresholds when making treatment decisions.

Damage assessment studies of the sunflower beetle show that adults are less damaging and larvae more damaging than previously thought. Consequently, the revised economic thresholds are higher for adults and lower for larvae. These thresholds are a substantial improvement over the guidelines previously available and should aid growers in deciding whether control is justified or not.

Damage simulation studies show that plants in their early vegetative stages (V4 and V8) are most sensitive to prolonged defoliation. Yield response to defoliation will vary, depending on the growth stage at which injury occurs or the plant stage at which damage is terminated. Defoliation thresholds will be substantially higher if control is intended early in the season (at V8 and V12 stages). Delaying control until plants are well on in their reproductive stages will lower the thresholds by 5-6 fold. The practical use of these thresholds must be cautioned against until the fidelity of surrogate damage to insect feeding has been tested experimentally.

A sequential sampling plan was developed based on larval dispersion studies in growers' fields. The plan will minimize sampling efforts and provide growers with a reliable method of determining whether a particular population warrents control. Since larvae are present throughout the field, application of insecticides along the borders is unlikely to be useful as a strategy for minimizing control costs.

CHAPTER 6

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Appendix 1: Location, planting dates and varieties of sunflower for sixteen farms in Manitoba, 1983-1985.

Farm	Location: Municipality	Location: Area	Planting Date	Variety[a]
1	Cartier	Dacotah	6 May 1983	7101 (IS)
2	Cartier	Elie	9 May 1983	7101 (IS)
3	N. Norfolk	Beaver	17 May 1983	135 DAH[b]
4	N. Norfolk	McGregor	23 May 1983	7101 (IS)
5	Dufferin	Carman	9 May 1983	7101 (IS)
6	Dufferin	Homewood	24 May 1983	844 DAH
7	De Salaberry	Dufrost	26 May 1983	7101 (IS)
8	De Salaberry	Dufrost	21 May 1983	7101 (IS)
9	Morris	Aubigny	9 May 1983	501 JAC
10	Morris	Aubigny	10 May 1983	7111 (IS)
11	MacDonald	Domain	20 May 1983	7101 (IS)
12	MacDonald	LaSalle	13 May 1983	131 DAH[b]
A	Ritchot	Glenlea	5 May 1984	131 DAH[b]
B	Hanover	Niverville	2 May 1984	844 DAH
C	Ritchot	Glenlea	12 May 1985	SIG 954[b]
D	Hanover	Niverville	7 May 1985	CAR 207

[a] Variety code: IS = Interstates, DAH = Dahlgren, JAC = Jacques, SIG = Sigco, CAR = Cargill.
[b] Confectionery type; all others oilseed type.

Appendix 2: Description of sunflower growth stages.

Stage[a]		Description
Emergence (VE)		Seedling has emerged and the first leaf beyond the cotyledons is less than 4 cm long.
Vegetative Stages (V + number)		These are determined by counting the number of true leaves at least 4 cm in length beginning as V1, V2, V3, V4, etc. If senescence of the lower leaves has occurred count leaf scars (excluding those where the coytledons were attached) to determine the proper stage.
Reproductive Stages (R + number)	R1	The terminal bud forms a miniature floral head rather than a cluster of leaves. When viewed from directly above the immature bracts form a many-pointed star-like appearance.
	R2	The immature bud elongates 0.5 or 2.0 cm above the nearest leaf attached to the stem. Disregard leaves attached directly to the back of the bud.
	R3	The immature bud elongates more than 2.0 cm above the nearest leaf.
	R4	The inflorescence begins to open. When viewed from directly above immature ray flowers are visible.
	R5	This stage is the beginning of flowering. The stage can be divided into substages dependent upon the percent of the head area (disk flowers) that has completed or is in flowering. Ex. R5.3 (30%), R5.8 (80%) etc.

[a]VE = Vegetative emergence, V = Vegetative, and R = Reproductive.

(continued....)

Appendix 2: (continued....)

Stage[a]	Description
R6	Flowering is complete and the ray flowers are wilting.
R7	The back of the head has started to turn pale yellow color.
R8	The back of the head is yellow but the bracts remain green.
R9	The bracts become yellow and brown. This stage is regarded as physiological maturity.

[a] VE = Vegetative emergence, V = Vegetative, and R = Reproductive.

(From Schneiter and Miller 1981)

Appendix 2: SUNFLOWER INSECT PESTS — SURVEY QUESTIONNAIRE

INSTRUCTIONS

1. There are 20 questions.** Please answer as many of the questions as possible. Even a partially completed questionnaire is of value.
2. Answer your questions by checking (✓) or printing in the appropriate box.
3. Return the completed questionnaire as soon as possible in the addressed postage-paid envelope provided.

NAME [ ] PHONE [ ]

LOCATION OF FIELD

Municipality	Township	Range	Meridian	Section	Quarter

I.

1. Indicate with a check (✓) the type of sunflower you had in the field this year (1984).

   OILSEED [ ] CONFECTIONARY [ ]

2. VARIETY [ ] DATE OF PLANTING

Day	Week	Month

3. Number of acres in the field [ ]

   Yield of crop (bu/acre) [ ]

4. Did you have any insect problems this year (1984)?

Yes	No

** There are four pages.

cont......

5. If you did, indicate with a check (✓) the type of insect (or insects) that caused damage this year (1984).

Cutworms		Sunflower beetle	
Sunflower budworm		Sunflower maggot	
Sunflower stem weevils		Sunflower seed weevils	
Thistle catterpillar		Head clipper weevil	
Sunflower moth		Sunflower midge	
Other (specify)			

6. List what you consider the most troublesome insect (or insects) this year (1984) in order of importance and if possible give the approximate number of acres damaged.

		Type of insect	Acres damaged
Most important	1.		
	2.		
	3.		
	4.		
Least important	5.		

7. Indicate with a check (✓) the extent of damage caused by the insect.

	Extent	Type of insect
Damage throughout the field		
" along the field margins		
" scattered in the field		
" in the centre of field		

8. If you had insect problems in previous years, list the insect that caused most damage and if possible give the approximate number of acres damaged.

	Type of insect(s)	Acres damaged
1983		
1982		
1981		

cont.......

II.

9. Do you check your field(s) for insect pests? Yes ☐ No ☐

10. If you do, how often do you check the field. Indicate with a check (✓).

Twice a week	Once/Week	Once/Month	On and Off
☐	☐	☐	☐

11. List the insects that you check for in the field.

Type of insect ☐ ☐ ☐

12. Do you know that there are economic thresholds* for some of the important insect pests of sunflower? Yes ☐ No ☐

*Economic threshold - a level of insect numbers at which damage becomes economically significant and hence control is necessary.

13. If yes, do you use these thresholds (count the number of insects) to decide whether to spray or not? Yes ☐ No ☐

14. Indicate with a check (✓) what you think of the economic thresholds.

Not Useful ☐ Useful ☐

15. If useful, indicate with a check (✓) how useful the economic thresholds are.

Partly Useful ☐ Very Useful ☐

III.

16. Did you adjust your planting time to avoid an insect problem this year (1984)? Yes ☐ No ☐

cont.....

17. If you did, list the insect for which you adjusted your planting time and indicate with a check (✓) whether planting was early or late (delayed).

Type of insect(s)	Early Planting	Late Planting

18. Indicate with a check (✓) the effectiveness of this control method.

Good ☐ Fair ☐ Poor ☐

19. Did you use insecticides to control an insect problem this year (1984)?

Yes ☐ No ☐

20. If you did use insecticides, please supply the information in the appropriate spaces below.

	1st application			2nd application			3rd application		
Name of insecticide									
Rate of application									
Date of application	Day	Week	Month	Day	Week	Month	Day	Week	Month
Method of application (aerial/ground spray)									
Approx. # acres sprayed in the field with the insecticide									
Cost per acre (insecticide and spraying)									
Name insects attempted to control									
Rate effectiveness of control (good, fair, poor)									

*Please mail the questionnaire no later than 15th November 1984.

THANK YOU VERY MUCH FOR SPENDING YOUR PERSONAL TIME AND EFFORT.

Appendix 4: Lateral view of sunflower heads showing symptoms of sunflower midge damage. 0 = no midge damage, 1 = only bracts damaged, 2 = head slightly distorted, 3 = head severely distorted, 4 = head beginning to cup, and 5 = head severely cupped.


0
1
2
3
4
5