7921210

UNTUNG, KASUMBOGO
THE DISTRIBUTION AND BIONOMICS OF THE
ARMYWORM, PSEUDALETIA UNIPUNCTA (HAW.) IN
MICHIGAN.

MICHIGAN STATE UNIVERSITY, PH.D., 1979

THE DISTRIBUTION AND BIONOMICS OF THE ARMYWORM, *PSEUDALETIA UNIFUNCTA* (HAW.) IN MICHIGAN

By

Kasumbogo Untung

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Entomology

1978

ABSTRACT

THE DISTRIBUTION AND BIONOMICS OF THE ARMYWORM,
PSEUDALETIA UNIPUNCTA (HAW.) IN MICHIGAN

By

Kasumbogo Untung

The two-year study of the armyworm is an effort to understand the relationship between the armyworm, host plants and its natural enemies. This study aims to investigate the preference of the armyworm to host plants for oviposition and feeding; the effect of parasitism on the amount of food consumed by the larvae; and the distribution of the larvae within and between fields both locally and regionally. The population dynamics of the armyworm and its parasites is briefly analyzed. The field study was done in a wheat field and an asparagus-crabgrass field in Cass County, and the food consumption and host preference studies were carried out in the laboratory.

The armyworm population in Michigan is a combination of overwintering and the migrating individuals from the southern states.

Moths prefer to oviposit on small grains rather than on grasses, with barley and rye preferred over oats. Larval and pupal survival and development rates are also higher in small grains, however larval consumption were greater on corn than either barley or oats. The parasite *Winthemia rufopicta* reduces food consumption by 50%, and *Apanteles militaris* reduces the consumption by 84%.

Kasumbogo Untung

The distribution pattern of larvae in the field depends upon the availability and distribution of food; the existence of places to hide against sunshine; the larval density; and the population age structure. The distribution in the wheat field has a tendency to be uniform under high densities, and the distribution of larvae in the asparagus field is clumped. Nearest neighbor and quadrat counts were used to analyze the distribution data. The Relative Net Precision method is utilized for finding the optimum sampling unit.

Winthemia is a major deterrent of armyworm increase during outbreak years due to its high numerical and functional response. *Apanteles* is a more host specific parasite to the armyworm, its parasitism was high in 1977 while the armyworm density was low. It seems that *Apanteles* does not exhibit a high response to the density changes of the armyworm.

DEDICATION

To Budi, Anto, Medi, Tantyo

ACKNOWLEDGEMENTS

I wish to express my sincere thanks and appreciation to my major professor, Dr. D. L. Haynes for his constant direction and guidance toward the philosopby of pest management. His friendship and encouragement will influence most of my career in solving agricultural pest problems in my home country, Indonesia.

I also owe special thanks to Dr. R. F. Ruppel, Dr. J. A. Webster, Dr. R. L. Tummala, and Dr. T. C. Edens for serving on my guidance committee.

I am indebted to my home university Gadjah Mada University and my sponsor MUCIA-AID for providing me a rare opportunity to study and have training in this outstanding Department of Entomology. I also wish to express my appreciation to the A.D.B. in the Netherlands which was willing to support me with an additional fellowship for my doctorate program.

I have enjoyed the interaction and aid from the marvelous students and friends, E. P. Lampert, F. W. Ravlin and A. J. Sawyer.

To Budi, my wife, thank you for all the patience and understanding throughout my training.

TABLE OF CONTENTS

Page

Page

LIST OF TABLES

TABLE | Page

TABLE Page

LIST OF FIGURES

FIGURE | Page

FIGURE | Page

FIGURE Page

INTRODUCTION

The armyworm, *Pseudaletia unipuncta* (Haw.) (Lepidoptera:Noctuidae) has been recognized as a potential pest of corn and small grains in Michigan. The significance of the armyworm to Michigan's agriculture has increased in the past 5 years, due to the unusual consecutive outbreaks which occurred in 1975, 1976, and 1978.

The effective measures developed by entomologists consist primarily of pesticide treatment of infested fields (Ruppel, 1973). The lack of the biological information about the armyworm and its environment contributes to the practice of "insurance spray" type of control. Due to the suddenness of armyworm outbreaks, most of the control treatments are applied improperly, which makes the pesticide applications increase the cost of control monetarily and environmentally.

Understanding the complex and dynamic relationship between the armyworm, host plants and its natural enemies is the prerequisite for a better armyworm management program. Biological information and environmental data are the most important parameters for developing various management strategies under the structure of on-line pest management (Haynes et al., 1973).

Within the context of the pest management framework, this research is an introductory contribution to the biological research component. Due to the preliminary characteristics of this report covers a broad subjects of distribution and bionomics of the armyworm. Techniques and analytical methods have been developed during the conduct of this research project.

The initial population source is an important element for the complete understanding of the armyworm ecosystem. An armyworm population in Michigan can result from a overwintering larval population and/or from a migrating adult population. There is no published information about the overwintering phenomenon of armyworm in Michigan. By using emergence traps, light traps and field observations, the seasonal occurrence of the armyworm in Michigan can be analyzed. In this study, observations of late fall development of armyworm larvae and pupae, and their supercooling points were made to provide some insight into the overwintering phenomena.

During the outbreak years it is necessary to understand the distribution between fields both locally and regionally, to estimate the regional density of the armyworm. This information can be obtained by checking the density of the armyworm population throughout the state by using an appropriate sampling method organized into systematic survey.

The sampling methods should be derived from the characteristics of the spatial distribution of the armyworm within the field. The optimum sampling unit is the unit which gives the highest accuracy for a given cost. Since the spatial distribution of the larvae will be different from one field to another, two types of fields were used to analyze within field distribution; a wheat field and an asparagus-crabgrass field.

For speeding up the process of determining the optimum sampline unit from a given distribution data, this study is trying to demonstrate the use of a computer programming. Computer programs have been developed to calculate various indices of armyworm dispersion and other distribution statistics. This step enables the user to calculate the optimum sampling unit "on-line", for wide ranges of density and distribution.

During the high population year (1976) and the low population year (1977), the interaction between the armyworm and its parasites, Winthemia rufopicta (Big), Apanteles militaris, and Meteorus communis have been briefly examined. Due to the moving behavior of the pest, the population dynamic study could be done only to the first generation of larvae.

Crop loss estimates due to the armyworm feeding required information about total food consumption of larval instars. Damage or crop losses depends upon many factors such as larval density, larval-age distribution, host plant condition and parasitism rates. The higher the percentage of parasitism the lower the damage caused by feeding larvae. This interaction was studied for Winthemia and Apanteles parasites.

Even though armyworm is known as a polyphagous species, field evidence was found to show that this pest has a host preference. Host preference studies were conducted which demonstrate preference to different plants for feeding and oviposition site. This information was used partially to explain the movement habit of the larvae in the field.

Based on the available references (Guppy, 1969; Danks, 1975b; Calkins and Sutter, 1976) and various experiments in the controlled growth chamber, the effect of temperature to the development and survival of the armyworm and its parasites is discussed. This information is essential for the development of population dynamics model.

LITERATURE REVIEW

Life History and Behavior of the Armyworm

Most of the literature on the armyworm deals with the life history especially during the outbreak years. These papers range from Riley (1883), Davis and Sattertwait (1916), Breeland (1958), Pond (1960), to the most recent studies by Guppy (1961 in Ontario, Canada.

The armyworm overwinters mainly as partially grown larvae (third to sixth instar) in the soil beneath thick mats of grassy vegetation. The species is able to add extra instars during overwintering, that depend on the length and temperature of the winter, and the instar in which overwintering began (Breeland, 1958). Guppy (1961) says that the armyworm does not overwinter in eastern Ontario, he suggests that moths in Ontario come from the overwintering stages in the more southernly regions.

In Michigan the first spring adults usually appear in the black light trap in the early spring, range from 100-200° DD (D > 46°F). If the physiological time analysis is applied to the development of the stages of the armyworm, this early spring emergence indicates that some of the insects might overwinter as adults or as pupae, or that there is spring flight northward from the southern part of the range of the insect.

The female moths emerge slightly earlier than the males. Moths are nocturnal, during the day they are rarely seen in the field. Mating usually occurs one to three days after adult emergence, apparently only one mating is required to fertilize the entire life production of female eggs. First oviposition occurs 6 days after adult emergence, and female moths continue depositing eggs for about a week.

Eggs are laid in masses, and are composed of several rows of eggs covered with a white adhesive fluid fastening them together. Moths prefer to lay eggs in dry materials such as straw of haystacks, corn stubble, and dry leaves. In small grain fields eggs are laid on dry leaves on the base of plants and on the tip of young leaves. Oviposition normally begins after dark.

The fecundity of armyworm moth is high, one moth has a potential to lay up to 2000 eggs, however, the number of eggs deposited by a single female can vary greatly. The lifetime egg production of the moth varies from a low of 5 to a high at 1759 and an average of 454 eggs (Breeland, 1958). After deposition of all eggs, there is usually a post oviposition period of a few days before death of the moth occurs. The life of a moth can be up to 27 days with an average of 10 days.

Moth oviposits most frequently in tight places as provided by the narrow space between sheath and blade of growing grasses or the same in cut, dried straw or corn stalks. Riley (1883) stated that early in the season the moths oviposited by preference in the cut straw of haystacks.

Eggs are laid in masses, the moth seldom deposits all of her eggs in one mass, but may deposit all of her eggs in a given oviposition period. Average incubation period in the middle of the summer is 6.4 days (Breeland, 195).

There are normally six instars of larvae in which the developmental rates are dependent upon the temperature. Guppy (1969) has investigated the effect of temperature on the development of immature stages of the armyworm.

All stages of larvae feed on leaves with a different consumption rates. Most of feeding damage is done by late instars of larvae. The first and second instar are very difficult to detect in the field because of their small size (3-6 mm. of length) and the habit of dropping on silken threads when disturbed. After dropping, the larvae remain motionless in a C-shape position for some time. The third to sixth instar have common habits. Larvae are active at dusk and dawn and do most of their feeding at night, during the day they remain concealed under foliage, ground debris, or in the crown of small grains. When disturbed larvae will assume a motionless C-shaped position. The larvae concentrate feeding on the available green leaves, and if most of the green leaves are chewed, they start clipping heads. If the available food in one field cannot support their numbers, larvae will start marching and migrating to adjacent fields.

First generation larvae feeding in small grains and corn, have either developed in the field or migrated from adjacent grassy fields. Pupation normally occurs in the soil to a depth of one inch or less depending upon the texture of the soil. In small grains fields pupation occurs in the soil under or around the base of the plant.

There are three generations of armyworms each year in Michigan. The first generation larvae are the most destructive to small grain crop. The second generation larvae rarely causes any economic damage, since they concentrate in forage crops, pastures and grassy fields. The third generation larvae also causes no economic damage.

Armyworm in Michigan

Records of armyworm outbreaks in Michigan since 1951 can be found in the Cooperative Economic Insect Report of USDA. Research before 1951 can be obtained from the Insect Pest Survey Bulletin and Losses of USDA, and Agricultural Crop Report of Michigan Secretary of State. Armyworm and other pest records in Michigan have also been reported in Pest Alert (previously a Weekly Pest Report). This publication has been circulated by the Department of Entomology, Michigan State University, since 1963.

According to the available records, armyworm before 1960 was a minor or unimportant pest of small grains in Michigan. The damage by armyworm was scattered and localized. In 1938 and 1954, armyworm infestations were confined mostly to localized areas of the middle and upper counties of Michigan. Monroe County was the only county in the southern part of the state which reported an armyworm infestation. Table 1 is the summarized record of armyworm outbreak in Michigan since 1900 with a list of counties where outbreaks were reported. Unfortunately, the information about acreage density and control treatment are lacking. After 1960 it appears that the armyworm became a more

Table 1. History of Armyworm Damage in Michigan

Year	Counties Where the Damage was Reported	Note
1938	Gratiot, Montcalm	
1952	Lapeer, Charlevoix, Oceana, Monroe	
1953	Local outbreak, location is not reported	100 acres are treated. The worst in US history.
1954	Bay, Gratiot, Saginaw, Mackinaw, Cheboygan, Alger, Chippewa	
1957	From Ottawa to Bay Co., included Ingham and Osceola	
1964	Monroe, Livingston, Berrien, Allegan, Van Buren, Cass, Kalamazoo, Wayne	2300 acres were treated
1965	St. Joseph, Van Buren, Berrien Allegan, Ottawa, Macomb	
1975	All southwestern counties from Berrien Co. up to Tuscola Co.	
1976	Berrien, St. Joseph, Cass, Van Buren, Kalamazoo, Allegan, Lenawee, Monroe, Tuscola, Bay, Saginaw	

important pest and infestation areas extend into southwestern and west-central counties. However, fewer reports came from northern and upper peninsula counties.

Control measures included applications of Toxaphene, 1953; and Sevin, Malathion, Parathion, Dylox or Diazinon in 1975 and 1976. The difficulties in applying pesticides for armyworm control are related to proper timing. Many fields were treated needlessly because treatments were either applied under light infestation or delayed until larval feeding was completed.

Natural enemies such as Tachinid fly, *Winthemia quadripustulata* and Braconid parasite (not mentioned by species but most likely *Apanteles militaris*), and diseases (fungus and virus) were considered as the main factor to control the population after the outbreak.

Compared with other states such as Tennessee, Missouri, Kentucky, Wisconsin, Illinois, etc., Michigan has less of a problem with armyworm damage. It appears that Michigan missed the worst outbreak of armyworm in the history of the United States and Canada, in 1953. While other states suffered hundreds of thousands of dollars damage to small grain and corn fields by the armyworm, Michigan experienced only 100 acres of light infestation. This situation can be seen in Figure 1 which is the map of the infestation area in 1953.

Even though the interval of an "armyworm year" in one location is not regular and cannot be predicted, it is interesting to note that after the first year of outbreak there will usually follow one or two more outbreaks less severe than the first. In Michigan, for example, the outbreak in 1964 was followed by 1965 outbreak, 1975 followed by

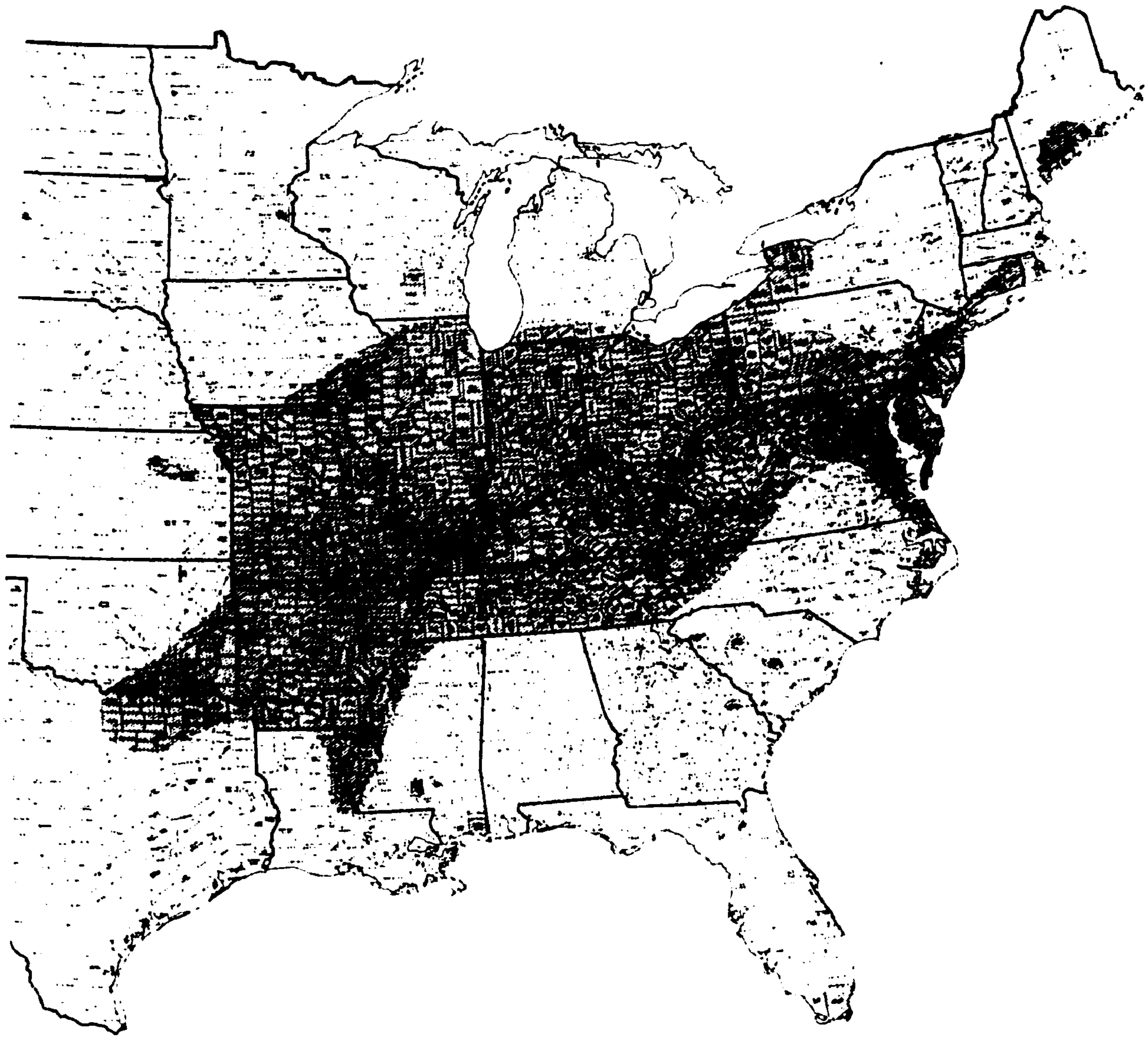

Figure 1. Map of armyworm infestation in the United States in 1953.*

---

*Cooperative Economic Insect Report Published by USDA.

1976 outbreak. In other states the 1953 outbreak was followed by outbreaks in 1954 and 1955.

Host Preference and Food Consumption

The armyworm is a polyphagous insect, feeding on a great variety of plants. The larvae have been reported to feed on small grain, corn, sorghum, grasses, beans, forage crops, vegetable crops and a few fruit crops. It is generally accepted that the armyworm prefers grasses over other groups of plants. However there should be a certain subset of the grass family which the armyworm prefers most.

Guppy (1961) reported that during the 1954 outbreak in Eastern Ontario most of the population was in oat field, but he suggested that it is unlikely that oats are the most preferred host. Crop maturity and stand density of stubble and dead leaves for oviposition sites may be more important in attracting the insect than host species. Breeland (1958) made an oviposition test using 6 small grains and grasses. Wheat received highest egg deposition, then Dallis grass (*Paspalum dilatatum*); Johnson Grass (*Sorghum halepence*); and barley (*Hordeum vulgare*). The lowest eggs were deposited in oats (*Avena sativa*); Sudan Grass (*Sorghum vulgare*). There is no report about the effect of different hosts to the development of larvae and pupae of the armyworm. For the comparison works of Tanaka et al. (1970) can be used as a reference.

Tanaka et al. (1970) working with the oriental armyworm (*Leucania separata*) did host preference investigations in the laboratory using seven different grasses. They checked the effect of hosts on mortality of larva and pupae, pupal weight, number of instar of larvae; Table 2 summarizes some of their observations. From this table it can be concluded that the armyworm cannot survive in certain grass such as Napier Grass, and suffered a high mortality in Bahia Grass and Rhodes Grass. Extra instars which developed while feeding on certain plants, demonstrate that the larvae are under stress.

Information about host preference of armyworm is important for understanding the migrational behavior of the pest in a field.

The potential food consumption by a single larva is high, which allows armyworm population to rapidly exceed an economic threshold. David and Satterthwait (1916) state that with 8,890 corn plants per acre, it would require 21,473 larvae to destroy an acre of corn two feet high. This number represents the potential progeny of only 40 moths.

Most food is consumed by the later instars. Tanaka and Wakikado (1974) reported that the first to fourth instars consumes 3.5% of the total food needed for larval development, the fifth instar consumes 12.8%, and the sixth instar consumes 84.7%. Ninety-seven percent of the total food consumed was done by the fifth and sixth instars.

Mukerji and Guppy (1970) investigate the quantitative relationship between food consumption and the growth of the armyworm. When the armyworm feeds at a high rate, it is able to accelerate development, increase growth, and maintain a high reproductive potential. When the rate of food intake is low; development, growth, and fecundity are reduced.

Table 2. Effect of Different Grasses on the Development of the Oriental Armyworm. *Leucania separata* (Tahaka et al., 1970)

Host Plant	Mortality of Larva	Number of Instar Larva	Pupal Weight (mg)
1. Fescue (*Festuca arundinaeca*)	5.8	6	385.0
2. Corn (*Zae mays*)	24.0	6	382.2
3. Sorghum (*Sorghum vulgare*)	17.0	7	384.9
4. Dallis Grass (*Paspalum dilatatum*)	16.7	7	357.3
5. Rhodes Grass (*Chloris gayana*)	47.6	9	272.2
6. Bahia Grass (*Paspalum notatum*)	90.9	7	340.7
7. Napier Grass (*Pennisetum purpureum*)	100.0	-	-0-

Spatial Distribution of Larvae Under Field Condition

Spatial distribution of a population in a natural habitat, is important in the study of the ecology of certain animals. Even though the spatial distribution does not tell much about the behavior and dynamics of population, it can be used for measuring population size and describing the condition of the population. The dispersion pattern of a population, at any instant represents the culmination of a history of birth, death and movement. By observing the dispersal pattern of the individuals some insight into the biological characteristics of the species, and the reasons behind the changes in the density of the population can be gained.

Indices of the dispersion are needed to clearly describe the spatial pattern or to use in testing the departure from randomness for sampling purposes. Many dispersion indices which have been developed, basically can be divided into two categories based on the sampling scheme, plot (quadrat) counts and distance measurements. The choice of whether to use plot counts or distance measurements might be dictated by physical conditions which are not under control of the researcher.

Observed field counts, resulting from a chosen sampling method, must be compared to a theoretical series of probability distribution, to find out which distribution is the most fit to represent the spatial characteristics of the population. A favorable agreement between the observed data and the calculated values of theoretical series should be made carefully, otherwise it may lead to an unwarranted conclusion.

Waters and Henson (1959) listed three possibilities that can result in misinterpretation:

1. The observed data might satisfactorily fit more than one distribution.
2. Some distributions can arise from several distinct mathematical and biological models.
3. The parameters of most discrete frequency distributions are strongly influenced by the form and size of sampling unit, and by population density.

There are three theoretical distributions which are used to describe the basic types of spatial dispersion of population: 1) random distribution; 2) regular distribution; and 3) contagious distribution.

1) Random distribution or Poisson distribution. The frequency distribution is a Poisson distribution given by the function

$$Px = \frac{a^x \; e^{-a}}{x}$$

where, Px = the probability of x individual in a sampling unit

x = number of individuals per unit

a = mean number of individuals per unit

e = base of natural logarithm = 2.71828

The assumptions that should be met by this distribution are:

a. Each individual has the same chance of falling into any unit.

b. Each unit has the same chance of being filled by any individual.

c. The presence of one individual in a unit does not in any way affect the chances of another falling into it.

d. The samples must be small relative to the population.

These conditions are less likely to happen in the field. As Elliot (1977) pointed out, the agreement with Poisson series simply means that the hypothesis of randomness is not disproved or, in another word, non-randomness is present but cannot be detected by sampling techniques in the field.

If the size of the sampling unit is much larger or much smaller than the average size of clumps of individuals, and these clumps are regularly or randomly distributed, then the dispersion of the population is apparently random, and non-randomness is not detected. The tendency to randomness often increase with the age of a population which could be due to the decrease in population density or to the division of larger clumps into several smaller clumps.

2) Regular or Uniform Distribution. The mathematical model for the regular distribution is a positive binomial which is given by the function:

$$P_{(x)} = \frac{k!}{x!(k-x)!} \quad q^{(k-x)} p^{x}$$

where, P_x = the probability of x individuals in a sampling unit

p = probability of any point in the sampling unit being occupied by an individual

q = $(1 - p)$

k = the maximum possible number of individuals a sampling unit could contain.

The dispersion of a population is regular when the individuals in the population are relatively crowded and move away from each other. Under these conditions, the number of individuals per sampling unit approaches the maximum possible, the variance of the population is less than the mean. Territorial behaviour will often produce a uniform spacing of the individuals. Therefore, a regular distribution rarely describe the dispersion of population over a large area, but sometimes describe the dispersion in a small area.

3) Contagious or Aggregated Distribution. The mathematical model for the contagious distribution is a negative binomial which is given by the function,

$$P_{(x)} = \left(1+\frac{u}{k}\right)^{-k} \quad \frac{(k+x-1)!}{x!(k-1)!} \left(\frac{u}{u+k}\right)^{x}$$

where, P_x = the probability of x individuals in a sampling unit

u = arithmetic mean

The parameters of this distribution are u and the exponent k, they are estimated from the frequency distribution of the sample by the statistics $\bar{x}$ and $\hat{k}$. There are several methods of calculating k value (Anscombe, 1949, 1950).

The spatial distribution of a population is contagious when the variance is significantly greater than the mean. There are always definite clumps or patches of individuals in this distribution. The individuals tend towards aggregation due to environmental factors or behavior of the animal. The dispersion pattern depends upon the size of the clumps, the distance between clumps, and the spatial distribution of individuals within each clump. Different species will usually show different contagious distributions within the same habitat, and the dispersion pattern of one species may vary within the same habitat.

Bliss and Calhoun (1954) explained that the negative binomial distribution can arise in the population in five different ways, i.e., 1) heterogeneity in the probability of occurrence; 2) true contagion; 3) compounding Poisson and logarithmic distributions; 4) birth-death immigration process; and 5) inverse binomial sampling.

In addition to these, the sampling method chosen by the experimenter may effect the apparent distribution, contagious distribution (or other distributions) involve both biologically significant and strictly artificial components.

Indices of Dispersion

Many different indices have been developed to compare different patterns of dispersion in populations. Elliot (1977) emphasized that the ideal index of dispersion should possess the following attributes:

1. It should provide real and continuous values over the range of maximum regularity, through randomness, to maximum contagion.
2. It should not be influenced by variation in the size of the sampling unit (quadrat size), the number of sampling units (n), the sample mean ($\bar{x}$), and the total numbers in the sample (Σx).

3. It should be easy to calculate from large amounts of data.

4. It should enable differences between samples to be tested for significance.

There is no perfect index of dispersion which fulfills all those conditions, some assumptions are made as a constraint of the indices. The following indices are most frequently used.

1. Variance to Mean Ratio - This test is based on the equality of variance and mean in a Poisson series, and the inequality of both parameters in the regular and contagious distribution. The variance to mean ratio, or index of dispersion (I) is calculated by the following formula,

$$I = \frac{S^2}{\bar{x}} = \frac{\Sigma(x-\bar{x})^2}{\bar{x}(n-1)}$$

if, $I > 1$, contagious distribution is suspected, $I = 1$ a random distribution and $I < 1$ a continuous distribution is suspected.

Because this index is strongly influenced by the number of individuals in the sample, it is a good statistical test for an agreement with the Poisson distribution, but it is not a good measure of the degree of clumping in a population.

2. k in the negative binomial - If the negative binomial can be fitted to the data, the value of k gives a measure of dispersion. The smaller the value of k, the greater the extent of aggregation; whereas, a large value (over about 8) indicates that the distribution is approaching a Poisson.

The disadvantages of this index are: 1) it is not independent of the number of sampling units; 2) it goes to $\pm$ infinity at randomness; and 3) the values of k is often influenced by the size of the sampling unit. Comparisons of the level of clumping can only be made with k, when n and the unit size are the same in each sample.

The statistic k has been used in measuring the degree of population aggregation for various habitats, and developmental stages (Waters, 1959; Harcourt, 1961, 1963, 1965).

3. <u>Morisita Index of Dispersion</u> - Morisita (1959, 1962, 1964) has developed the following index of dispersion,

$$I\delta = n\,\frac{\Sigma[x(x-1)]}{\Sigma x(\Sigma x-1)} = \frac{n\Sigma(x^2) - \Sigma x}{(\Sigma x)^2 - \Sigma x}$$

This index has the advantage that, it is independent of the sample mean, total numbers in the sample, and type of distribution, but it is affected by the number of sampling unit (n). Therefore, it is a good comparative index of dispersion, when each sample contains the same number of sampling units. When the distribution is Poisson this index will approach unity, when the distribution is contagious the index will be greater than one, and when the distribution is regular the index will be less than one.

Morisita (1959) has investigated changes in $I\delta$ with different sizes of quadrat size. From this he could estimate the mean size of the clumps.

4. <u>Nearest neighbour method</u> - All of the above three indices with the other indices (i.e., Lloyd index, Deevey's, Cole's index, etc.) are

affected to a greater or lesser extent by quadrat size, and it is often impossible to detect non-randomness when clumps of individuals are very small. These problems can be overcome by using indices which are based on nearest neighbor measurement such as nearest neighbor method of Clark and Evans (1954), and closest individual or distance method of Cattain and Curtis (1956).

In this method, the individual is selected at random, and the distance between it and its nearest neighbor is measured. If N is the number of observations, the observed mean distance between an individual and its neighbor is,

$$\bar{r} = \frac{\Sigma r}{N}$$

If the dispersion of individuals is random, the expected or mean value of the average distance between a randomly selected individual and its nearest neighbor is,

$$E_{(r)} = \frac{1}{2p^{\frac{1}{2}}}$$

where, p = the density of the population expressed as the number of individuals per unit area.

The ratio,

$$R = \frac{\bar{r}}{E(r)}$$

is the measurement of the departure from randomness. If $1 > R > 0$ the distribution is aggregated. The more clumped the closer R is to zero. The population has a regular distribution if R is between 1 and 2.496.

To test the significance of the deviation of R from expected value, Clark and Evans (1954) suggest the use of a standardized normal variate,

$$c = \frac{\bar{r} - E(r)}{SE(r)}$$

where,

$$SE_{(r)} = \frac{.26136}{(Np)^{\frac{1}{2}}}$$

A limitation of the nearest neighbor analysis in a spatial study is that population density must be known and individuals must be stationary while measurements are being taken.

Selection of Sampling Unit

The study of spatial distribution of individuals is useful in selecting a sampling unit for a sampling program. Morris (1955) laid down six criteria for selecting a sample unit:

1. It must be such that all units of the universe have an equal chance of selection.
2. It must have a stability.
3. The proportion of the insect population using the sample unit as a habitat must remain constant.
4. The sampling unit must lend itself to conversion to unit areas.
5. The sampling unit must be easily delineated in the field.
6. The sampling should be of such a size as to provide a reasonable balance between the variance and cost.

In this report I have emphasized the sixth criteria. The familiar principle of selecting a unit is the one that gives the smallest variance for a given cost, or the smallest cost for a prescribed variance. From preliminary sampling variances of each of different units size (Su^2) can be calculated. By calculating a common basis for these units it is possible to arrive at the size of the smallest unit. Cochran (1963) used the term "Relative Net Precision" (RNP) to compare different unit sizes. For a given fixed cost,

$$RNP \quad \alpha \frac{Mu^2}{CuSu^2}$$

where, Mu = relative size of unit

Su^2 = variance among unit totals

Cu = relative cost of measuring one unit.

Cu can be calculated as a ratio of unit size over a number of square foot that could be sampled with a fixed resources (fixed resource = sampling time). For example this value shall include the amount of resource (time) spent for processing one sample, and resources (time) spent to travel between samples.

For a fixed cost, a sample unit with the high RNP gives more precision than one with lower RNP. The comparison between RNP of different unit sizes can be used to indicate the optimum sample unit for a certain distribution type.

Comparisons of the Various Indices of Aggregation

For a given species, it is important to know whether different populations have a similar pattern, or whether the patterns vary. Population patterns may differ due to the geography, population density or various environmental factors. Observing the changes in pattern that accompany a reduction in size of a population is essential if the objective is to follow long-term population trends. The sample scheme must be adjusted to reflect any fundamental change in distribution.

Each index of aggregation is a single statistic that describes only a single aspect of spatial pattern. Each index should be thought of as providing only a measure of the extent to which pattern departs from randomness. Pielou (1974, 1977) stated that the patterns of a population spread over a continuum has two obvious properties which may be called intensity and grain. The intensity of a pattern is the extent to which density varies from place to place. The grain of a pattern is independent of its intensity. The grain is coarse if its clumps and the gaps among them are large; if converse, the pattern is fine-grained.

Indices of aggregation calculated from data obtained by sampling with quadrats of one size are all measures of the intensity of a pattern, and not the grain. To study "grain" by means of quadrat sampling it is necessary to use several quadrat sizes, as introduced by Greig-Smith (1954, 1964). Clark and Evan's index of R clearly measures only the intensity of pattern.

For the purpose of comparing the intensity of different patterns, the indices which are used should not be affected by the population density. Two patterns can have the same intensity although their densities differ. Among different indices Lloyd's Index of Patchiness (C), and Morisita's Index of Dispersion (I delta) are the most useful measurement. The R value of Clark and Evans is probably the best if one particularly wishes to measure the pattern intensity, because the distances between individuals are included (Pielou, 1974, 1977).

Armyworm-Parasite Relationship

The armyworm is attacked by a complex of natural enemies which as a whole plays a decisive role for controlling armyworm population. Many parasites, predators and diseases of armyworm are recorded in published literature. The most complete list of armyworm natural enemies were presented by Breeland (1958) and Guppy (1967). Breeland presented a list of 16 parasite species, two predators and three diseases, and Guppy (1967) recorded 69 species of primary insect parasites and 12 associated hyperparasites which are presented in Table 3.

Two species of parasites, Winthemia rufopicta (Big) (Diptera: Tachinidae) and Apanteles militaris Walsh (Hymenoptera: Braconidae), and a Nuclear Polyhydrosis Virus are the most important natural enemies of armyworm. Their presence in the field during the epidemic years has often been reported.

Winthemia rufopicta (Big) has been confused with another species Winthemia quadripustulata F. All old records of the armyworm always used Winthemia quadripustulata if they referred to Tachinid parasites of the armyworm. Recent papers prefer using Winthemia rufopicta instead (Danks, 1975; Ravlin, 1978 personal communication). This confusion needs some clarification and verification by taxonomist.

Winthemia rufopicta is an aggressive parasite, having a high search ability, rapid development, and high reproductive potential. The female prefers to lay eggs on the 5th and 6th armyworm larvae. The flies have a diurnal pattern of activity, which contrasts strongly with that of its armyworm host (Danks, 1975). Number of eggs laid on a host

Table 3. List of Recorded Insect Parasites of the Armyworm (Guppy, 1967)

Order	Family	Species
Hymenoptera	Braconidae	Meteorus autographae Mues.
		Meteorus communis (Cress.)
		Meteorus laphygmae Vier.
		Apanteles flaviconchae Riley
		Apanteles forbesi
		Apanteles laeviceps Ashm.
		Apanteles marginiventris (Cress.)
		Apanteles rufocoxalis Riley
		Microgaster auripes Prov.
		Microplitis alaskensis Ashm.
		Microplitis melianae Vier.
		Microplitis varicolor Vier.
		Rogas aciculatus (Cress.)
		Rogas atricornis Cress.
		Rogas politiceps Gahn.
		Rogas terminalis (Cress.)
		Rogas sp.
	Ishneumonidae	Pimpla pedalis Cress.
		Netelia geminata (Say)
		Netelia ocellata (Vier.)
		Netelia sayi (Cush.)
		Phaeogenes hebrus (Cress.)
		Melanichneumon brevicinctor (Say)
		Splichneumon superbus (Prov.)
		Cratichneumon brevipennis (Cress.)
		Ichneumon ambulatorius F.
		Ichneumon annulatorius F.
		Ichneumon canadensis Cress.
		Ichneumon laetus (Brulle)
		Campoletis oxylus (Cress.)
		Hyposoter exiguae (Vier.)
		Therion sassacus Vier.
		Enicospilus purgatus (Say)
		Enicospilus sp.
	Eulophidae	Eulophus sp.
		Euplectrus mellipes Prov.
		Euplectrus plathypenae How.
	Scelionidae	Telenomus minimus Ashm.
		Telenomus sp.

continued

Table 3--continued

Order	Family	Species
Diptera	Tachinidae	Peleteria texensis Cn.
		Archytas apicifer Wlk.
		Archytas marmoratus (Tnsd.)
		Athrycia cinerea (Coq.)
		Periscepsia laevigata (Wulp)
		Periscepsia helymus (Wlk.)
		Compsilura concinnata (Mg.)
		Eucelatoria rubentis (Coq.)
		Euphorocera claripennis (Macq.)
		Euphorocera sp.
		Exorista mella (Wlk.)
		Exorista larvarum (L.)
		Chaetogaedia monticola (Big.)
		Triachora unifasciata (R.D.)
		Winthemia quadripustulata (F.)
		Winthemia rufopicta (Big.)
		Gymnocarcelia ricinorum Tnsd.
		Lespesia aletiae (Riley)
		Lespesia archippivora (Riley)
		Lespesia melalophae (Allen)
		Madremyia saundersii (Will.)
		Patelloa leucaniae (Coq.)
		Phryxe vulgaris (Fall.)
		Phryxe pecosensis (Tnsd.)
	Sarcophagidae	Helicobia rapax (Wlk.)
		Blaesoxipha (Blaesoxipha) hunteri (Hough)

larva is positively correlated with the size of that larva. Maggots hatching from the eggs will penetrate the cuticle and develop in the body of the host.

The survival of maggots inside the larval body depends on the ability of the host to support maggot development; the number of maggots entering the host; and the interaction with other species competing for the same host (Danks, 1975). Usually the host larvae are killed 2-3 days after maggots penetrate into the host body.

Winthemia rufopicta is not a host specific parasite, it attacks mostly Noctuid larvae. The success of its development and survival depends on the availability and suitability of different hosts distributed through time and space. Besides the armyworm, Danks (1975) recorded 6 other hosts of this species; namely, *Laphigma frugiperda* (A & S.), *Heliothis zea* (Boddie), *Heliothis virescens* (Fab.), *Trichoplusia ni* (Huebn.), *Prodenia ornitogalli* Guen., *Peridroma saucia* (Huebn.). *Agrotis ipsilon* (Hufn.), *Feltia ducens* Walk, and *Feltia subterrania* (Fab.) also become potential hosts for *W. rufopicta*.

In North Carolina the first generation of *W. rufopicta* emerges during April, and probably parasitizes hosts that overwinter as partly grown larvae (e.g., the armyworm) or that begin development very early in the year (e.g., *Peridroma saucia*). The parasite may build up on any common suitable host that is abundant later in the year (Danks, 1975).

Apanteles militaris Walsh, a gregarious braconid parasite, is an endoparasite, with a good searching ability and high reproductive potential. It is, more or less host specific to the armyworm.

It attacks third to fifth instars of armyworm larvae. No _Apanteles_ larvae emerged from armyworm larvae exposed to attack in instars 1, 2, and 6 (Calkins and Sutter, 1976). Towers (1915) reported that the wasps did attempt to oviposit on the 5th and 6th instar, but were generally unsuccessful (except in newly molted 5th instar) because of the toughness of the cuticle. Parasitized armyworm larvae will be killed in the late 6th instar.

The rate of _A. militaris_ development within larvae of armyworm decreased proportionately with increases in ambient temperatures between 21 and 27°C. The parasite seems to develop well at moderately high temperatures, but in the field, its slow development at lower temperatures would probably prevent it from becoming a major deterrent factor during cool spring weather (Calkins and Sutter, 1976).

The parasite always emerges as a third instar larvae and only from sixth instar host larvae, regardless of the host instar that was originally attacked. The number of parasite larvae emerging from one host body ranges from 1 to 161 (Calkins and Sutter, 1976), or from 6 to 101 (Breeland, 1958).

Armyworms parasitized by _A. militaris_ show no signs of their plight until nearly mature when they become sluggish, and death comes only after the parasite larvae have emerged and spun their cocoons. During the time before the larvae is killed, its food consumption is significantly reduced. Tower (1916) states that armyworms parasitized by _A. militaris_ eat approximately half as much as do non-parasitized larvae during the same period.

Overwintering and Supercooling Ability

Insects are able to overwinter either in a diapause or hibernation state. Usually the diapause is induced by seasonal changes in photoperiod, temperature or diet. A combination of short photoperiod, low temperature, and dry diet may take an insect into diapause. Winter dormancy or hibernation is controlled by two factors, environmental and genetic factors. Most insects enter a period of dormancy when some environmental factor,such as temperature, becomes unfavourable and they will resume their activity when conditions are favourable.

The armyworm's success in surviving the winter conditions depends upon its ability to withstand low winter temperatures. Salt (1961) divided cold hardiness of the insect into two classes: 1) avoidance of freezing by supercooling, and 2) freezing tolerance. The former group are called freezing-susceptible and the latter group are called freezing-tolerant or freezing-resistant. The armyworm is included in the first group.

The ability of an insect to supercool is an indicator of cold tolerance. Most researchers use the supercooling point as an index of cold tolerance even though the mean supercooling temperature of any species will not alone determine whether the species will overwinter on a particular habitat. Most insects do not survive freezing and the supercooling point is the lethal limit of low temperature. Supercooling point of an insect is dependent upon many intrinsic and extrinsic factors, and takes place as a probability function (Salt, 1961).

MATERIALS AND METHODS

Field Sampling and Parasite Observation

Field Research, 1976

Larval and pupal sampling of armyworms were undertaken in a wheat and rye field in Cass County, Michigan. A quadrat count method was used as the sampling method. Larval sampling, unfortunately, was done during late instars, due to the late report of the location outbreak. The sampling was done four times, June 8, 12, 19, and 25. No larva or pupa were found in the field after June 25. Sampling and observations were carried out during the daylight hours.

One square foot of soil surface was used as a sampling unit, and ten samples were taken per observation date. All larvae were collected, counted and checked for instar and *Winthemia* parasitization. Instars of armyworm were checked by measuring the head capsule, using Guppy's (1969) criteria. Parasitism was checked by the presence of parasites eggs on larval body. Larvae were placed in paper containers and transferred to the laboratory for additional parasites observations.

Soil samples were taken by digging soil 1-2 inches deep and placing the soil in a plastic bag, and transferring the bags to the Collins Road Field Station. The next day soil samples were run through a soil sifter, and checked for armyworm pupae. The number of pupae were counted, and the pupae were reared in a 70°F room for checking parasitism and survival.

Field Research, 1977

To measure population density and study the spatial distribution of larvae in the field, a 10 x 10 foot plot was set and observed on May 24th, June 4th, 10th and 17th. Locations of larvae in the plots were marked with bamboo sticks and they were mapped onto a 10 x 10 graph paper. Due to the low count of larvae found in the 10 x 10 sq. ft. plot, quadrat count technique was not appropriate as a sampling plan. Instead, night sweeping was used as the sampling method for larvae during the rest of the season.

Sampling of larvae in 1977 was done in the wheat field located in Cass County. Sweep sampling was carried out after dark between 10 and 12:00 p.m. The sampling unit was one hundred sweeps, taken ten times at each observation date. Sampling and observations were done on May 20, 24, 27, and June 1, 4, 7, 14, and 21. After June 21, no armyworm larvae were caught by the net.

Collected larvae were placed in plastic cups, and all larvae were transferred to a 70°F room for checking instars the following day. Parasite identification, developmental rate, and percentage of parasitism were obtained by rearing collected larvae. For each observation date, larvae were separated by instar, and placed in 5-inch Dixie cups, and fed on barley leaves. A maximum of 5 larvae were placed in each cup. Every day, the larvae were checked for instar, frass removal, food renewal and parasite emergence and development.

The cocoon or puparium of the emerging parasites were separated and kept individually in small plastic cups with a perforated cover. The emergence of adult parasites was recorded for each cup. The unknown parasite specimens were mounted for further identification. Tachinids eggs and Apanteles cocoons were also counted at this time.

Effect of Parasitization by Winthemia and Apenteles on the Amount of Food Consumed

Winthemia rufopicta

Experiments were done from August 15, 1976 to August 30, 1976 in the 70°F room. The tested larvae were taken from an asparagus field in Cass County. Only the sixth instar larvae were tested in this experiment.

Larvae were separated into parasitized and unparasitized larvae by using the presence of parasite eggs on the armyworm body. Larvae were placed individually in 5-inch Dixie cups, with a perforated lid. Barley leaves were used as a food. Total leaf area given to the individual larva were measured everyday with a Licor ® Area Meter, before and after feeding. Total daily larval consumption was assumed to equal the difference between these leaf area measurements.

Each day frass was removed, and wet cotton and paper towels were renewed in each cup. Leaves were measured and changed each day until the parasitized larva died or the unparasitized larva pupated.

Food consumption records were maintained for each larvae since some of the "unparasitized larvae" (no Tachinid eggs attached) were later killed by Winthemia.

Apanteles militaris

These experiments were conducted at two places. Apanteles rearing was done at CLB greenhouse, while the consumption test was done inside the 70°F room at the Natural Science Building. The experiments were carried out between July 8, 1977 and July 29, 1977.

Groups of Apenteles cocoons from several hosts were held in 10 oz. clear plastic cups, with a perforated cover to provide continuous aeration. Wasps were kept in the cups for 5 days to assure that mating was successful. Twenty female wasps were removed from the cups with an aspirator, and placed with armyworm larvae. Ten third instar armyworm larvae, and ten Apanteles wasps were placed in a 5-inch Dixie cup. Armyworm larvae were exposed to the parasites for 24 hours at a rearing room temperature (73°C).

These twenty exposed larvae were removed from the cups and placed individually in 5-inch Dixie cup. Barley leaves were used as food. Total leaf area given to the individual larva every day was measured with Licor ® Area Meter, as described in 1976 section. All other procedures are identical to those described for 1976.

Bucket Experiment

During July to September 1977, armyworm populations were very low in the Cass County field and no larvae were caught in net samples. Therefore, a new method was devised for continuing the observation of field parasitism during the rest of the season. Greenhouse reared larvae were exposed to field conditions. Containers with foliage provided enough fresh food, and shade for the test larvae during the exposure period. The method was successful due to the high larval recovery rates, after a short exposure period, however, some larvae escaped.

Several techniques were tested, and the best design is diagrammed in Figure 2. Two buckets were used, the first is the outer bucket which contains water for maintaining the plants, and the inner bucket for holding plants that were inserted in 5 plastic tubes. Vermiculite was placed in the inner bucket between the tubes, for reducing the chance of larval escaping. Food plants were any grass or small grain which had green leaves and roots. Larvae were placed between or on these plants.

All armyworm larval instars were exposed on each observation date. In each bucket 20 individuals of each instar were placed. On the next observation date, before the new larvae were put in, the remaining larvae in the bucket were transferred and reared in the 70°F room at the Natural Science Building. The method of checking the armyworm parasitism was identical to the method described earlier. The bucket experiment was carried out twice a week, from June 8 to October 11, 1977.

Spatial Distribution Study

The study of the distribution of the armyworm was done in two Cass County locations; in a wheat field, and in an asparagus-crabgrass field. Two different methods were used in successive years; namely,

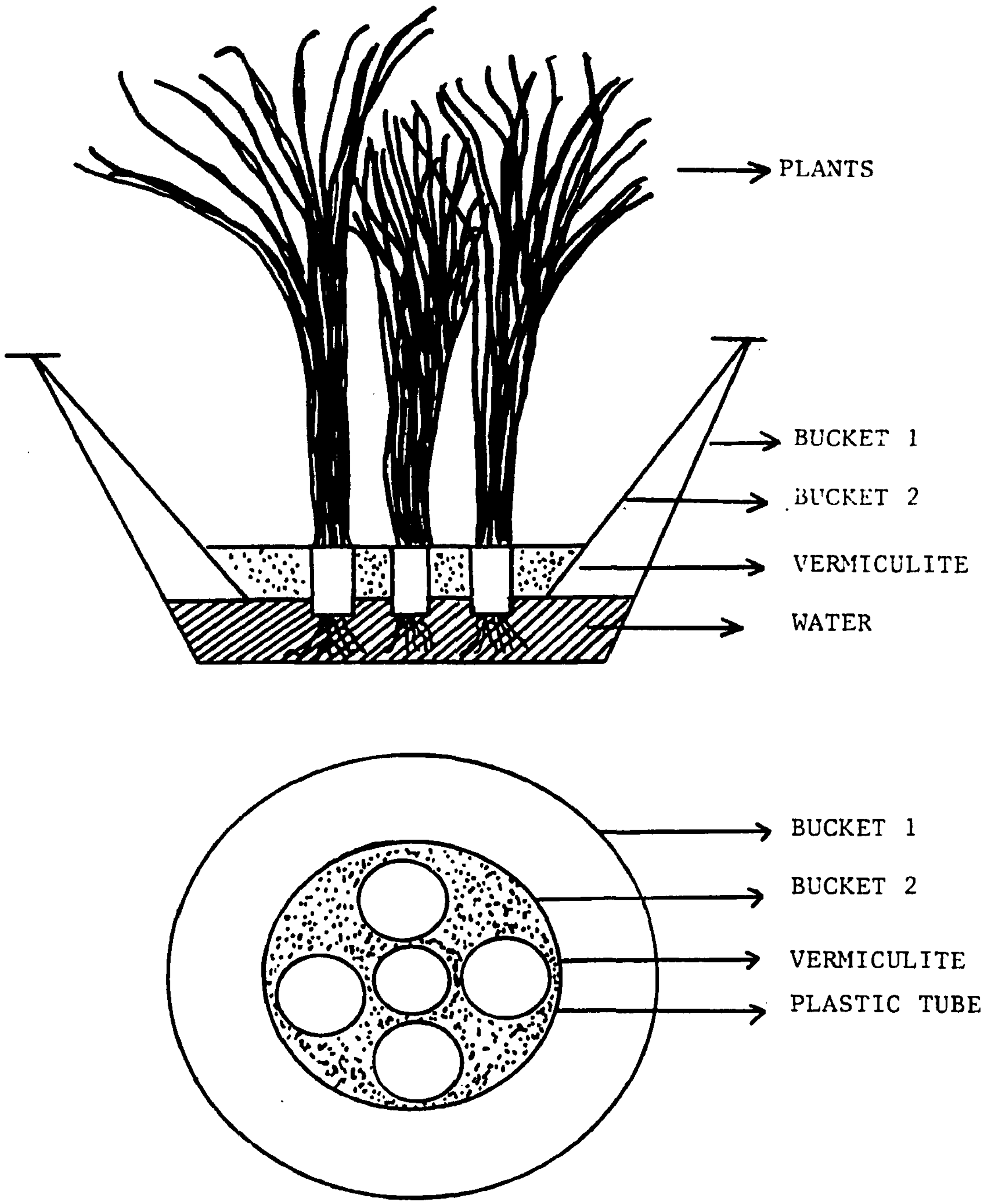

Figure 2. The diagram of the bucket experiment used for checking field parasitism of armyworm larvae in Cass County 1977.

quadrat counts for the wheat field in 1976, and individual mappings in 10 x 10 ft. sw. plots in 1977. Quadrat counts were also used for the asparagus field in 1976 and 1977.

Quadrat Count Method

Three sample unit sizes were used; 1 sq. ft., 4 sq. ft., and 1 sq. yard in a wheat-rye field near Marcellus, Cass County on June 12, 1976. Samples were taken randomly, for each unit size five replications were used, except that only 3 replicates of the large unit (1 x 1 sq. yard) were taken.

To investigate the distribution of the larvae, the field was divided into five regions according to the condition of plants and elevation. Figure 3 shows these regions in the field. Five 1 sq. ft. sample units were taken at random from each region, and the number and instar of larvae were recorded.

Quadrat counts were also used to study the larval distribution between fields. Eight wheat fields in Cass County were checked during the peak of the first generation larvae on June 14, 1976. Five 1 sq. ft. samples were randomly taken from each field, and the number and instar of larvae recorded. The same observations were done in four fields near Mason in Ingham County June 16, 1976.

Individual Mapping

One spot in the 1977 wheat field was selected randomly. One plot of 10 x 10 sq ft. was measured by using a rope and bamboo sticks as a border. All wheat rows inside the plot were examined for armyworm larvae, if a larva was found the location of the larva was marked with a

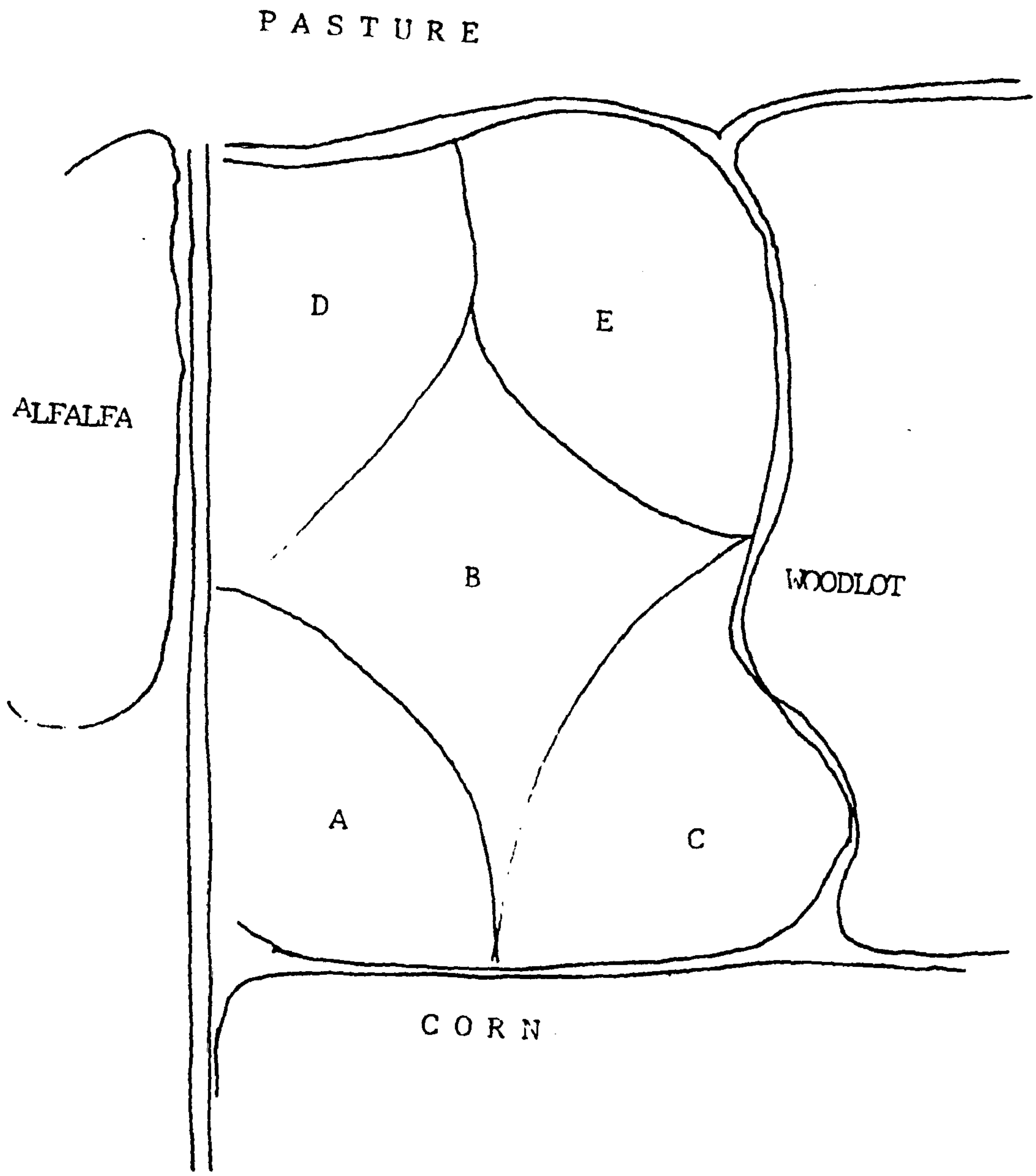

Figure 3. Map of five regions in the wheat field in Cass County, 1976.

bamboo stock and removed. After all larvae were marked and removed, their locations were mapped onto a 10 x 10 scale graph paper for later analysis. Mapping of individuals in the wheat field was performed 4 times, May 24, June 4, 10 and 17.

The asparagus-crabgrass field were located in Silver Creek Township, Cass County, Michigan. These asparagus fields were heavily infested with crabgrass and other weeds. The two fields together were about 5 ha and were surrounded and separated by an apple orchard.

One field was designated as a high density field, and one a low density field. From each field one 10 x 10 ft. of sample was selected randomly. The mapping routine was as previously described for wheat 1977, except the grass was cut to insure that every larva in the plot was counted. Observations were made on August 9, 12, 17, 23 and 29 of 1976, with 2 samples taken on each date in the high field, and one in a low field (15 data sets).

Pupal locations in the 10 x 10 plots was investigated by dividing each plot into 100 squares of 1 x 1 sq. ft. These squares were numbered from 1 to 100. All plants on the plot were cut and removed. Each square was dug 2-3 inches deep, and the soil was screened through a soil sifter (Gin shifter). Some of the soil squares were put in a numbered plastic bag and taken to the Collins Road Field Station. The samples were held in a 40°F room until they could be processed, which was less than 3 days. The number of pupae found in each soil square was recorded, the pupae were located in the middle of the square.

In 1977 observations were taken only in a high density asparagus-crabgrass field.

Observations on larval distribution were taken on July 29, August 5 and 12 of 1977, and on pupal distribution August 16, 1977. Basically the observations were similar to what was done in 1976. Besides the location and instar of armyworm larvae the presence of Tachinid's eggs were also checked and recorded. The location of Apanteles coccoons and Rogas terminalis puparium were recorded in the mapping. Distribution of plants in the plot area was recorded as they were in 1970.

Computer Analysis of Spatial Distribution

Field mapping data for 1976 and 1977 were inputed into the CDC 6500 computer using the CDEXSPOCS program developed by Dimoff, 1977. Two computer programs were developed for the analysis of these data, one based on the nearest neighbor method and the other based on quadrat counts.

The flow chart of the nearest neighbor method is presented in Figure 4, and the program listing is presented in Appendix A. All of the formulas which are used to calculate distribution statistics are based on Clark and Evans' paper (1954).

In the quadrat count analysis the programs have been developed using the following assumptions:

a) The field where the population is located is composed of large numbers of similar 10 x 10 ft. plots with a same type of distribution.

b) A plot where one sampling unit is taken, will not be included in the next sampling. The sample design therefore is without replacement.

PLEASE NOTE:

In all cases this material has been filmed in the best possible way from the available copy. Problems encountered with this document have been identified here with a check mark ✓.

1. Glossy photographs _______
2. Colored illustrations _______
3. Photographs with dark background _______
4. Illustrations are poor copy _______
5. Print shows through as there is text on both sides of page _______
6. Indistinct, broken or small print on several pages ✓ throughout _______
7. Tightly bound copy with print lost in spine _______
8. Computer printout pages with indistinct print _______
9. Page(s) _______ lacking when material received, and not available from school or author _______
10. Page(s) _______ seem to be missing in numbering only as text follows _______
11. Poor carbon copy _______
12. Not original copy, several pages with blurred type _______
13. Appendix pages are poor copy _______
14. Original copy with light type _______
15. Curling and wrinkled pages _______
16. Other _______________________________

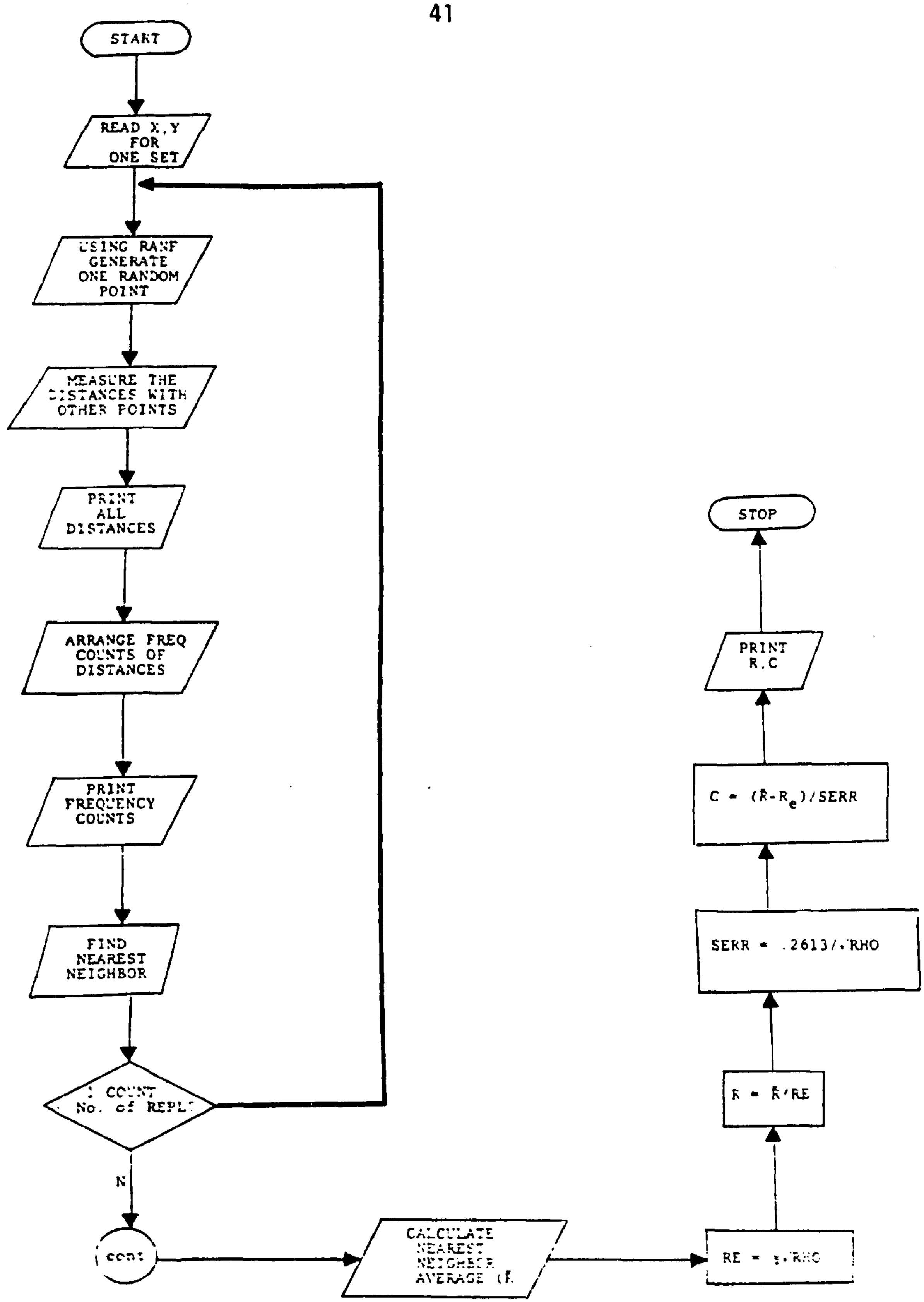

Figure 4. The flow chart of nearest neighbor analysis.

c) To avoid the effect of a border between plots, or to avoid duplication in taking samples, sample space was limited to the area inside the plot with a border space that is equal to one-half of the sample unit length (see Figure 5).

Random points are taken from any spot in the sample space. Individuals in the border space will be included in the sample counts, if the respective random points are on the margin of the sample space. Because of this restriction the maximum sampling unit (quadrant) which could be used is one-half of 10 x 10 sq. ft. or 5 x 5 sq. ft.

Statistics which are calculated by the program are the mean of the population (Mμ), mean and variance of the sample, variance/mean, I delta, K value of negative binomial, and Chi-square test values for variance/mean and I delta.

Mμ is calculated as the average number of individuals in the sampling unit inside the sample space. The mean and variance of the samples are calculated from the sample counts. I delta is calculated by Morisita's formula

$$\text{I delta} = n\Sigma(x^2) - \Sigma(x)/\Sigma(x)^2 - \Sigma x$$

and k of negative binomial is estimated by,

$$K = (\bar{x}^2) / (s^2 - x)$$

chi-square test value for I delta is calculated as

$$\text{Id}\ (x - 1) + n - \Sigma x$$

and for variance/mean is calculated as

$$(s^2/\bar{x})\ (n - 1).$$

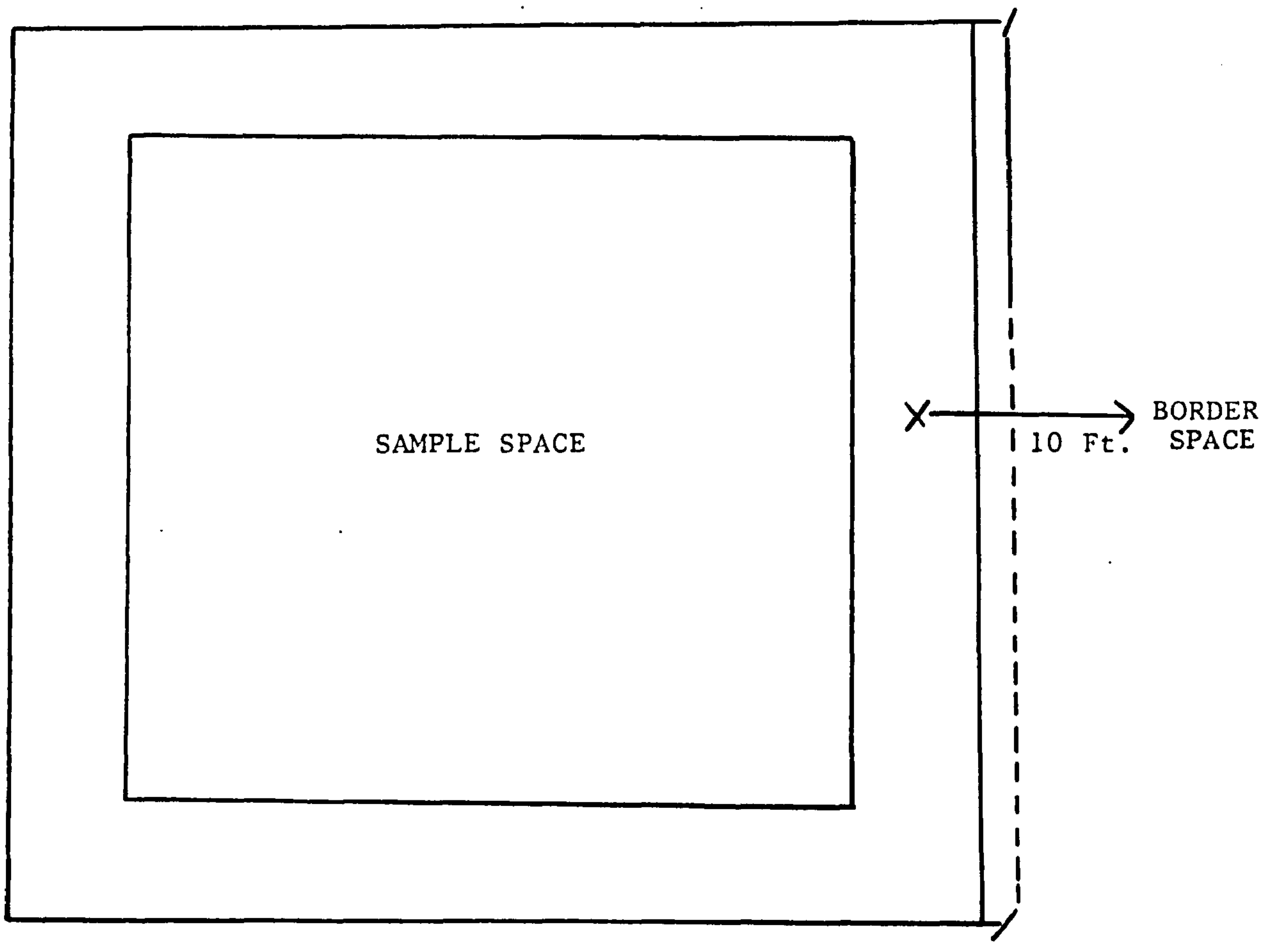

Figure 5. Sample space inside 10 x 10 sq. ft., with 1 x 1 sq. ft. as a sampling unit.

The debugging value for I delta and K are set = -9.999, if

$$(\Sigma x)^2 = \Sigma\bar{x} \text{ and } s^2 = \bar{x}.$$

The flow chart of the program is presented in Figure 5A, and program listing is in Appendix B.

Optimum Sampling Units

For calculating RNP, we need data on Cu, or relative cost of measuring one unit. Cu is calculated as a ratio of unit size over a number of square feet which could be sampled with a fix resource. In practical field sampling the principal resource is time; that is, the amount of time spent for processing one sample, the time spent to travel between samples.

Data for this time resources was calculated in 1977, for the asparagus-crabgrass field in Cass County. The time spent processing one sample unit includes the time required for cutting the grass, cleaning the soil surface, finding the larvae, and counting and recording the larvae. The sampling time of eight quadrat units (i.e., .4, .6, 1.0, 1.6, 2.0, 3.0, 3.6, and 4.0 sq. ft.) was recorded, etc., with 5 replications for every unit.

Wood frames of various quadrat sizes were used to measure the soil surface for processing. The entire sampling process was performed by one person. Between sample time was estimated from 30 samples taken from a single field.

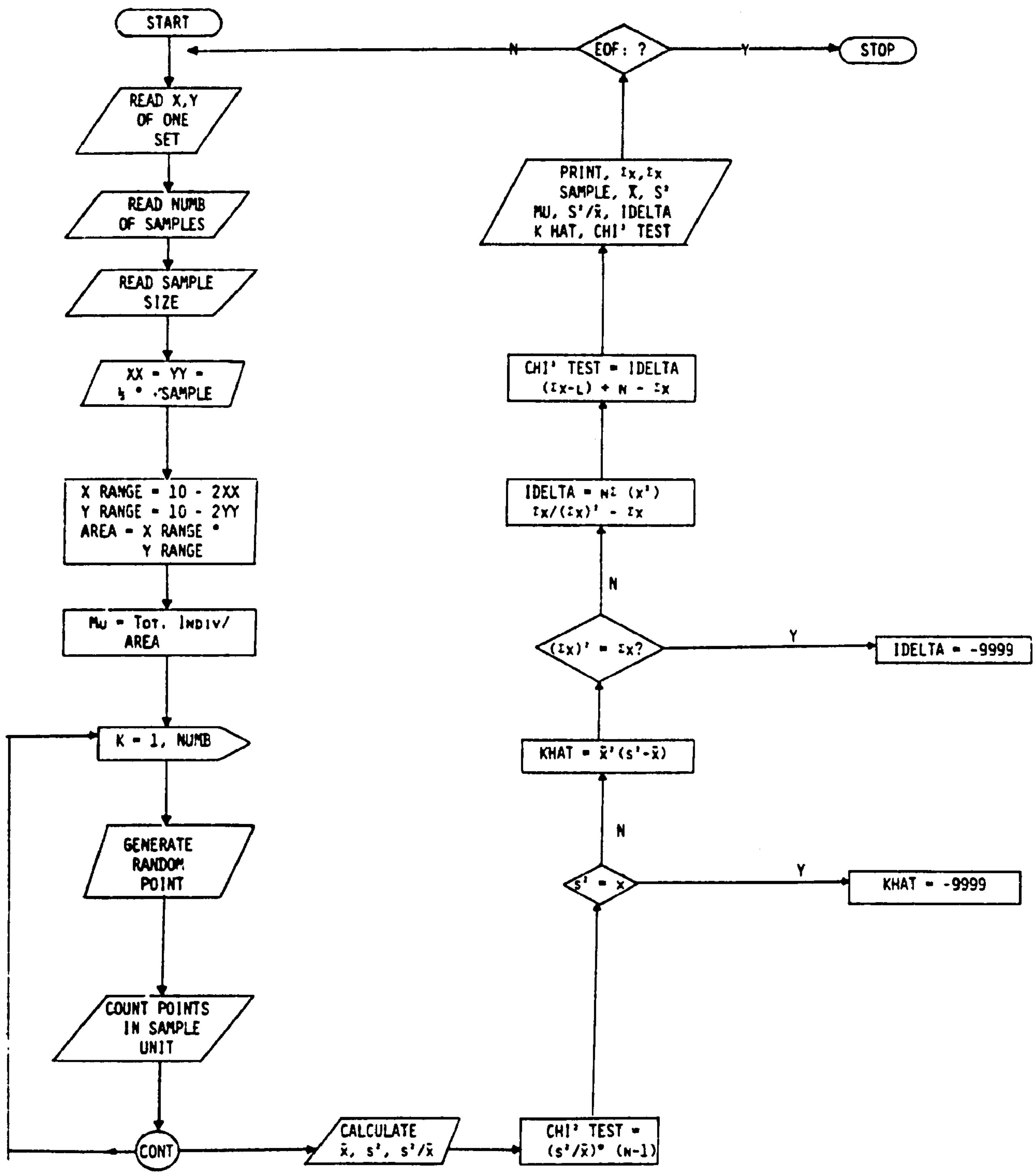

Figure 5A. The flow chart of quadrat count analysis.

Host Preference

Armyworm cultures were maintained by using natural food for the larvae. All larvae were obtained from adults which were collected in the field. The studies consisted of 3 parts: an oviposition test--to investigate the preference of adult moths in egg laying; a developmental growth test--to investigate the effect of different host plants to the growth and development of larva and pupa; and a food consumption test--to investigate the rate of food consumption of the armyworm on different host plants.

Oviposition Test

Barley (Larker cultivar), Downy (hairy leaf surface) wheat, Genesee (smooth leaf surface) wheat, oats (Clintland 64), corn (Dekalb XL 22B), and rye (Wheeler cultivar) were tested. Timothy (*Phleum pratense*), Brome Grass (*Bromus inermis*), and Quack Grass (*Agropyron repens*) were used in the first experiment, but later, due to poor seed germination, these plants were not used.

Three seedlings of test plants were sown in 1.5 inch Dixie cups. Different plants were set in 16 x 17 x 10" oviposition cages with nylon screen on three sides. Cups were arranged in the cage in randomized block design, with 3 replications for each entry. A pair of moths was released in the cage and fed with a solution of 1:10 of honey and water. The moths were given a free choice to mate and lay their eggs. The egg counts were done on the second day after oviposition began. The temperature in the rearing room was maintained at 70-73°F, with 50-60% relative humidity and 16 hours of light.

This test was conducted 4 times with a different composition of plants, number of cups and number of moths. The description of these experiments is presented in Table 4.

The Developmental Rates

Three newly hatched larvae were placed in a cup containing 3 host seedlings. A lantern globe was used as a cover for each cup, its top was closed by a nylon sleeve to allow for circulation of air inside the cage. Six small grains (i.e., Downey Wheat, Genesee Wheat, Barley, Rye, Corn and Oats) and two grasses (Timothy and Brome Grass) were tested. The plants were changed once every two days in the early instars and every day in the late instars.

Larvae were weighed twice, at 10 and 15 days, in the first experiment (from 2/10/76 to 3/30/76) and once at 13 days in the second experiment (4/5 to 5/15/76). Every day the stage of each individual was checked. Observation of larval instars was performed by measuring the width of the head capsule, using Gyppy's data (1969). The mortality of larvae for every plant was recorded. Pupae were weighed two days after the completion of pupation. The mortality of pupae was also recorded. The temperature in the rearing room was maintained around 70-75°F, with 50-60 relative humidity, and a 16 hour light cycle.

Food Consumption Rates

Ten newly hatched larvae were fed individually on each test plant. Leaves were taken from greenhouse seedlings of Barley, Genesee wheat, Downy wheat and oats. The individual larva and seedling leaves were put in 5-inch Dixie cup with a clear plastic cover. To maintain high

Table 4. Description of Four Oviposition Tests of the Armyworm at CLB Greenhouse

Experiment Number	Date	Number of Replication	Number of Pairs of Moth
A	2/4 - 2/11/76	6	2
B	2/21 - 3/2/76	5	2
C	2/9 - 2/1/76	3	6
D	2/13 - 2/23/76	4	6

humidity inside the cup and the freshness of leaves, a moist paper towel was used to cover a piece of wet cotton placed at the base of all leaves. Each day leaves, paper towel and cotton were checked and changed. The frass was cleaned from the cups, and the larval instars were checked by measuring the head capsule width, or by finding old head capsules.

Leaf consumption by the larva, was measured by determining the leaf surface area before and after feeding. Leaf surface area was measured by Licor Model LI-3000 Portable Area Meter. This meter utilizes an electronic method of rectangular approximation to measure the leaf surface. However, first and second instar larva feed by skelotinizing the leaf and their damage cannot be detected by the meter since light does not pass through the damaged areas. The damage by these instars was measured indirectly by taping each damaged leaf to a clear plastic sheet. The sheet was then photocopied, and the damaged areas were marked with a pencil then cut out. These cut out pieces were then run through the area meter.

The damage produced by the third to sixth instar forms clean holes or the entire leaf is eaten. The area meter could be used directly to measure total surface area consumed by the larva each day by obtaining the difference between the total area of leaves before and after being fed to the larva. Care was taken so that the amount of leaf tissue given each day was more than the larva needed for this period. Food consumption measurement was done from the first day the larva hatched to the prepupa stage.

Experiments on the Effect of Temperature on the Armyworm Development

Effect of Temperature to Oviposition

This study was done at the CLB greenhouse and the Natural Science Building from July to October 1977. The main objective of this study was to investigate the effect of constant temperature on the development of adult moths and their oviposition rate. The test was done in environmental chambers at the CLB greenhouse which were set at 15, 22.8, and 25°C. The light period was 16 hrs./day and the relative humidity was 50-60%. Two males and one female were placed in a 1 cb. ft. oviposition cage, and moths were fed with a 10:1 honey solution. Barley seedlings were used as an oviposition site. Three replications were used at each temperature.

In order to gain the effect of a wider range of temperatures, other oviposition tests were done at the Natural Science Building by using 5 "wooden growth chambers". These chambers are made out of wood and measured 24 x 24 x 18 inches. It was equipped with a heater, a fan, self-timer switch, and an automatic temperature controller. Five temperatures were set, they were 10, 12, 16, 30, and 32°C. The first three growth chambers were in the 50°F room, and the other two chambers, with temperatures of 30 and 32°C, were placed in the 70°F room. Only one oviposition cage could be put into the chamber. For every temperature the oviposition test was done three times. The test was stopped if two out of three moths were dead. Every day barley leaves were checked for eggs, and if eggs were found, the number was recorded.

Late Fall Development

Armyworm individuals of different instars were taken from the CLB greenhouse to the insectary on Collins Road. The insectary rearing program was started on August 15, 1977 and continued until November 5, 1977. Larvae were reared inside 16 x 16 x 16 inches nylon cage and fed with barley seedlings. In order to follow the instar development, ten new larvae were reared individually in 5-inch Dixie cups. The leaves in the cup were changed each day when the larvae were checked for instar development. The larvae were kept in the cup from September 9, 1977 until they were killed by the first frost on November 11, 1977.

Several days before the first frost, 200 larvae and pupae were placed on the ground and covered with grass to study the mortality effect of the first frost and probable winter mortality. Ten larvae or pupae were placed in 5-inch plastic cups which were filled with soil. Nylon screen was used to cover each cup to avoid the larvae moving out of the cup. One cup (10 individuals) of larva or pupa were checked the first day after the frost, and at two week periods in winter. The mortality of each instar was recorded every observation date.

Refrigeration Test

In order to study the ability of armyworm pupa to survive under a cold temperature, 250 pupae from the culture in the CLB greenhouse were kept in a refrigerator. The average temperature was 40°F, and the relative humidity was 50%.

The pupae were kept in the refrigerator for three and four months, starting from April 21, 1977 to July 21, 1977. The pupae were removed from the refrigerator and placed in the rearing cage at room temperature (73°F). The number of moths that emerged either normally and mulfunctionally were recorded. The dead pupae were removed and counted.

Supercooling Test

Larvae and pupae for the supercooling test were obtained from the greenhouse rearing program and Collins Road Insectary. The greenhouse specimens were kept at 40°F for 24 hours before testing, the insectary specimens were tested right away because they had been exposed to naturally falling temperatures. The test was done from October 18, 1977 to October 20, 1977.

The supercooling point is determined by placing the specimen on the bottom of a pit of an aluminum bar. The circular aluminum bar serves as a heating sink with a length of 16.5" and a diameter of 1.5". The well for the specimen is 1.8" deep and 0.8" diameter. Before a specimen was placed in the well, the well was lined with modelling clay to insure transfer of released body heat to the thermocouple. The thermocouple was attached to the base of a plastic plug. The plug was lowered in the well until the thermocouple touched the body of the test specimen. The thermocouples were attached to a Honeywell ® potentiometer to provide a continuous record of the test specimen body temperature. The bar was placed into a freezer chamber which contains a mixture of dry ice and ethyl alcohol 90%. The ambient temperature of the freezer could reach -70°F.

The temperature in the well dropped an average of 2.85°F per minute. Upon freezing, the larvae or pupae emitted heat of crystallization which was recorded as a sharp momentary increase in temperature. The lowest temperature reached prior to the increase was the supercooling point of that individual.

RESULTS AND DISCUSSION

Spatial Distribution of the Armyworm in Michigan

Regional Distribution

Since 1900 armyworm outbreaks have been scattered and localized, however, for the last 4 years (1975-1978) outbreaks have been more common and intensified (see Figures 6, 7, 8, and 9). The data for these figures was obtained from: 1) Insect Alerts*, 2) Pest Management Assistant, and 3) county agents.

In 1975, outbreaks population levels were restricted (with one exception) to the southwestern portion of the state (Figure 6); in 1976, 23 counties in the Lower Peninsula and one county in the Upper Peninsula (Figure 7); in 1977, only two counties (Figure 8) had outbreak populations. The year 1978 was considered to have the most severe outbreak of armyworm ever recorded in Michigan (see Figure 9).

In 1975 and 1976, most of the damage was reported from small grains (wheat, rye and oats). This was due to the rapid development of the armyworm, and placed the 5th and 6th instars in heading grain fields. In 1978, damage was reported in small grains but the crop most heavily damaged was corn.

---

*Insect Alerts is published by the Cooperative Extension Service of Michigan State University.

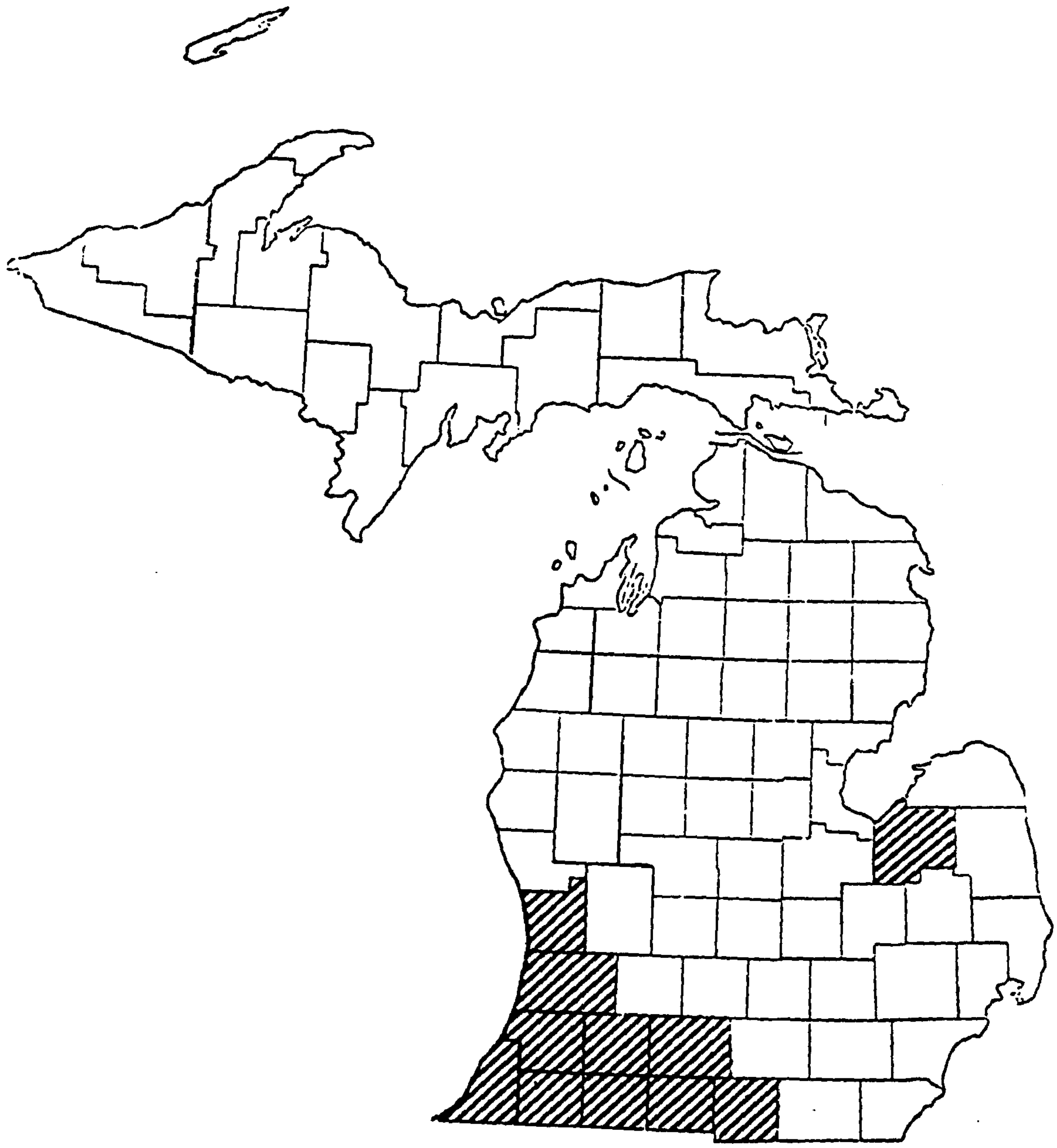

Figure 6. Distribution of armyworm outbreak--1975.

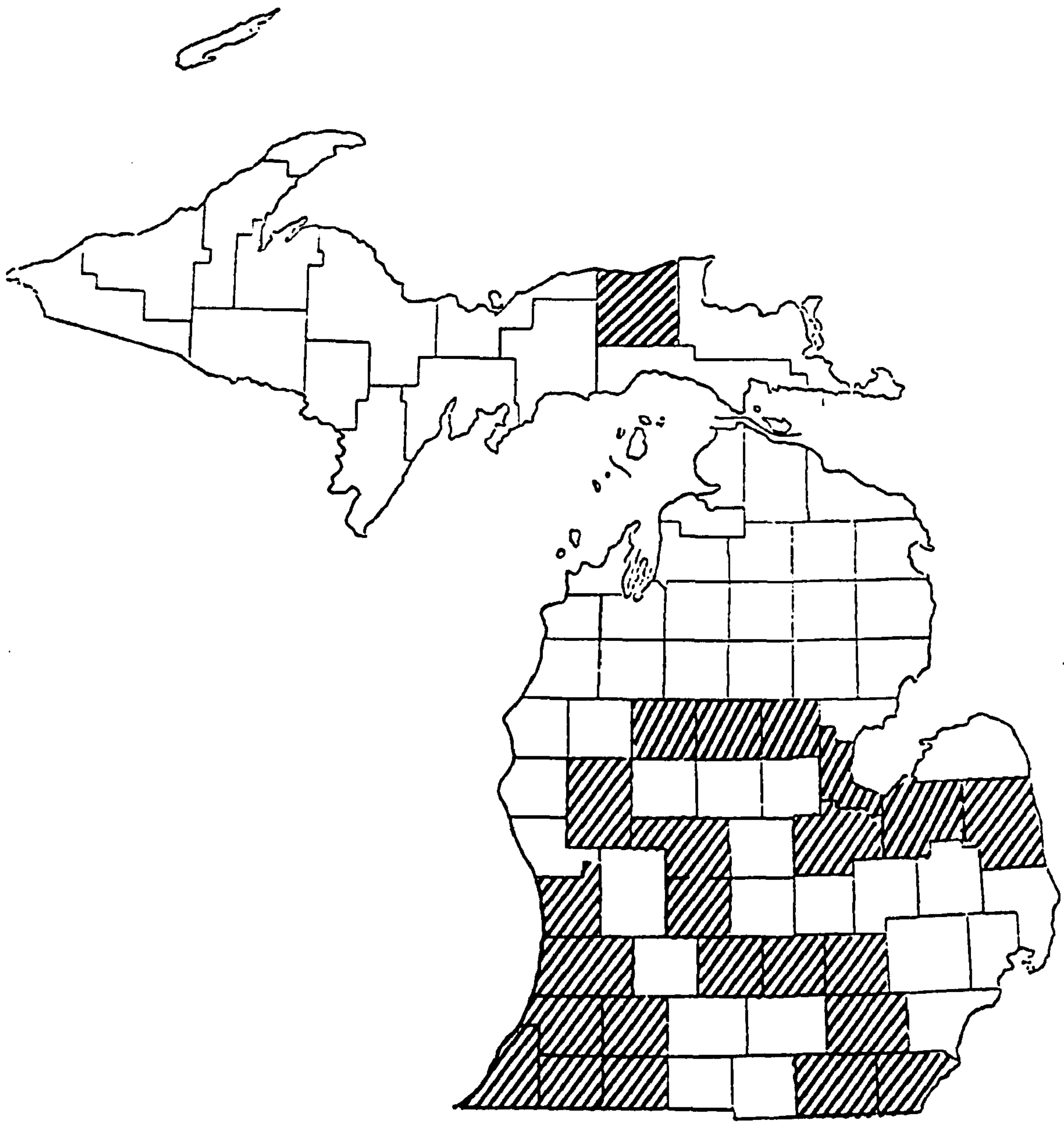

Figure 7. Distribution of armyworm outbreak--1976.

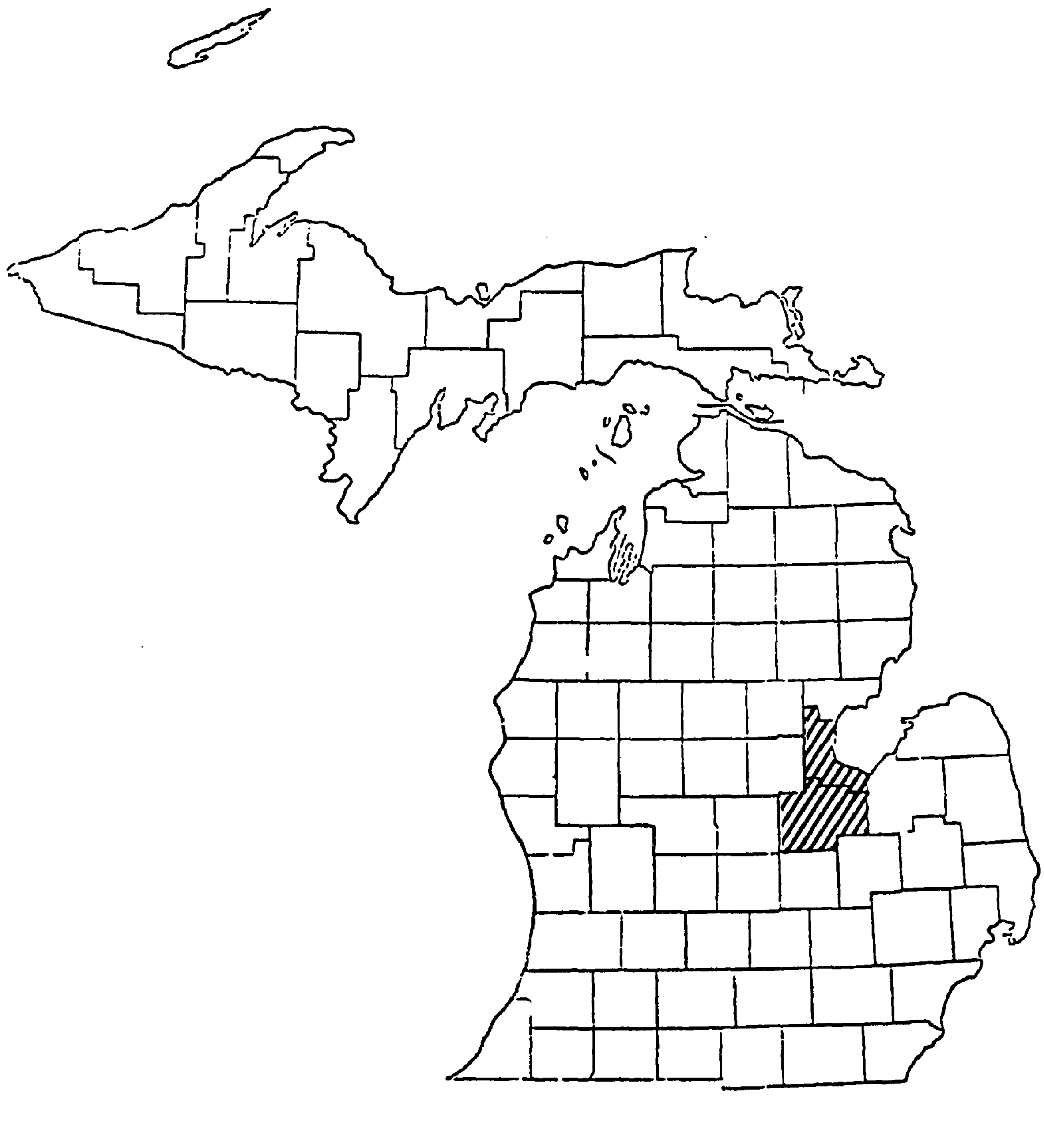

Figure 8. Distribution of armyworm outbreak--1977.

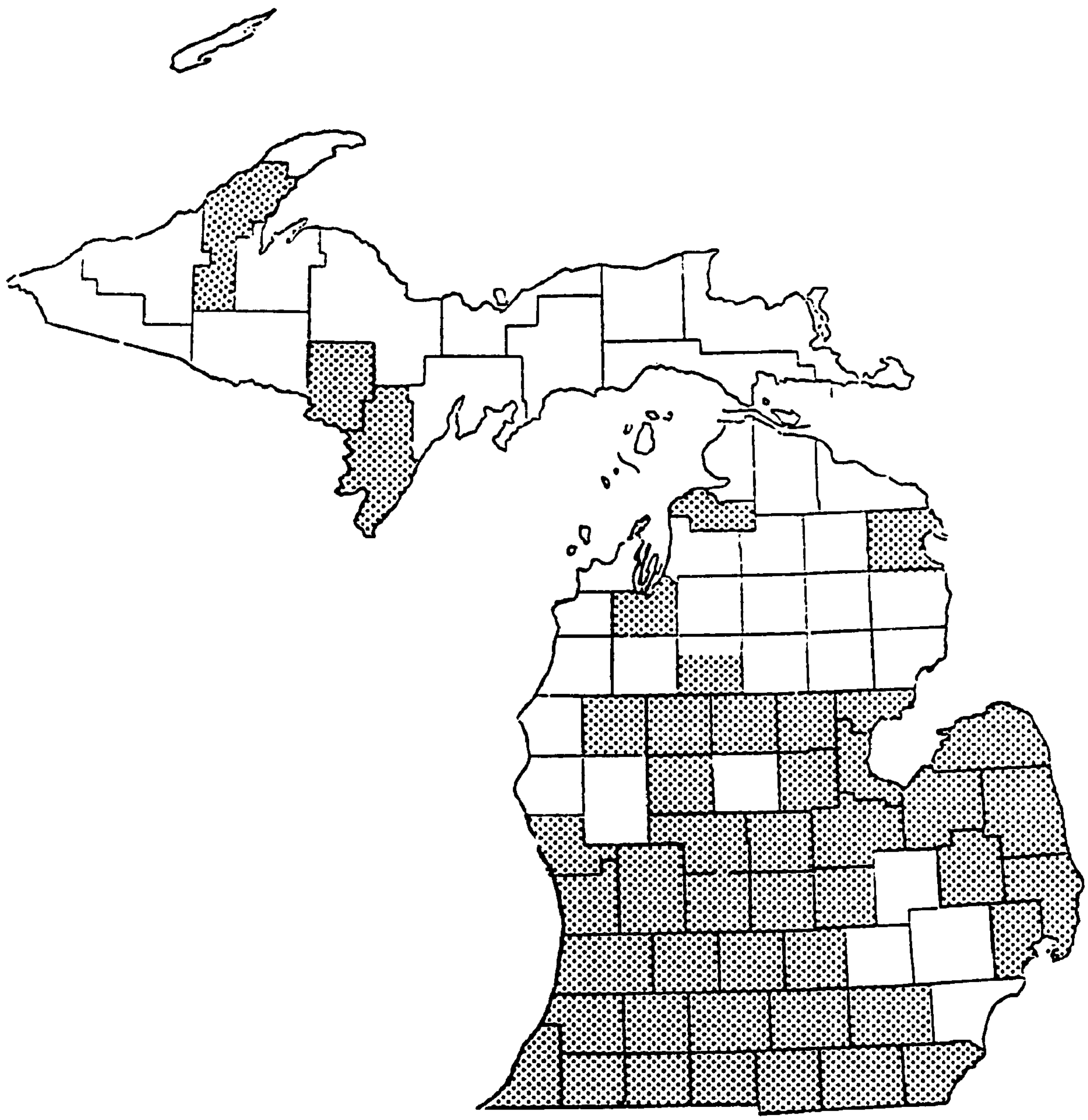

Figure 9. Distribution of armyworm outbreak--1978.

In 1978, the armyworm development was protracted due to the cool weather, therefore, larvae reached 5th and 6th instar when small grains were being harvested. These populations were forced to move from the grain to the adjacent corn fields. In the corn field two phenomena were observed: 1) the damage was apparently restricted to that part of the corn field bordering the grain field or grassy areas, and 2) the most severe damage occurred when grasses were well-established in the corn field.

Figures 10, 11, and 12 present the distribution of armyworm larva in wheat fields during the 1976 outbreak in Cass and Lenawee Counties. These maps are based on survey data collected by the author and a Pest Management Field Assistant. These figures show that there is a significant variation of larval density between fields.

Within and Between Field Distribution of Larvae

Table 5 summarizes the within field distribution study (see Materials and Methods, pp. 35-37). Analysis of the variance indicates that the difference between regions is highly significant, and there is no significance between samples within each region. This test indicates that the uniformity of the larval distribution in the field is only limited within a small area. This seems to be related to the uniformity of plants within the field. The denser and taller the plants are in a certain area, the higher the density of larvae. The availability of shade during the day appears to be the main factor resulting in a higher density of larvae in any particular location.

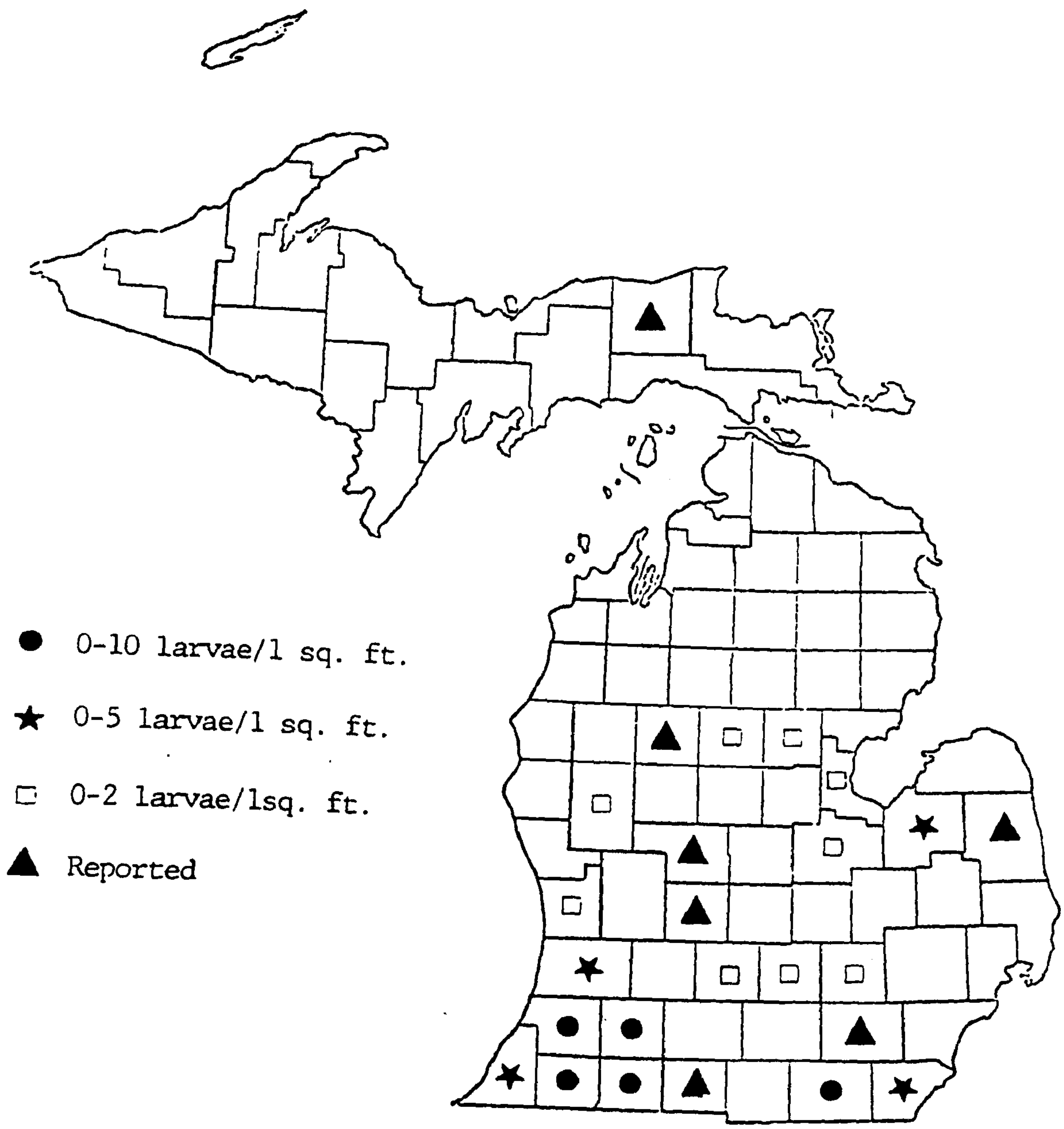

Figure 10. Armyworm larvae distribution in wheat fields (1976).

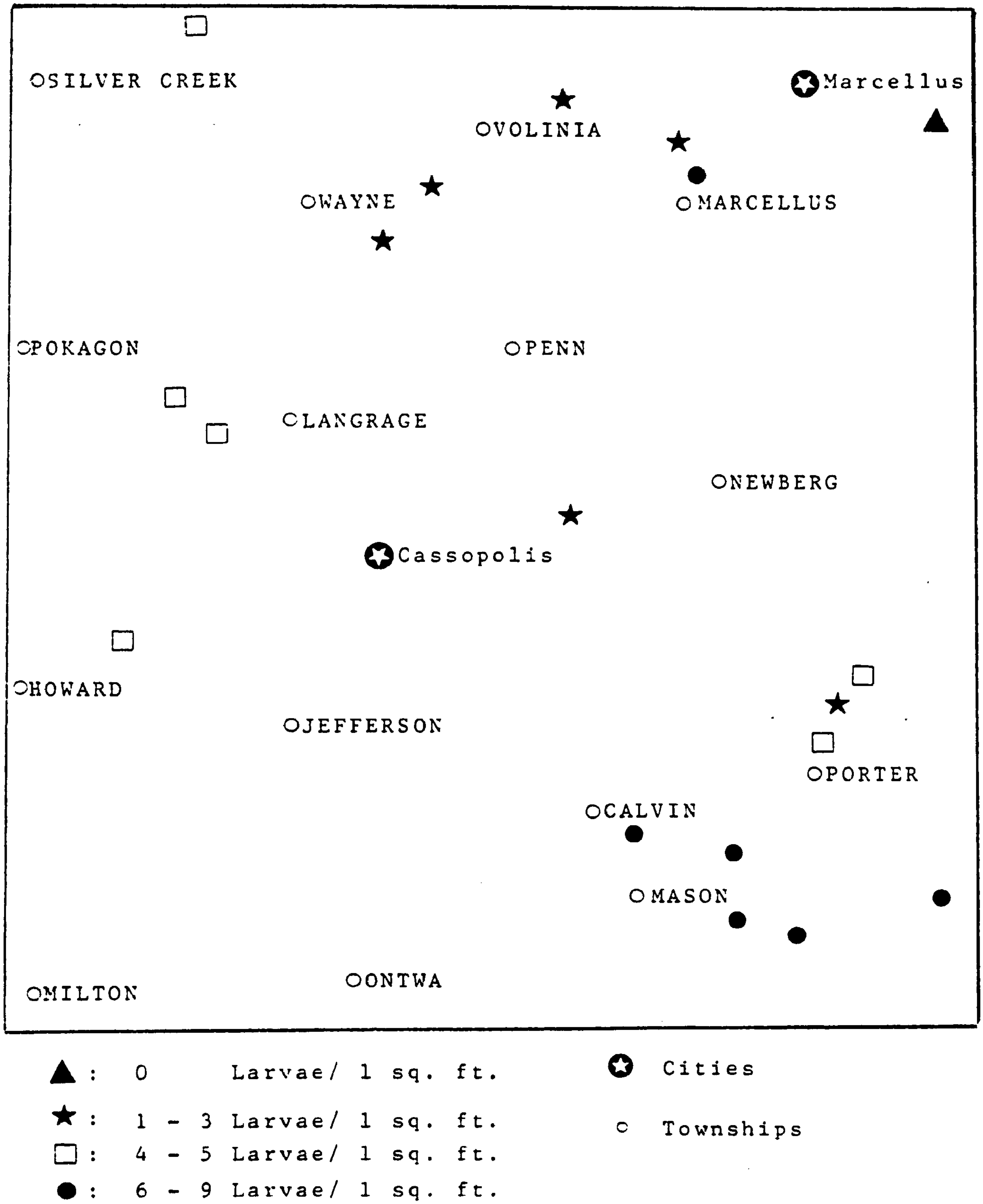

Figure 11. Armyworm larvae distribution in Cass County wheat fields (1976).

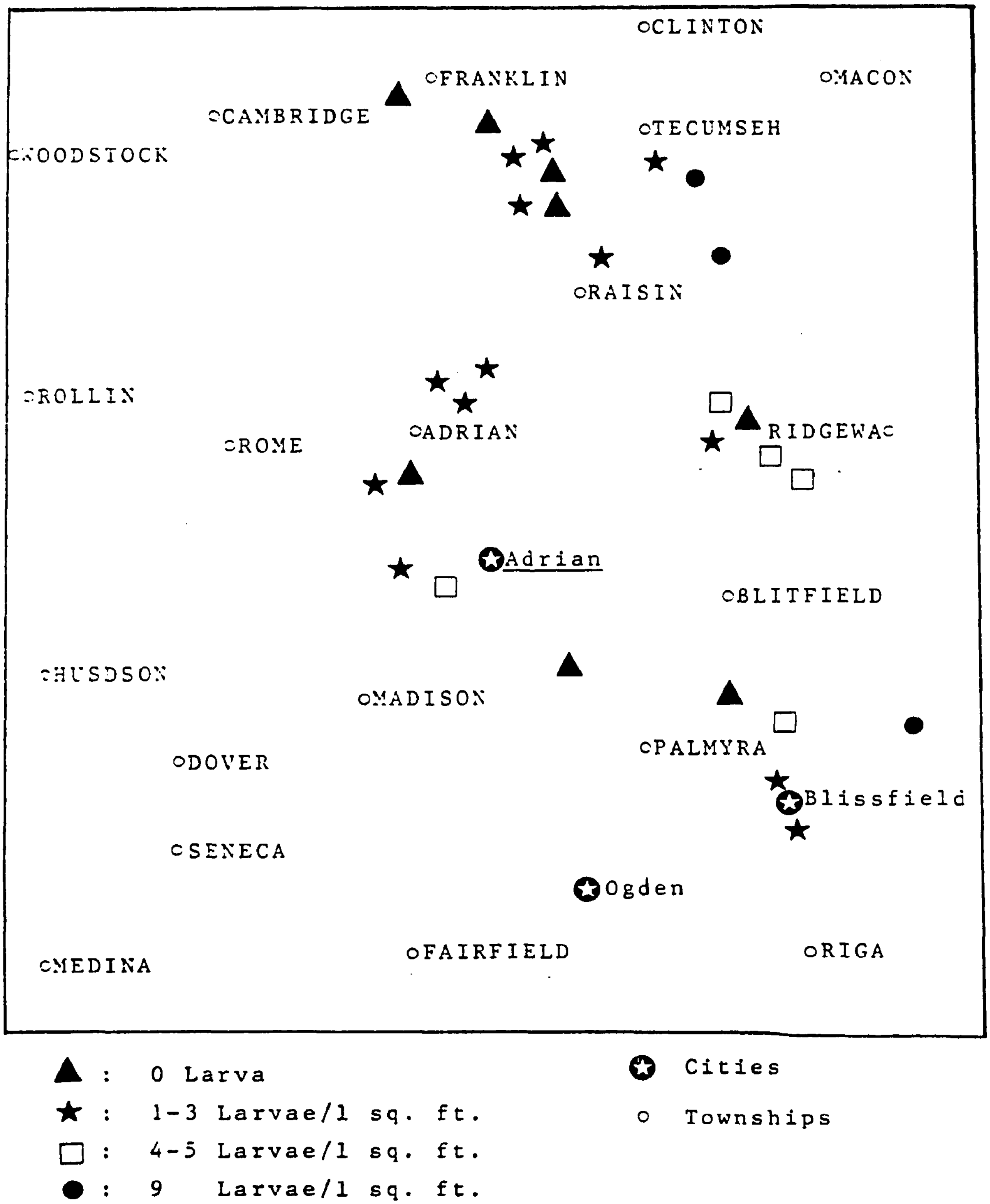

Figure 12. Armyworm larvae distribution in Lenawee County wheat fields (1976).

Table 5. Total of Armyworm Larvae in Five Sample Regions of the Wheat Field (Cass County, 1976).

Regions	Sample Numbers 1	2	3	4	5	Total
A	15	11	9	14	15	64
B	4	5	3	9	7	28
C	2	2	3	5	8	20
D	14	15	23	15	17	84
E	13	21	14	14	13	75
Total	48	54	52	57	60	

Table 6 summarizes the between field distribution study (see Materials and Methods, p. 37). Analysis of variance test for a completely randomized plant design was utilized to interpret the data in Table 5. The test indicates that the density of the armyworm larvae between fields is significantly different.

Seasonal Appearance of the Armyworm in Michigan

In order to better understand the armyworm phenology, continuous and intensive observations must be carried out over a large geographical area. This is complicated due to the distribution of the insect and the difficulty of detection of certain life stages (adults, eggs, and L-1 and L-2 instars).

During two years of field observations, the author was only able to collect and locate late instars of the first and second generations. No eggs and early instars were found. Third generation populations were monitored in Fall 1976 and Fall 1977, but no larva or pupa were found.

By assuming that the development of the armyworm in the southern lower peninsula of Michigan is uniform, several methods were utilized to interpret seasonal development of the armyworm.

Spring Emergence

Few armyworm larvae were collected from grassy areas near Mason (Ingham Co.), Gull Lake (Kalamazoo Co.), and Marcellus (Cass Co.) in mid-April, 1977. Most of the early collected larvae were 4th and 5th instar. Thirty-five emergence traps were set out in Cass County to

Table 6. Armyworm Density in Wheat Fields in Cass and Ingham Counties (June 1976)

County/Field Number	Number of Samples 1	2	3	4	5	Total
Cass County						
1	5	10	8	6	7	36
2	2	0	3	1	3	9
3	1	3	0	1	1	6
4	0	0	0	1	1	2
5	9	11	7	8	11	46
6	7	8	10	9	11	45
7	2	2	3	0	1	8
8	3	5	2	5	4	19
Ingham County						
1	2	1	1	2	1	7
2	0	2	1	1	3	7
3	0	1	1	2	0	4
4	1	3	3	2	3	11

to collect emerging moths. Two traps caught one moth each on May 20, 1977. This indicates that the armyworm does overwinter in Michigan, and it seems that they overwinter as 3rd or 4th instar larvae. Even though this investigation does not provide sufficient information about overwintering conditions, it clarifies the uncertainty about the ability of the armyworm to survive during Michigan winters.

Field Occurrence of Armyworm Stages in 1976

In 1976 armyworm larvae were abundant in the first and second generation. The 3rd and 4th instar larvae were first found in Lenawee and Van Buren Counties during the second week of June, while the 5th and 6th instars were abundant in Cass County and other southern counties in late June. Pupae were collected at the end of June and the beginning of July. The 3rd and 4th instar larvae of the second generation were collected from hay/alfalfa fields at the end of July, and the 5th and 6th instar were observed in asparagus fields in Cass County about the middle of August. The moths peak appearance in Cass County light-traps was at the end of July, and another small peak occurred at the beginning of September.

Figure 13 was constructed from the records of degree-day accumulation in Cass County and the field occurrence of armyworms. In this figure the first occurrence of adults was obtained from the data of black-light catches in Lenawee County. This figure clearly indicates that the "distance" between the field occurrence of one instar in one generation and the following generation is around 1300-1400 degree-days accumulation. This conforms to Table 7. The developmental data of

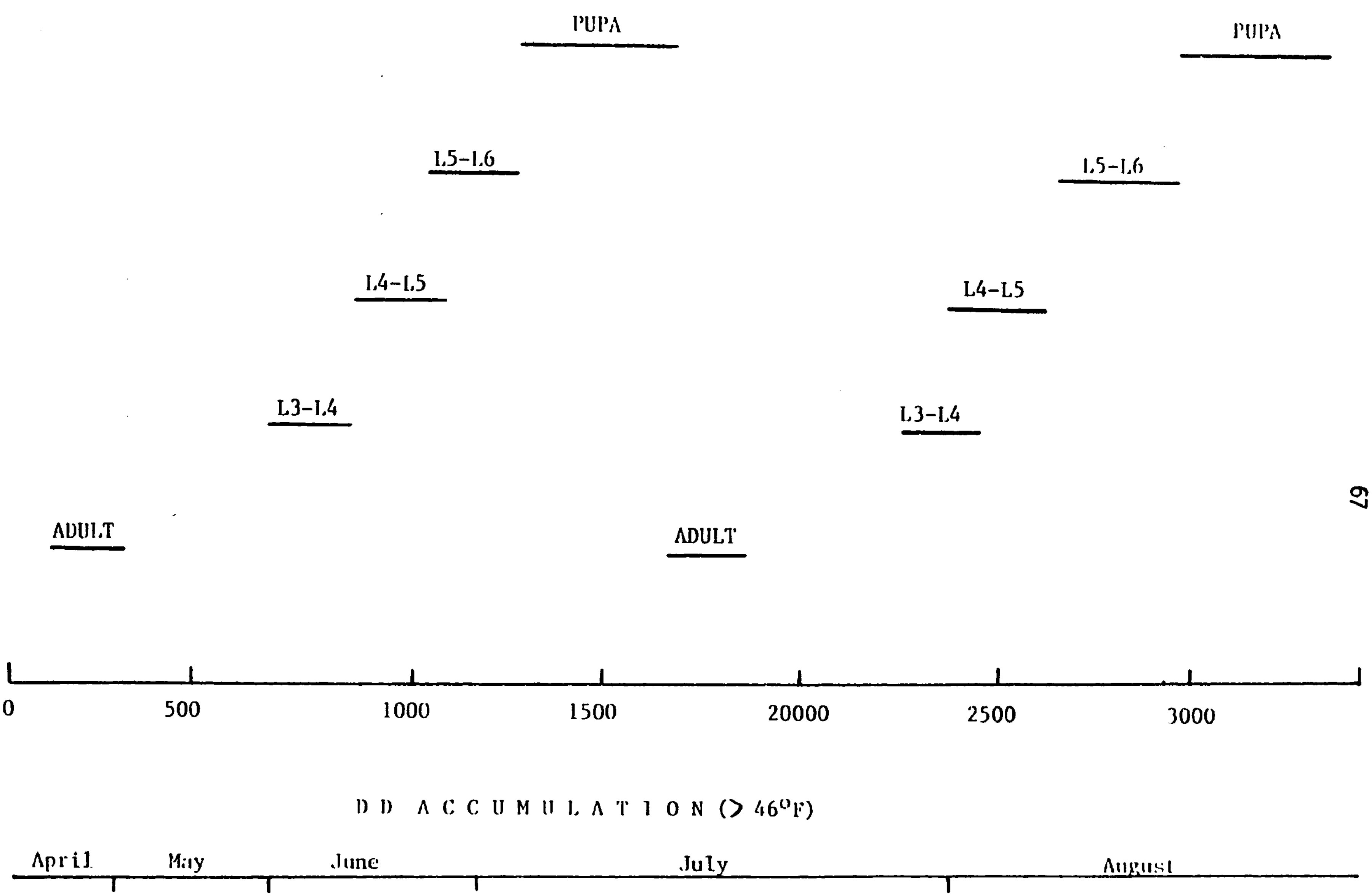

Figure 13. Field occurrence of armyworm stages in Southern Michigan, 1976.

Table 7. Degree-days Requirement for the Development of Armyworm Instars (Base = 46°F)

Instar	DD Required to Complete Instar's Development	DD Accumulation for Completion of Instar's Development
Egg	156	156
Larva 1	107	263
Larva 2	72	335
Larva 3	76	411
Larva 4	86	497
Larva 5	106	603
Larva 6	223	826
Pupa	390	1216
Preov-adult	214	1430

Guppy (1969) was used to calculate degree-days accumulation needed by each instar at base 8°C. The table shows that the armyworm takes approximately 1400 degree-days to develop from one stage to the same stage in the next generation. This inference explains that Table 7 can be used as a rough estimator of the appearance of armyworm instars in the field. The seasonal occurrence information, therefore, could be used to validate a simulation model of the armyworm eco-system.

Black-light Data Interpretation

Using black-light traps to monitor insects (especially Lepidoptera) has been a common practice of the Cooperative Extension Service for many years. The function of black-light data is to provide a rough estimate about the occurrence and abundance of insect adults and for identifying pest species which could damage crops.

Black-light data is always biased. This is due to many factors such as: 1) the location and elevation of the station; 2) amount of light surrounding the trap; 3) the intensity of light; 4) type of trap; 5) different attractiveness to the light by both sexes; and 6) weather conditions.

Black-light records from Michigan and other states indicates that these traps consistently captured armyworm moths. As an example, Figures 14 and 15 show the fluctuations of armyworm catches in Lenawee, Cass and Bay Counties in 1976 (Cass County black-light was started in the middle of the season). The physiological date (with Base Temp. = 46°F) is used as the X-axis, and the number of moths caught per degree-day is used as the Y-axis. Accumulation of degree-days from January 1

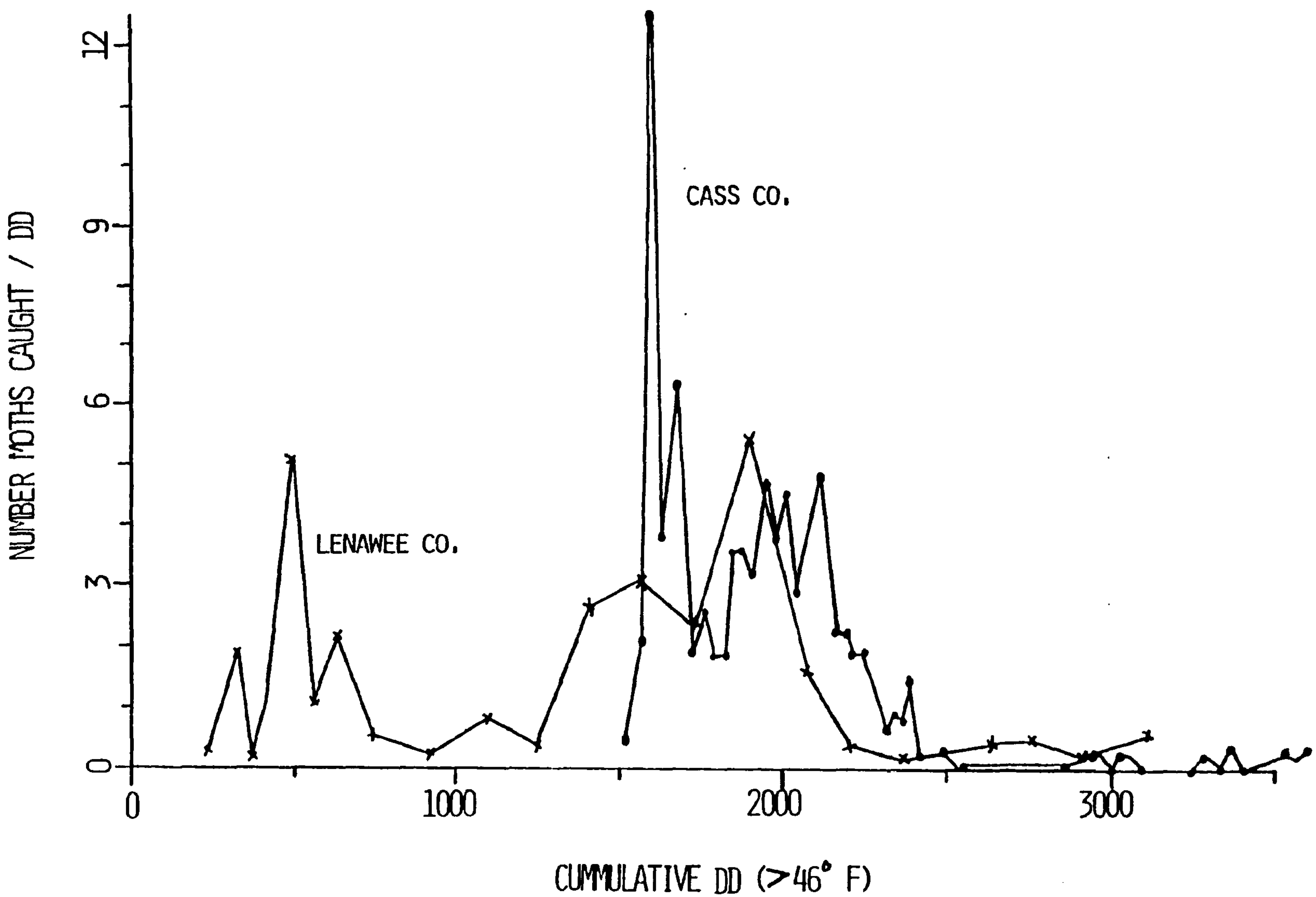

Figure 14. Number of armyworm moths caught in the black-light traps in Cass and Lenawee Counties 1976.

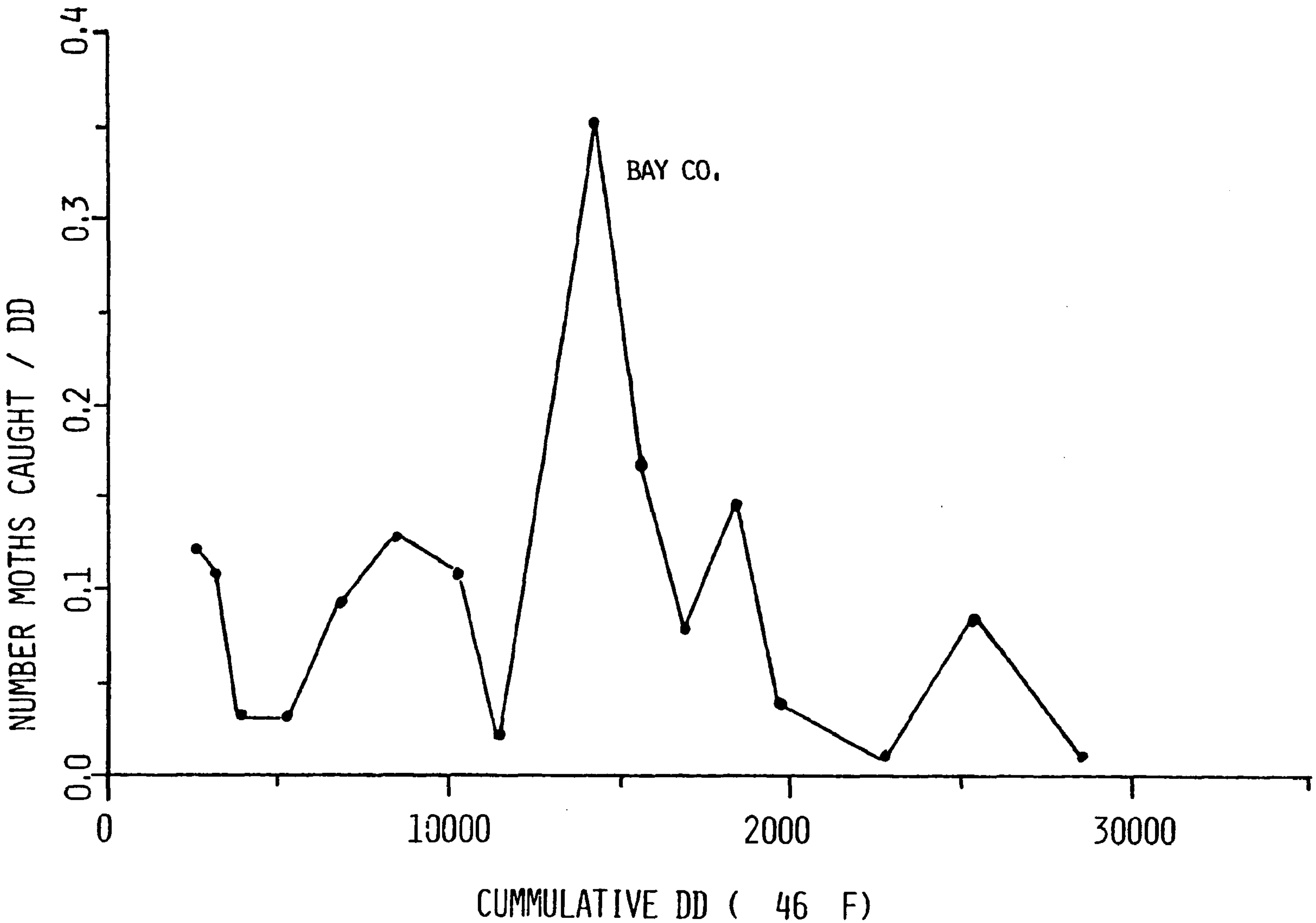

Figure 15. Number of armyworm moths caught in the black-light trap in Bay County 1976.

to October 1, 1976, in Lenawee, Cass, and Bay Counties are listed in Appendix .

Even though there is an obvious differential moth catch between locations, they have a similar trend; namely, that in one year there are more than 5 distinct peaks of armyworm moth flight activity. This could be due to, 1) a continuous adult emergence in one region throughout the season, and 2) imigrations of moths from southern areas which have already completed the development. A continuous observation of the armyworm development at a controlled temperature indicate that the development of individuals in a population is nearly uniform, therefore, this makes the first possibility doubtful.

It seems that armyworm moths in Michigan are coming from two sources: 1) a native population that emerges from a local overwintering population; and 2) populations that were moved or carried by the wind from southern states. The first flight peak (at approximately 200 DD accumulation) is the migrating population, and the second peak is the native population. The migrating population may have caused the outbreak in 1976.

Spatial Distribution Study

Wheat, 1976

Variance/mean ratio is used as an index of dispersion. Table 8 indicates that as the sample size increases the distribution moves from random towards a more aggregated population.

Table 8. Distribution of Armyworm Larvae in Quadrat Units of a Wheat Field (Cass County, 1976)

Sample Unit	Number of Samples	$\bar{x}$	s^2	$s^2/\bar{x}$	Chi Square	Distribution
1 sq. ft.	5	11.00	6.00	.56	2.18	Random
4 sq. ft.	5	38.4	92.74	2.15	9.66	Random
1 sq. yd.	3	134.0	1338.82	9.99	29.97	Aggregate

The relationship between the mean and variance of the larval count in one square foot is presented by Table 9 and Figure 16. Table 9 shows that all data is in agreement with the Poisson series or random distribution, (X^2 = 9.49 for P = .05). Even though statistically the table does not show a significant difference from a regular distribution, some fields indicate a tendency toward a regularity. The regularity of the distribution in wheat fields is likely to be caused by the behaviour of the larvae. In the daytime the larvae are not active, and can be found in protected areas. The most suitable hiding place is in the plant crown. High larval density causes the insects to move away from each other, and occupy empty crowns. Territorial behaviour produces a uniform distribution of individuals over a small unit area. As the unit area increases the influence of territoriality decreases.

Wheat, 1977

Figures 17 and 18 show the distribution maps of armyworm larvae in the wheat field in Cass County. It is obvious that due to the low density, the larval distribution was random.

Asparagus and Crabgrass, 1976-1977

Figures 19, 20, and 21 are three examples of the distribution of larvae and plants in the sample plots. These figures show that the distribution of the armyworm larvae was aggregated, to some extent, throughout the field. These clumps were the result of the nocturnal behaviour of the larvae. Most of the larvae were found under crabgrass. This grass offered protection during the daylight hours, and was a ready

Table 9. Relationship Between Mean and Variance of Larval Density in a One Square Foot Sample of Wheat Fields in Cass and Ingham Counties, 1976

Number	$\bar{x}$	s^2	$s^2/\bar{x}$	Chi Squared	Distribution
1	11.00	6.00	.55	2.18	Poisson
2	5.60	5.81	1.04	4.15	Poisson
3	12.80	7.18	.56	2.24	Poisson
4	16.80	13.18	.78	3.14	Poisson
5	15.00	11.49	.77	3.06	Poisson
6	4.00	6.50	1.63	6.50	Poisson
7	1.40	.80	.21	2.29	Poisson
8	1.40	1.30	1.30	3.71	Poisson
9	.80	.70	.87	3.50	Poisson
10	7.20	3.69	.51	2.05	Poisson
11	1.80	1.69	.94	3.76	Poisson
12	1.20	1.21	1.01	4.03	Poisson
13	.40	.30	.75	3.00	Poisson
14	9.20	3.17	.34	1.38	Poisson
15	9.00	2.50	.28	1.11	Poisson
16	1.60	1.30	.81	3.25	Poisson
17	3.80	1.14	.30	1.20	Poisson
18	1.40	.30	.21	.86	Poisson
19	1.40	1.30	.93	3.71	Poisson
20	.80	.71	.85	3.55	Poisson
21	2.20	.70	.32	1.27	Poisson

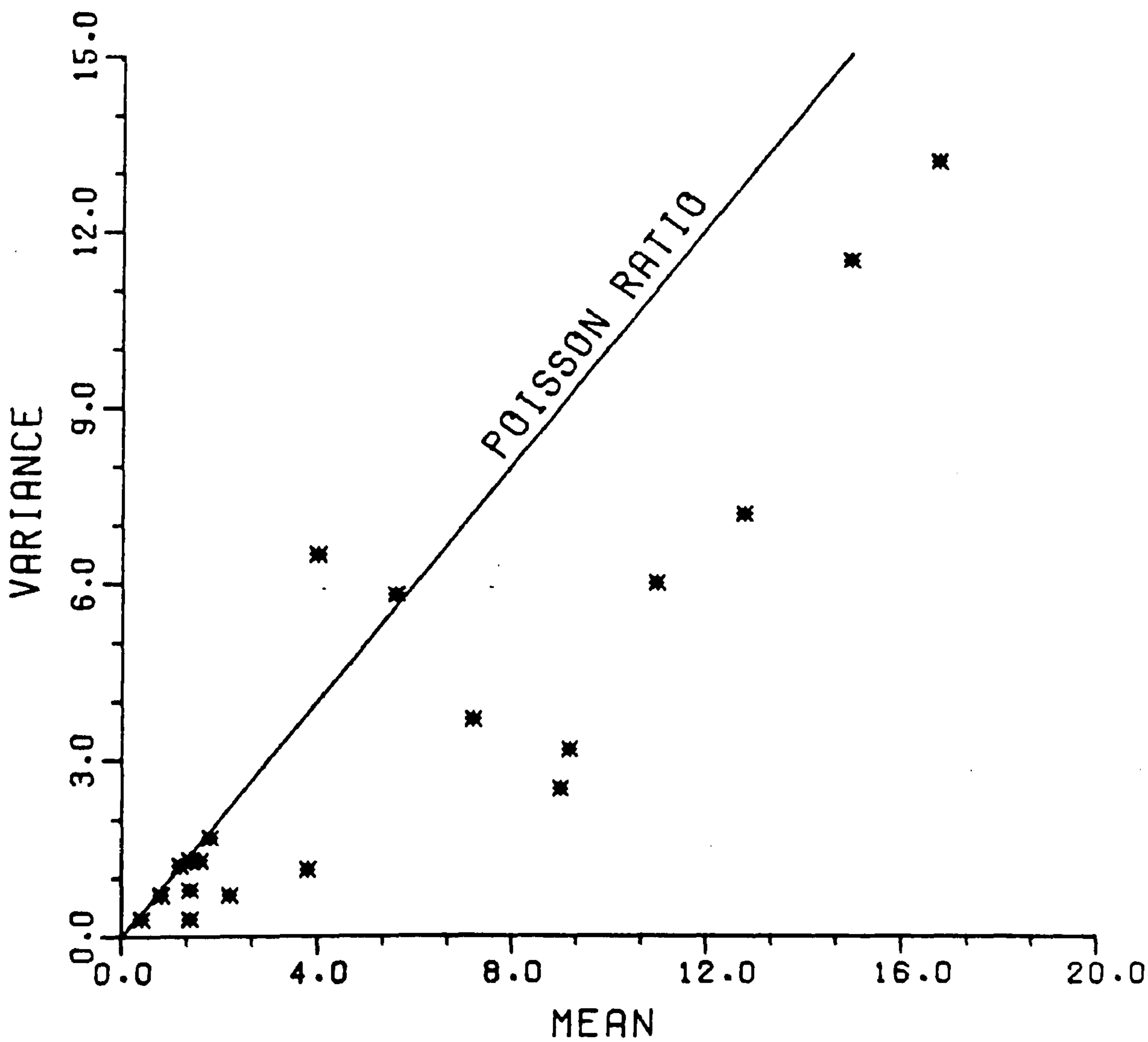

Figure 16. Variance/Mean ratio of armyworm larvae in 1 sq. ft. sample in a wheat field.

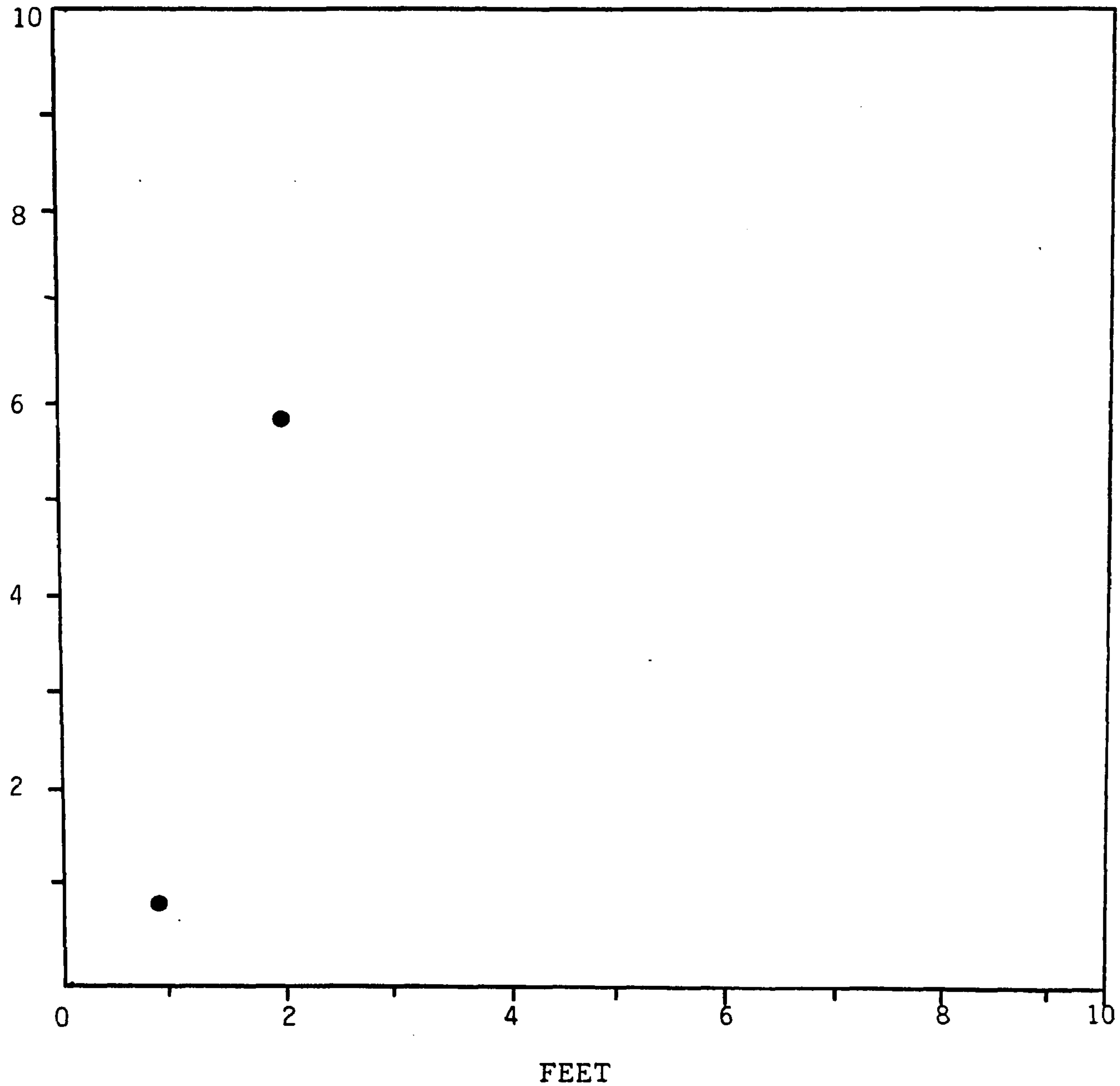

Figure 17. Distribution of armyworm larvae in a wheat field in Cass County, May 24, 1977.

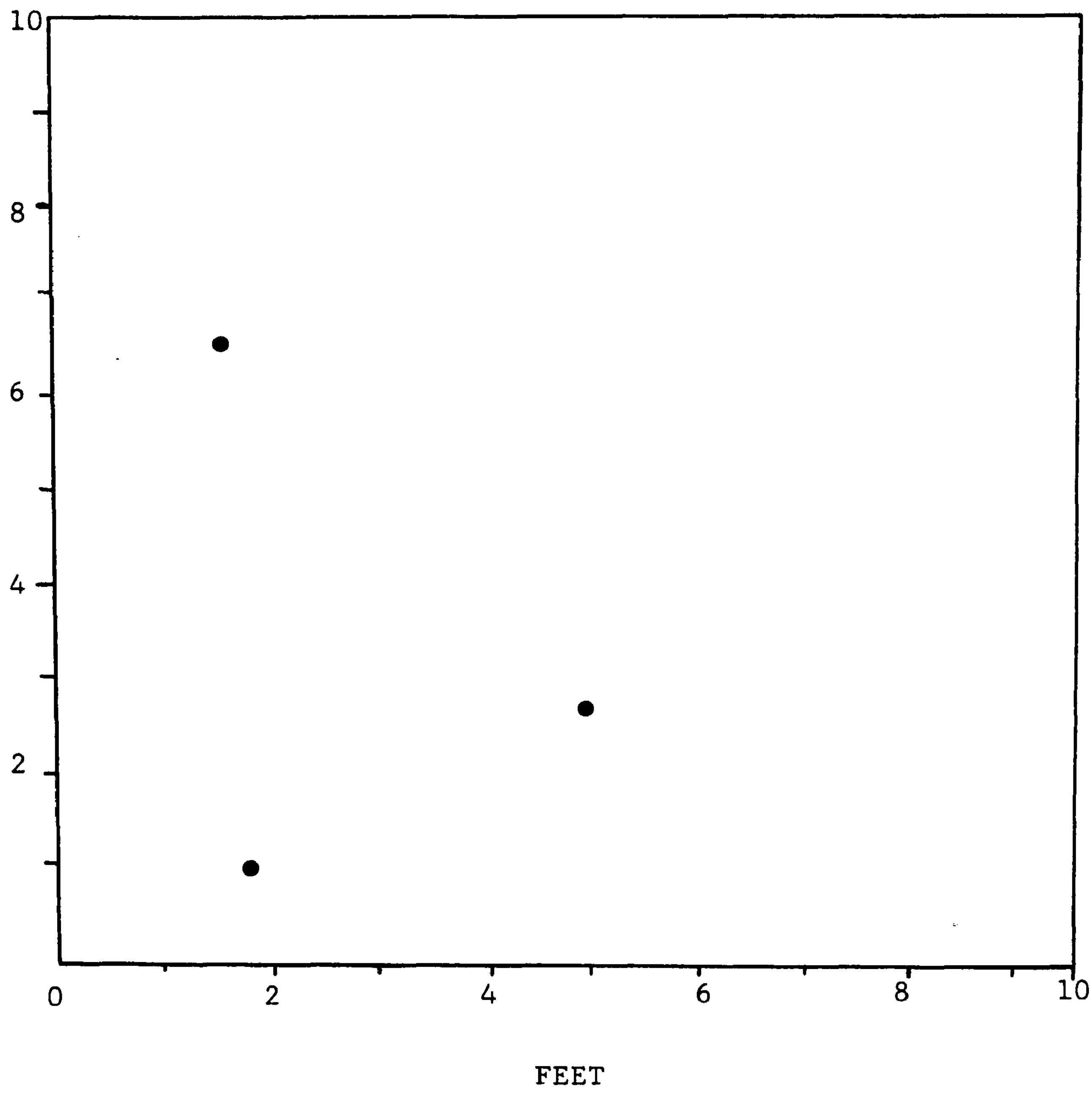

Figure 18. Distribution of armyworm larvae in a wheat field in Cass County, June 10, 1977.

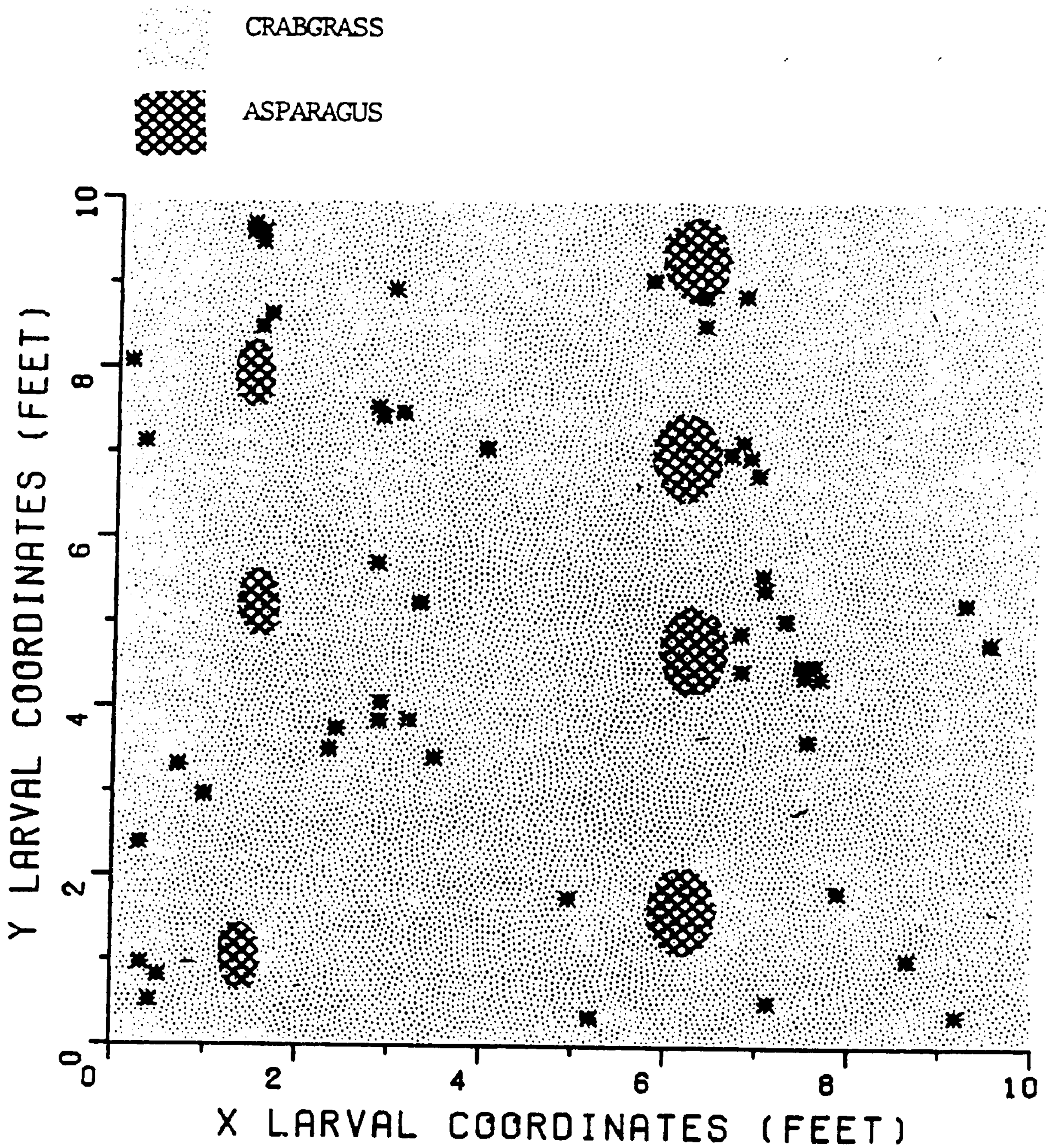

Figure 19. Distribution of armyworm larvae and plants in an asparagus field (field 111-3).

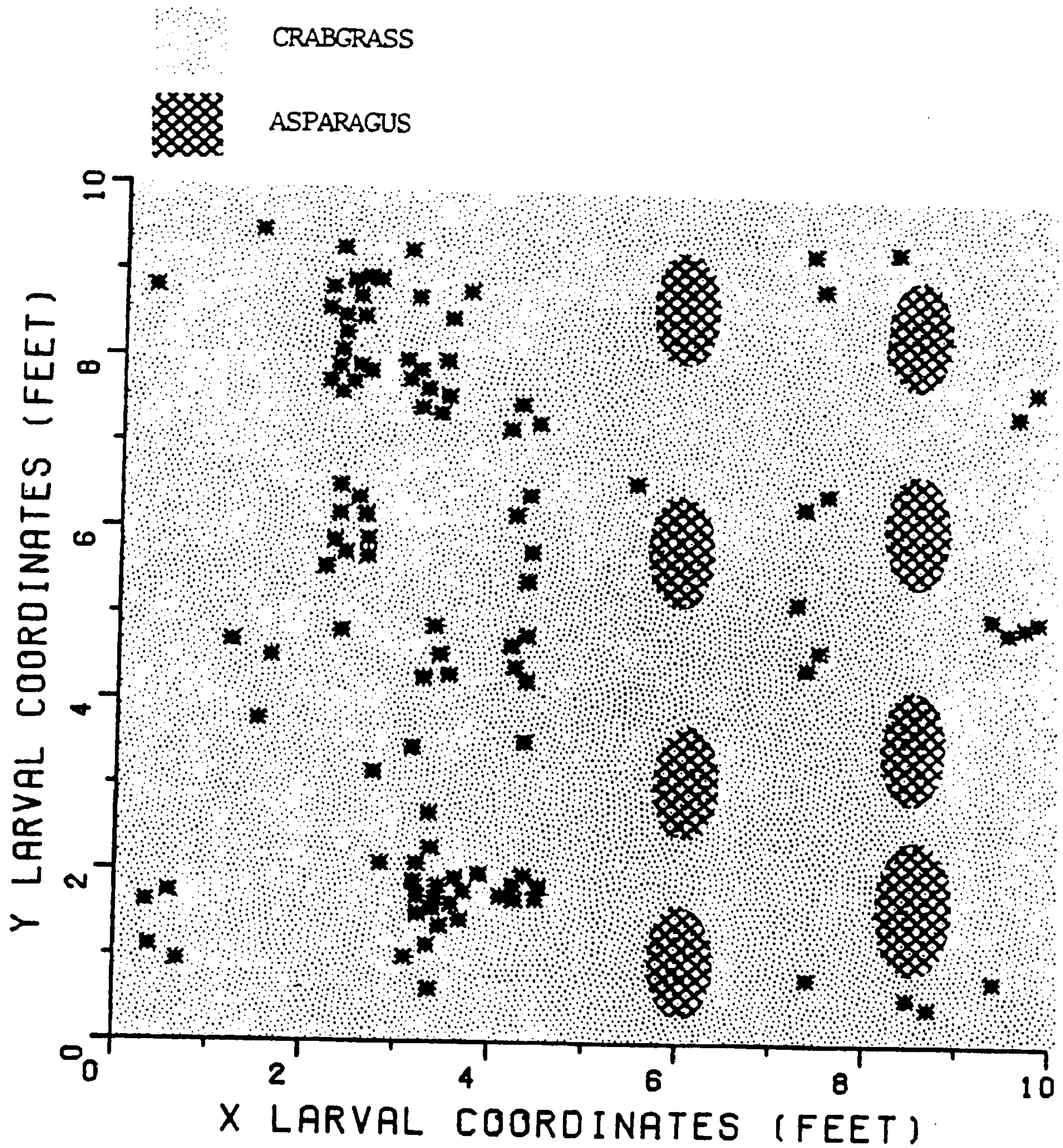

Figure 20. Distribution of armyworm larvae and plants in an asparagus field (field 333-1).

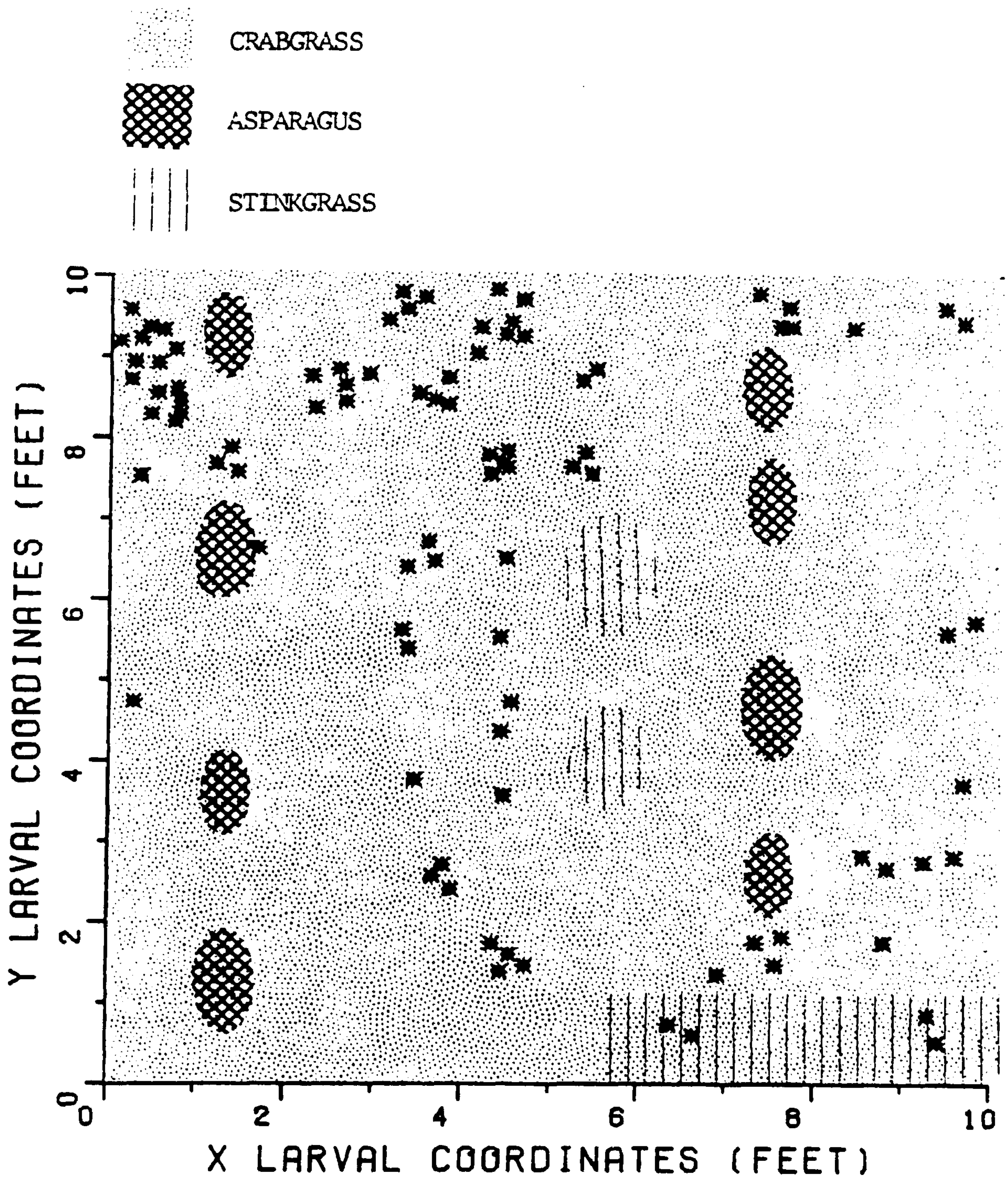

Figure 21. Distribution of armyworm larvae and plants in an asparagus field (field 444-1).

food source for the foraging larvae. Very few larvae were found under stinkgrass and asparagus because they did not provide adequate protection and were not a preferred host.

Two computer programs were developed for analyzing distribution of the armyworm larvae in a 10 x 10 sq. ft. plot. They provide unlimited possibilities of studying sampling characters, which would have been difficult to perform in a field experiment. Effects of unit sizes, unit shapes, the number of samples, etc., to the final result were easily derived from the program. The program provided the best estimate of variance of population for any desired sample units. All larval distribution data from asparagus and crabgrass fields is presented in Appendix C.

Nearest Neighbor Analysis

The distance from one individual to another provides a variable for a measurement of spacing, that obviates the use of quadrats and, therefore, eliminates that effect of quadrat size. The result of the nearest neighbor analysis was utilized as a "standard" in comparing and discussing the results of quadrat count analysis.

Output of nearest neighbor analysis from all fields are presented in Appendix E. A number of distance measurements (N) range from 5 to 200, depending on the density of the plot. The program stopped executing data when N was higher than the number of individuals. Column C (Appendix E) is the test of significance of the departure from randomness.

The weakness of this method is in selecting individuals at random to measure distances. If the random points are within clumps, the R value will be smaller than if random points are between clumps. Table 10 presents the effect of a number of distance measurements (N) and the value of R. The table shows that R becomes more stable if N is closer to the number of individuals. The larger the N the greater the accuracy of the derived distribution type, because more nearest neighbor are measured and random effects are reduced.

Table 11 is an expanded version of Table 10. Instead of R values, the conclusion about the distribution pattern for each field and each N is listed. The last column for every field is the actual distribution pattern for a given population. Table 11 also shows that most of the field data renders a clumped distribution of individuals, independent from the density and time of observation.

Spatial and Temporal Effect on Larval Distribution

Table 12 is the list of R values of different observations in 1976 (summarized from Appendix A). The table shows that the difference of individual patterns between dates and plots are not significant. It seems that the difference of distribution patterns are due to random factors.

The 1977 data shows a change in individual patterns (Table 11). High density indicates a clumped distribution and low density indicates a random distribution. The random characters of the late larvae and pupae were probably due to random mortality factors.

Table 10. Effect of N to the Values of R of Selected Fields

Field	Number of Distance Measurements (N)									
	5	10	20	30	40	50	100	125	150	200
333-1	.81	.75	.94	.49	.62	.63	.63	-	-	-
333-2	.33	.68	.39	.34	.58	.58	.41	-	-	-
444-1	.49	.60	.80	.50	.64	.63	-	-	-	-
111-3	.61	.84	.78	.67	.69	.68	-	-	-	-
555-1	1.16	.78	1.02	.71	.78	.92	.76	.87	.83	.91

Table 11. Nearest Neighbor Analysis of Asparagus Field Data (Cass County, 1976 and 1977)

Field	Date	Density	Number of Distance Measurements (N)										
			5	10	20	30	40	50	75	100	125	150	200
Data 1976													
333-1	8- 9-76	110	R	R	R	C	C	C	C	C	-	-	-
444-1	8- 9-76	93	C	C	R	C	C	C	C	-	-	-	-
333-2	8-12-76	115	C	R	C	C	C	C	C	C	-	-	-
444-2	8-12-76	29	C	C	R	-	-	-	-	-	-	-	-
111-1	8-12-76	14	C	C	-	-	-	-	-	-	-	-	-
222-1	8-12-76	12	R	C	-	-	-	-	-	-	-	-	-
444-3	8-17-76	25	C	R	C	-	-	-	-	-	-	-	-
444-4	8-17-76	17	C	R	-	-	-	-	-	-	-	-	-
111-2	8-17-76	23	R	C	R	-	-	-	-	-	-	-	-
222-2	8-17-76	7	R	-	-	-	-	-	-	-	-	-	-
333-3	8-23-76	29	R	R	R	-	-	-	-	-	-	-	-
111-3	8-29-76	53	R	R	R	C	C	C	-	-	-	-	-
222-3	8-29-76	13	R	RG	-	-	-	-	-	-	-	-	-
333-4	8-29-76	22	R	R	R	-	-	-	-	-	-	-	-
444-5	8-29-76	36	R	R	C	C	-	-	-	-	-	-	-
Data 1977													
555-1	7-29-77	266	R	R	R	C	C	R	R	C	C	C	C
555-2	8- 5-77	54	R	R	R	R	R	C	-	-	-	-	-
555-3	8-12-77	25	R	R	R	-	-	-	-	-	-	-	-
555-4 (Pupa)	8-16-77	16	R	R	-	-	-	-	-	-	-	-	-

R = random distribution; C = clumped distribution; RG = regular distribution.

Table 12. R Values of Different Dates of Observation and Fields/Plots of Armyworm Larvae in Cass County, 1976

Date	Field	Density	R of the Highest Calculated $\check{N}$
8- 9-76	333-1	110	.75
	444-1	93	.58
8-12-76	333-2	115	.51
	444-2	29	.93
	111-1	14	.45
	222-1	12	.58
8-17-76	444-3	25	.54
	444-4	17	.68
	111-2	23	.92
	222-2	7	1.26
8-29-76	111-3	53	.68
	222-3	13	1.33
	333-4	22	.78
	444-5	36	.72
8-23-76	333-3	29	1.18

Quadrat Count Analysis

Spatial analysis, utilizing this method, was based on frequency counts of individuals in the arbitrarily chosen sample unit, number of samples, and number of individuals. To understand the effect of sampling to the distribution type, the output of the program will be compared with the output of the nearest neighbor method.

Randomized Sampling Effect

Table 13 shows the coefficient of variations of distribution statistics of two data sets. The complete result of each run is presented in Appendix F.

Table 13 demonstrates that the larger the number of samples taken, the smaller the variation. According to the nearest neighbor analysis both sets of data are aggregated, but from the analysis using $n = 5$, and 10 these data could be random or aggregated. For $n = 100$, variance, variance/mean, and I Delta have the lowest variation. The effect of randomization is reduced by using a large number of samples.

Relative Cost Estimates

The result of the calculation of the relative cost measuring one unit (Cu) from observations in the asparagus field (1977), is shown in Table 14. The number of 1 sq. ft. samples counted in one hour (NF) is calculated as $NF = (60/TS + TM)A$ where TS is the time needed to count one sample and TM is the average moving time, and A is the unit size.

Table 13. Coefficient of Variations of Distribution Statistics of Armyworm Larvae in Asparagus Fields (Cass County, 1976)

Statistics and Field	Number of Samples 5	10	30	50	70	100
Variance						
Field 111-3	94.92	52.38	44.01	37.11	45.01	21.36
Field 333-2	449.85	219.79	93.28	47.59	56.72	24.66
Variance/Mean						
Field 111-3	63.85	42.38	45.19	29.09	18.81	8.76
Field 333-2	83.69	155.77	90.31	41.52	39.93	19.84
I Delta						
Field 111-3	177.78	90.30	52.91	55.33	30.58	14.49
Field 333-2	32.33	82.80	87.63	32.29	25.33	20.87

Table 14. Relative Cost Estimates of Asparagus Field (1977)

Unit Size in Sq. Ft. (A)	Time Needed to Count 1 Sample in Minutes (TS)	Number of 1 Sq.Ft. Sample Counted in 1 Hour (NF)	Relative Time Required to Count One Unit (Cu)
.4	1.08	18	.027
.6	1.23	20	.030
.8	1.71	21	.038
1.0	2.38	20	.050
1.2	2.44	24	.05
1.4	2.63	26	.053
1.6	2.88	28	.057
1.8	3.26	28	.065
2.0	3.71	28	.071
2.2	3.80	30	.073
2.4	4.02	32	.075
2.6	4.24	32	.082
2.8	4.53	33	.084
3.0	4.90	33	.091
3.2	5.15	34	.094
3.4	5.35	35	.097
3.6	5.70	35	.103
2.8	5.85	36	.105
4.0	5.89	37	.108

The average moving time (TM) is .55 minutes. The relative time required to count one unit is not proportional to the unit size.

Optimum Sampling Analysis

Cost estimates from Table 13 were used for calculating Relative Net Precision (Cochran, 1963). Variance of sampling units were obtained from outputs of the program (N = 100). Appendix G presents the results of RNP calculations for the data.

For a fixed cost, the sampling unit with a higher RNP gives better precision than units with low RNP's. Ratings of RNP of different fields in 1976 and 1977 are presented in Tables 15 and 16. Only the first to the fifth sampling units, with the highest RNP, are included in these tables (see also Figures 22, 23, and 24).

The relationship between the optimum sample unit size and population density was not clear (Tables 15 and 16), even though there is a trend that the smaller sample unit is for the higher density. RNP is dependent on the method of sampling, unit size, and the type of distribution.

It seems that the optimum sampling unit size is larger than 1 sq. ft., and averages around 2.5 sq. ft. As population density and distribution (hence variance) is always fluctuating, not too much stress should be placed on a precise determination of the optimum size of the sampling unit.

Table 15. RNP Ratings of Field Distribution of Armyworm Larvae in Asparagus (1976)

Date	Density	Field	Rating of RNP for Sample Units (sq. ft.) 1	2	3	4	5
8- 9-76	110	333-1	1.2	3.2	1.6	2.8	2.6
	93	444-1	1.2	4.0	3.4	1.6	2.6
8-12-76	115	333-2	4.0	2.6	2.8	2.2	3.2
	29	444-2	1.2	3.8	3.2	4.0	2.0
	14	111-1	1.4	2.2	.8	2.4	3.8
	12	222-1	1.4	1.0	2.4	3.8	2.2
3-17-76	25	444-3	.8	1.6	3.4	1.8	1.0
	17	444-4	3.4	3.0	1.8	2.4	2.6
	23	111-2	2.0	1.6	3.0	3.6	.4
	7	222-2	2.2	3.2	3.6	3.8	2.8
8-23-76	29	333-3	4.0	3.2	3.6	3.8	2.0
8-29-76	53	111-3	2.6	1.6	2.2	2.4	.8
	13	222-3	2.6	2.8	4.0	3.0	3.2
	22	333-4	3.4	3.6	3.8	1.4	2.4
	36	444-5	4.0	2.2	3.8	3.4	1.2

Table 16. RNP Ratings of Field Distribution of Armyworm in Asparagus (1977)

Date	Density	Field	Ratings of RNP for Sample Units (sq. ft.) 1	2	3	4	5
7-29-77	266	555-1	2.2	3.4	2.0	4.0	3.8
8- 5-77	54	555-2	2.6	1.8	2.8	3.6	1.6
8-12-77	25	555-3	2.8	1.6	2.2	4.0	.6
8-16-77	16	555-4	3.2	3.4	3.8	4.0	1.2

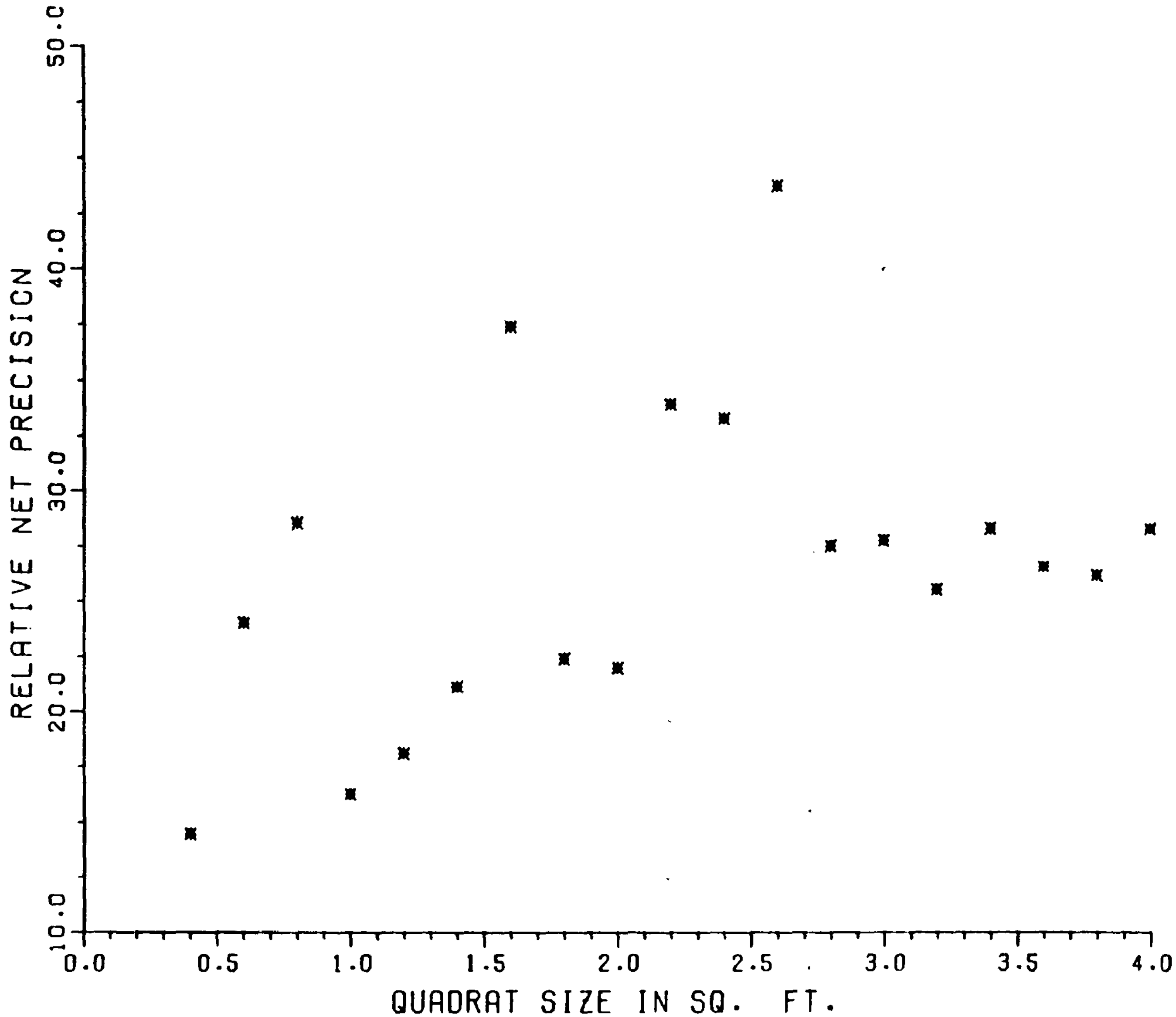

Figure 22. Relative net precision of quadrat sizes for armyworm larval sampling (field 111-3 the density = 53).

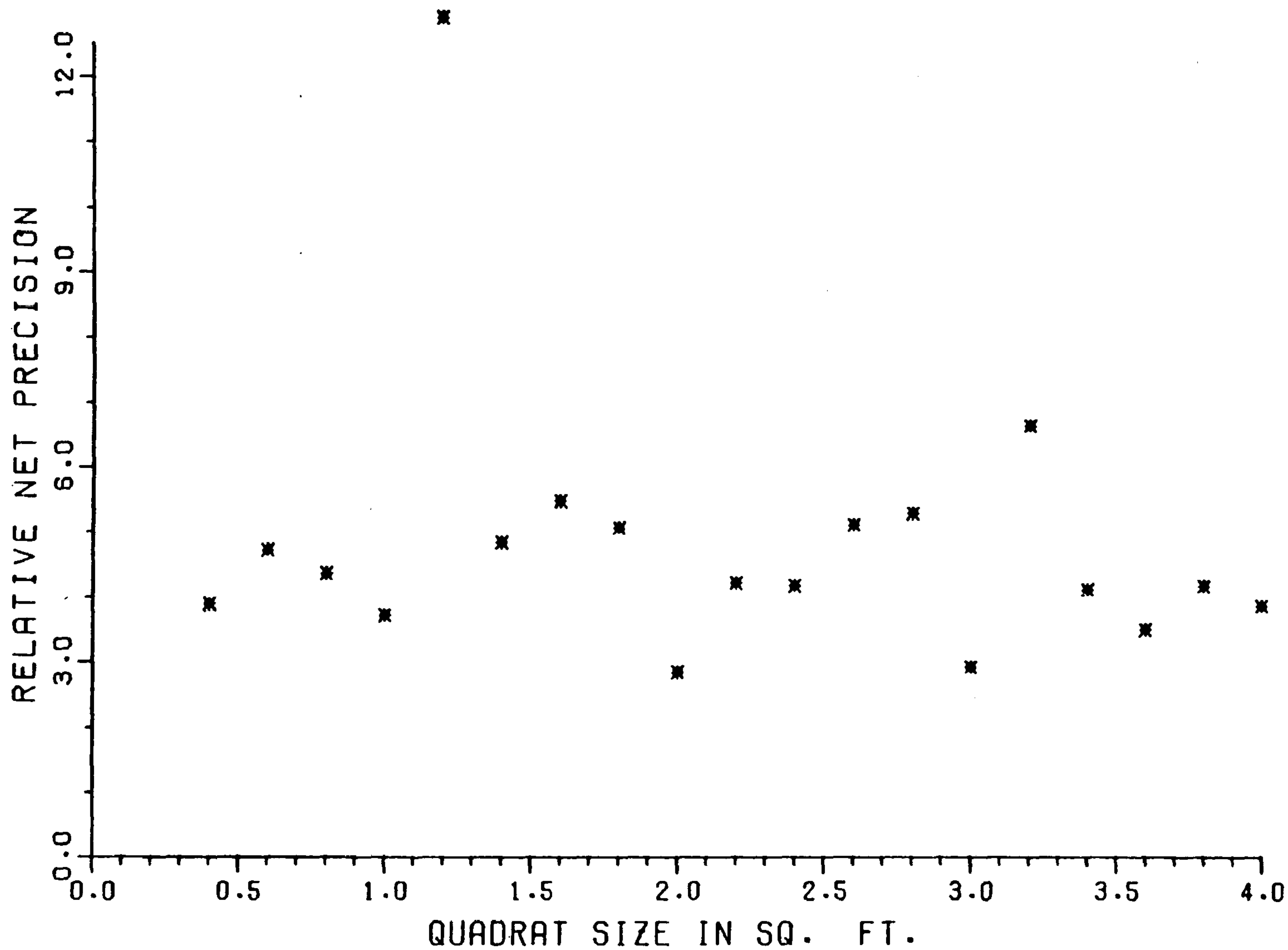

Figure 23. Relative net precision of quadrat sizes for armyworm larval sampling (field 333-1, the density = 110).

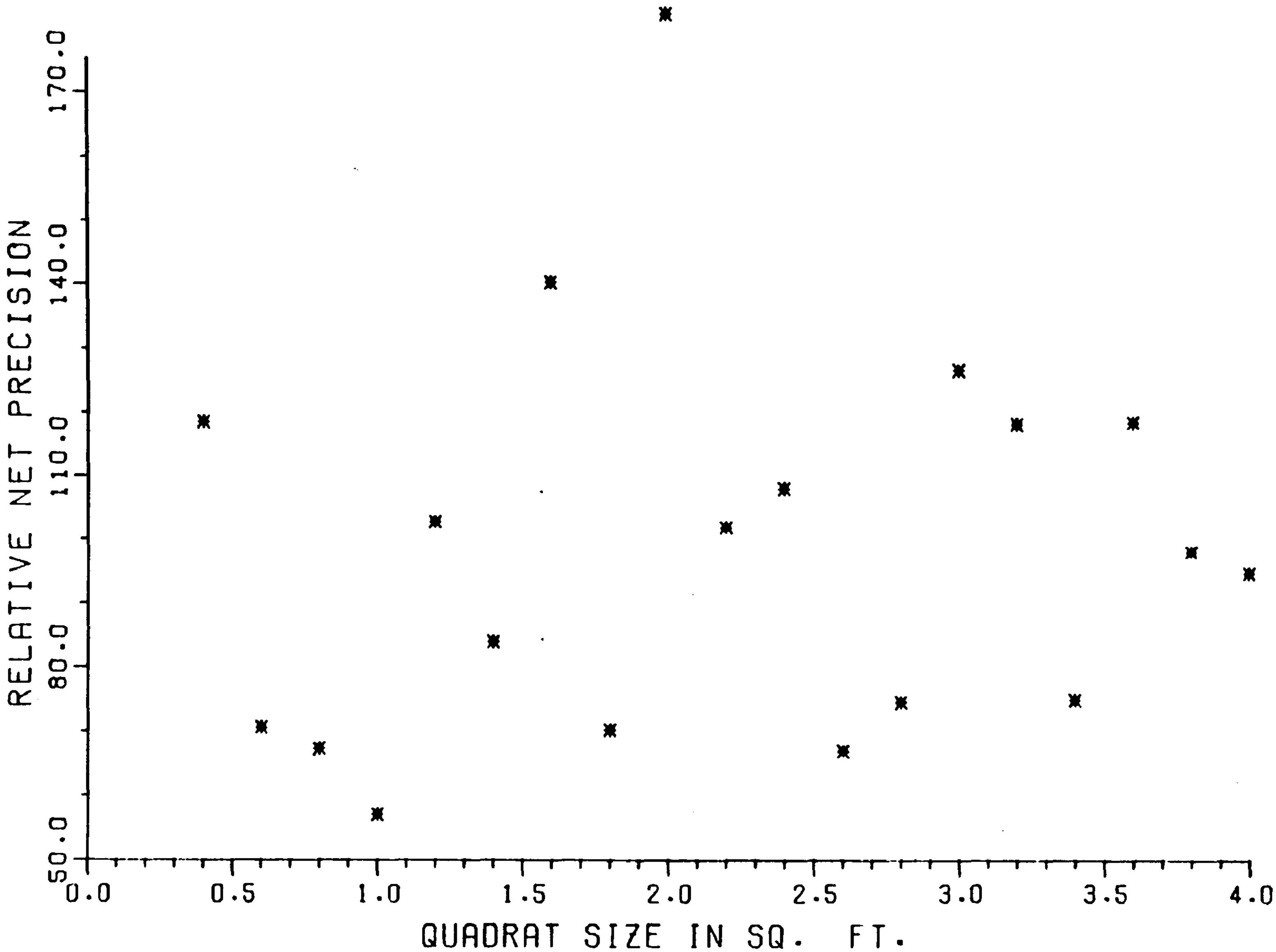

Figure 24. Relative net precision of quadrat sizes for armyworm larval sampling (field 111-2, the density = 23).

Standard Deviation as an Estimate of Precision

For any given density, a sample unit which gives the lowest variance/standard deviation of the estimated population mean is the most precise sampling unit.

Figures 25, 26 and 27 were obtained from the output of the spatial distribution program, that presents calculated standard deviations, estimated means, and "true" means of different quadrat sizes ranging from 0.2 to 4.0 sq. ft. The data for additional figures is available in Appendix C.

The "true" mean or the population mean is obtained as the average number of individuals per 1 sq. ft. quadrat of the inner area of 10 x 10 sq. ft. plot. The standard deviation of the estimated mean was calculated by using number of samples = 100.

These figures show that small quadrat sizes (less than 1.5 sq. ft.) have a high variability, and a larger quadrat size gives a stable and low standard deviation. This can be interpreted that the best sampling unit size for the 3 densities was greater than 1.5 sq. ft. This statement does not differ from the result of optimum sampling calculations using Relative Net Precision.

Parasite Identification

Table 17 presents the identification result of armyworm parasites collected in 1976 and 1977. Only *Periscepsia laevigata* (Wulp) is not in the list of recorded armyworm parasites constructed by Guppy (1967). The other eight are parasites common to the armyworm in North America.

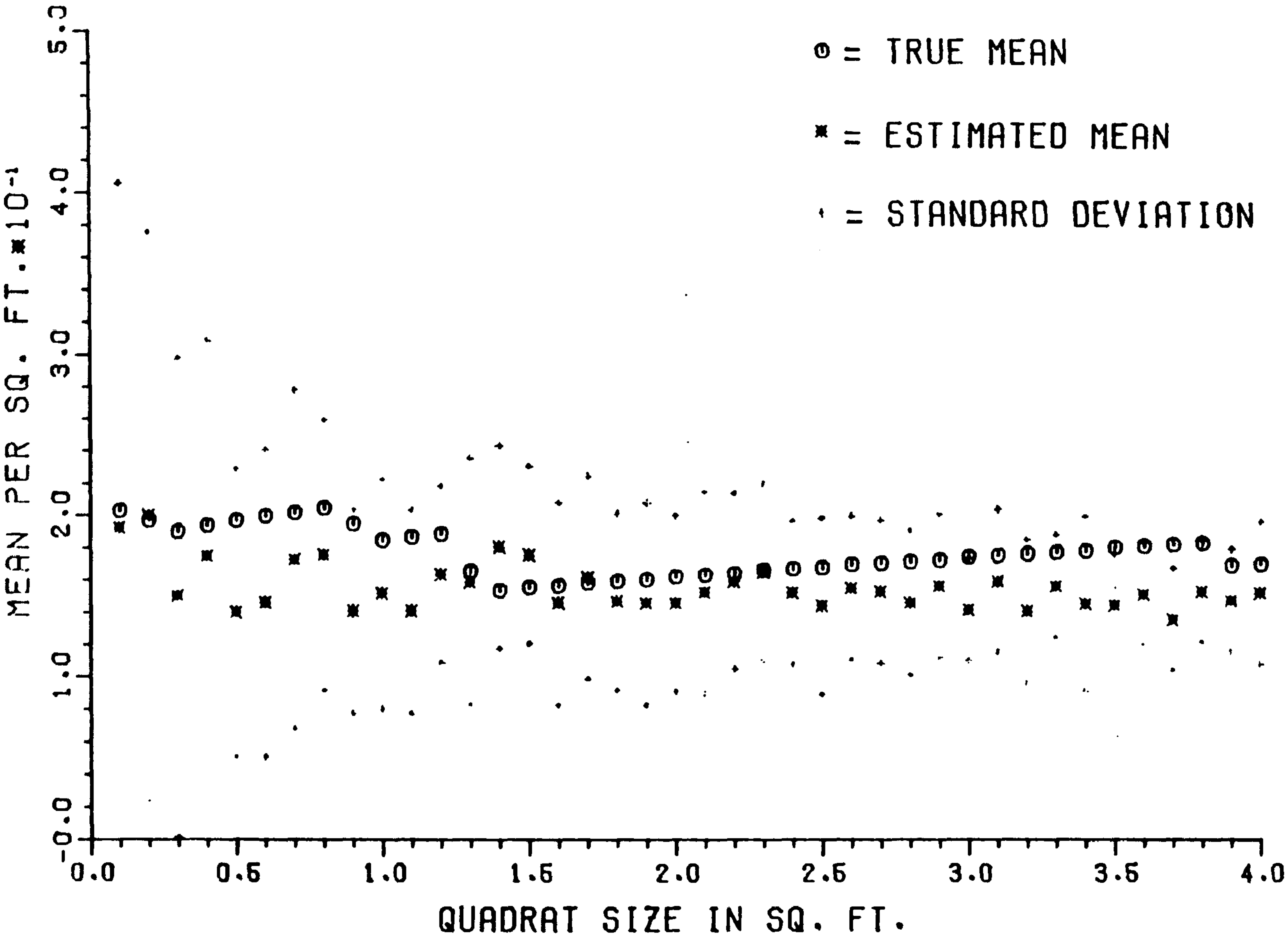

Figure 25. Relationship between quadrat size and density estimates (field 111-2, density = 22).

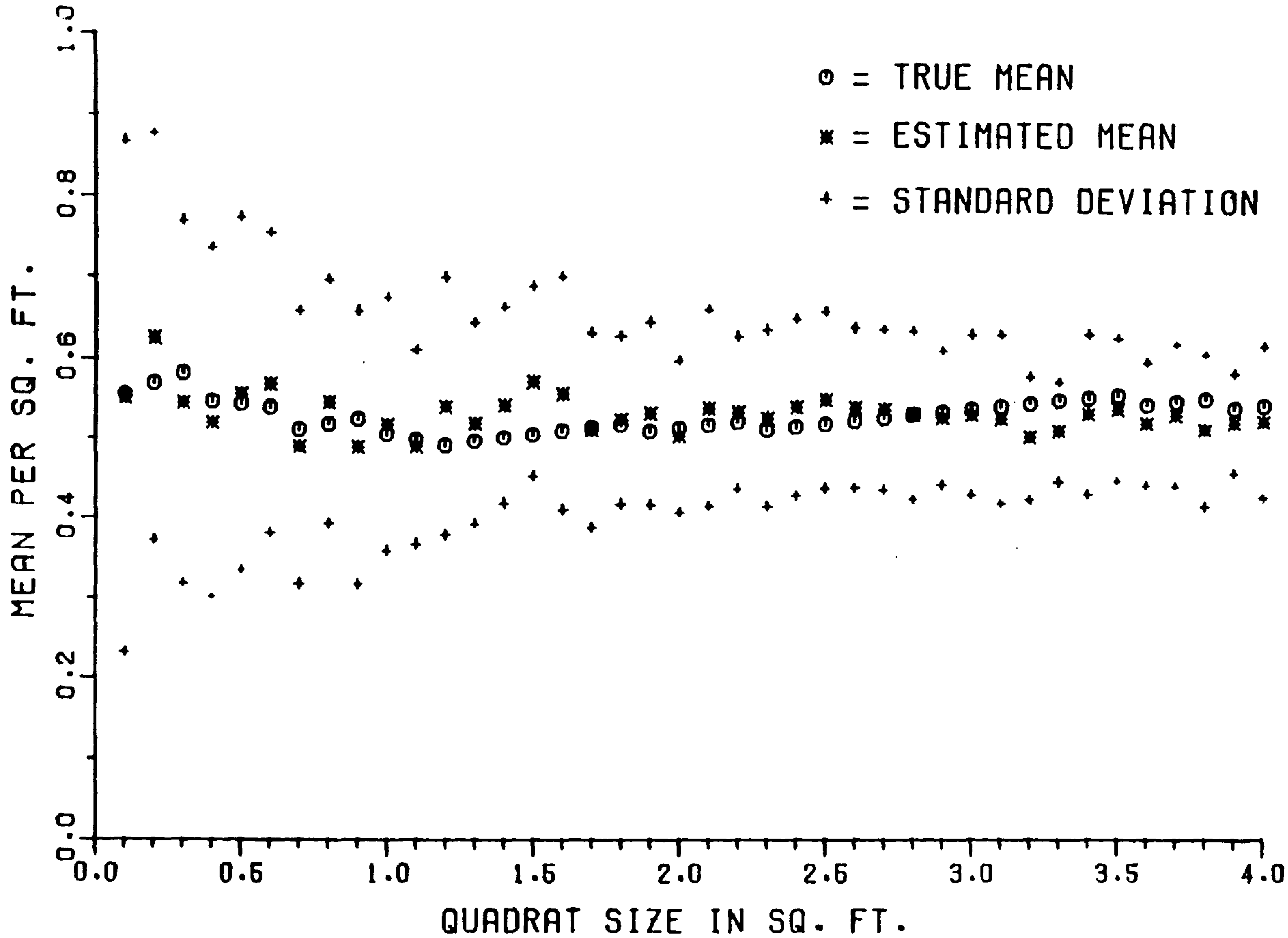

Figure 26. Relationship between quadrat size and density estimates (field 111-3, the density = 53).

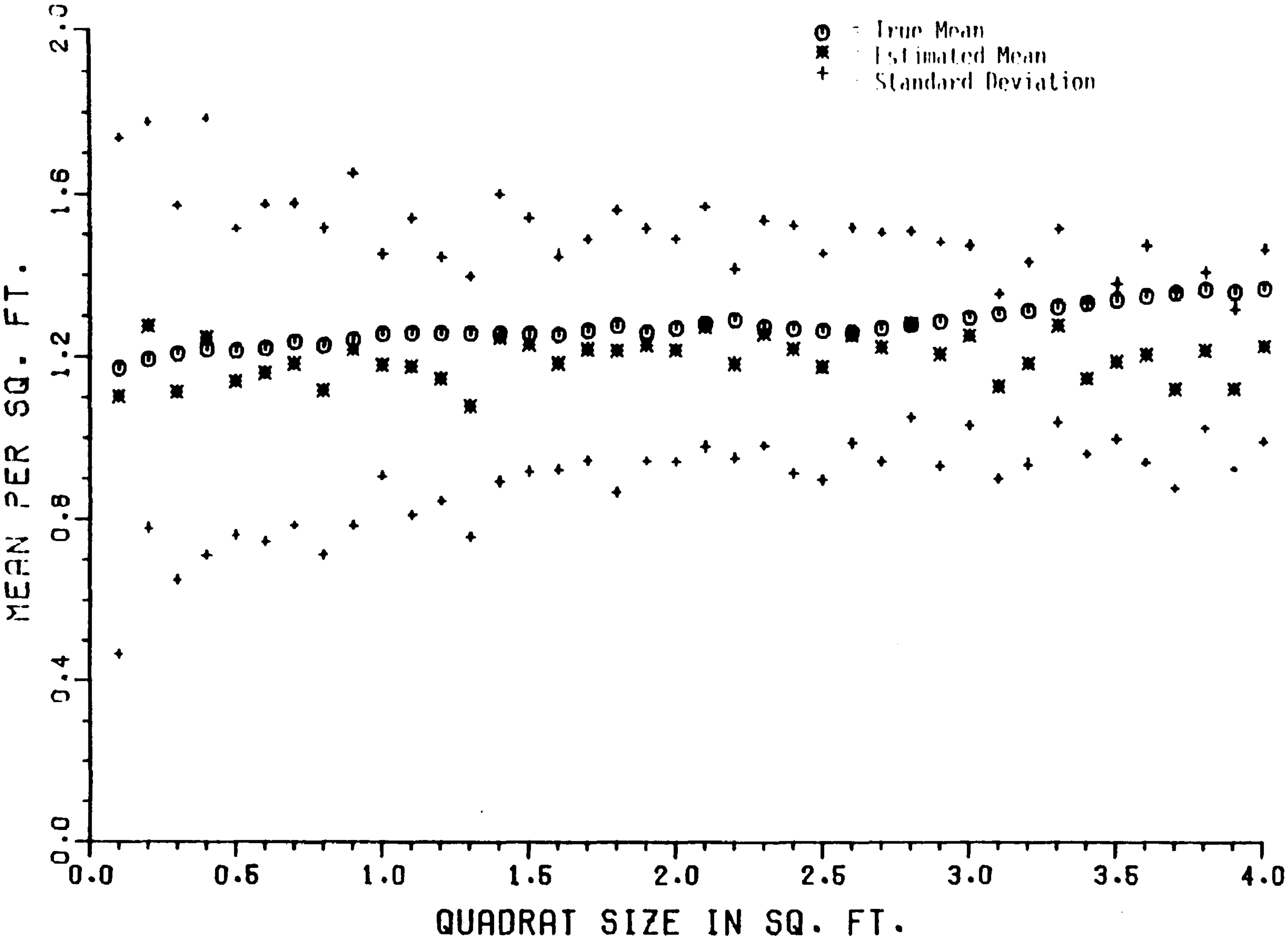

Figure 27. Relationship between quadrat size and density estimates (field 333-1, the density = 110).

Table 17. List of Parasites of the Armyworm in Michigan. (Reared from Field Collections in 1976-1977*)

Diptera:

Tachinidae

Winthemia rufopicta (Bigot)

Archytas apicifer Wlk.

Chaetoplagia atripennis Coquilett

Periscepsia laevigata (Wulp)

Hymenoptera:

Braconidae

Apanteles militaris Walsh

Meteorus communis (Cresson)

Rogas terminalis (Cresson)

Ichneumonidae

Enicospilus purgatus (Say)

Hyposoter sp.

---

*Thanks to Dr. R. L. Fischer for the identification of parasitic wasps and to F. W. Ravlin for Diptera identification.

Parasite - Host Development

Winthemia rufopicta (Big)

Host Size Preference - The result of Winthemia egg count on armyworm larvae obtained from several fields in 1976 and 1977 is presented by Table 18.

The table shows that females tend to deposit smaller numbers of eggs on smaller larvae. There is a positive correlation between the size of the larvae and the number of eggs laid by Winthemia, as mentioned by Danks (1975b) based on his observations in North Carolina using Heliothis larvae as the host. The table also demonstrates that the number of eggs laid on armyworm larvae in 1976 was higher than the number in 1977. This is probably due to the population density of the armyworm and the presence of interspecific competition. The armyworm population in 1976 was higher than the population in 1977; available hosts were abundant, and Winthemia was more active. Some larvae might have been parasitized by more than one female (up to 27 eggs per larva were recorded). In 1977 the armyworm population was low, and the competition from other parasites (especially Apanteles militaris) was high. This situation reduced Winthemia activities and they might have sought other, more available, hosts.

Eggs and Maggot Survival - Figure 28 represents the relationship between the number of parasite eggs laid in a single larva, and the percent of eggs that produced adults. Even though some larvae bore numerous eggs, only a small number of them were able to penetrate the host, and fully develop in the limited volume of the larval body.

Table 18. Number of Eggs Laid by *W. rufopicta* on Late Instars of Armyworm Larvae, Under Natural Conditions (1976 and 1977)

	1976		1977	
	L V	L VI	L V	L VI
Number of observed larvae	9	26	4	32
Mean	1.89 $\pm$ .93	6.31 $\pm$ 5.56	1.5 $\pm$ .58	2.75 $\pm$ 2.36
Range	(1 - 4)	(1 - 27)	(1 - 2)	(1 - 12)

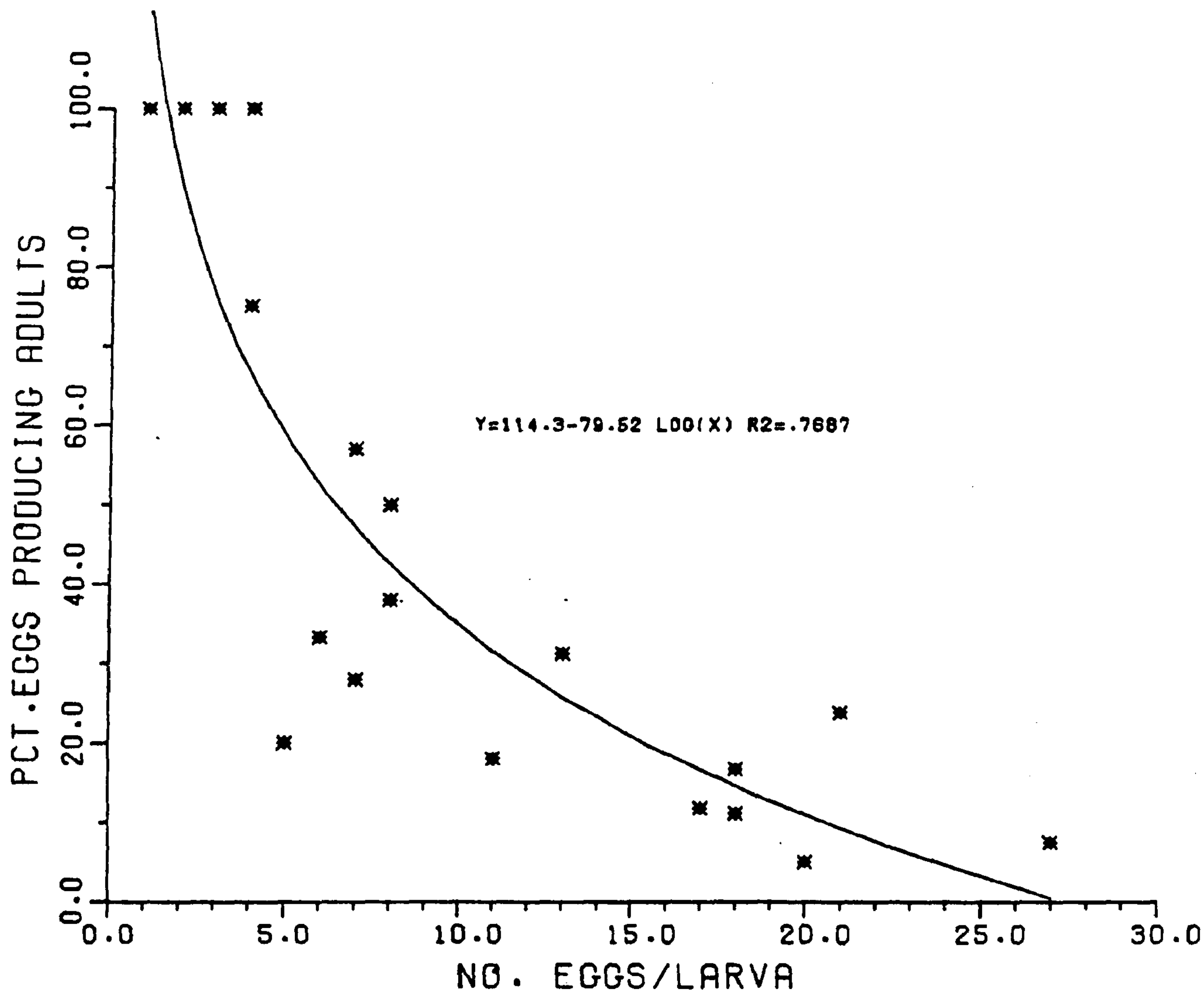

Figure 28. Relationship between the number of Winthemia eggs laid on one armyworm larva and the percentage of eggs producing adults.

The survival of eggs depends on: 1) host instar, 2) food plant of any particular host, and 3) temperature. The survival of maggots is affected by the success of penetration by the first instar maggot and the maggot development. Maggots could fail to penetrate due to: 1) eggs were loosely attached, 2) eggs were destroyed by the host, 3) debility of maggots, and 4) host unsuitability. The survival and development of the maggot depends on the ability of the host to support maggot development, intraspecific competition, and interspecitic competition (Danks, 1975b).

Development of Prepupae and Pupae - The result of observations of the development of prepupae and pupae of *W. rufopicta* in 70°F (21°C) is presented in Table 19.

The information obtained from Table 19 is not significantly different from what was observed by Danks (1975a). This study concluded that the developmental rate of *Winthemia rufopicta* in *Heliothis* spp. presented by Danks (1975a) can be applied for *Winthemia* which attacks armyworm.

Effect of *W. rufopicta* Parasitism on Host Food Consumption - The time from the first day when the parasite eggs are laid to the death of the host larvae at 21°C, is about 6-7 days (Danks, 1975a). The eclosion takes place in 2-3 days. The host dies in the last 3-4 days. If it is assumed that eggs are laid in the first day as the host enters the sixth stadium, the larva has 2-3 days for normal development and feeding. Parasitic maggots which enter the larva will cause a reduction of the ability of the larva to consume food.

Table 19. Average Time of Development of Prepupae and Pupae of
<u>W</u>. <u>rufopicta</u> in 70°F.

Year of Observation	Stage	Mean Duration (in days)	No. of Observed Individuals
1976	1. Host death to maggot in cell	2.67 ± .59	18
	2. Puparium	11.95 ± .80	56
1977	Host death to fly emergence	14.12 ± 1.50	42

Larvae which were collected from the field consisted of different ages of the sixth instar. Most of them were in the middle or last stage of sixth instar development. They subsequently died one or two days after being transferred to the rearing room. Assuming that the developmental time of the parasites in all individual host larvae is uniform, the average total food consumption of parasitized larvae can be derived (Table 20).

This approach can also be used for calculating the amount of food consumption of the unparasitized larvae. Assuming that all the sixth instar larvae spent 7 days before they turned into prepupa, the average total food consumption of unparasitized larvae is shown also in Table 20. This table indicates that the amount of food consumption of a parasitized larvae in the first 2 days is not different from a healthy one. After the second day its consumption is significantly less than the food consumption of unparasitized larvae. The total food consumption of parasitized larvae is 49.25% or 50% of the amount of food consumed by the healthy larva. By using the data of Table 34 for the amount of food consumption of instars I to V, Figure 29 depicts the difference of food consumption between parasitized larva with the total of 144.53 cm^2 leaf area, and the food consumption of unparasitized larva with the total of 253.50 cm^2.

Crop loss due to armyworm attack is determined by the density and stage of the armyworm larvae, parasitism of <u>Winthemia</u> and the growth stage of the plants. The damage which is done by the first to the fifth instar could result in a significant loss, if the density is high and the plant is still in a vegetative growth stage. In this case the

Table 20. Average Total Food Consumption of Unparasitized and Parasitized 6th Armyworm Larvae by <u>Winthemia</u> (cm^2 of Barley Leaf Area)

Day	Unparasitized Larva	Number of Larvae Observed	Parasitized Larvae	Number of Larvae Observed
1	11.44	5	18.28	1
2	20.45	7	23.97	2
3	32.95	7	18.01	5
4	35.59	15	20.68	9
5	39.71	18	17.35	20
6	43.29	18	7.48	25
7	31.31	18	0	died
8	0	prep.		
Total	214.74		105.77	

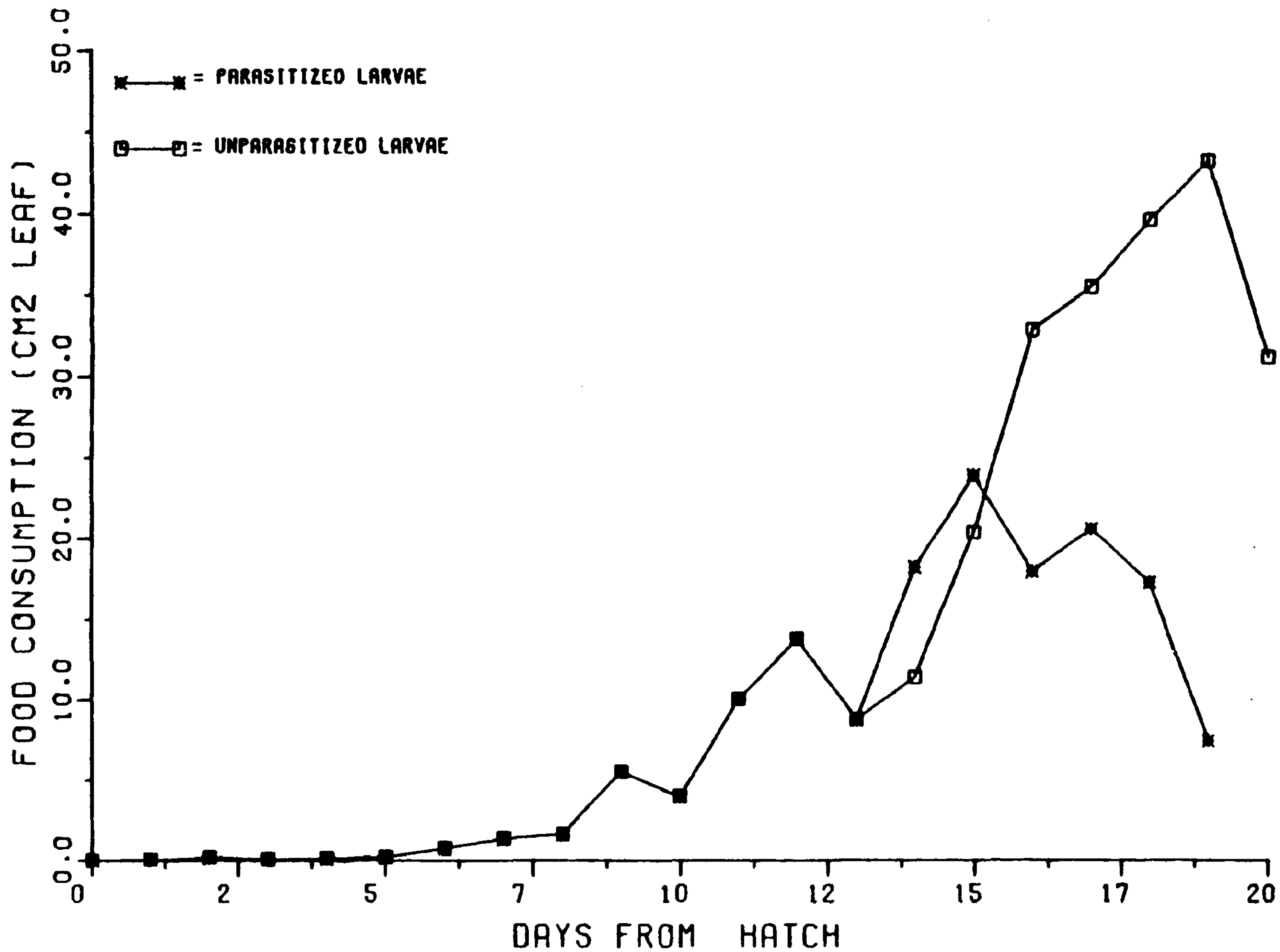

Figure 29. Daily food consumption of unparasitized armyworm larvae and larvae parasitized by <u>Winthemia</u>.

effect of Winthemia parasitism to the reduction of crop losses might be less significant than if the damage is done in a later stage of the plant.

The dynamic relationship between the armyworm larvae, Winthemia parasitism and the crop yield should be investigated. This study eventually will determine the level of economic threshold of the armyworm.

This investigation could be improved later, by using artificial infestations in the laboratory. Exposing the larva to the parasite in the laboratory will give exact information about oviposition time, and the instar of infested larva.

Apanteles militaris Walsh.

Development of Pupae - There were a total of 130 parasitized larvae taken from the field in 1977, and their development was observed. Most of those larvae (98%) were killed during stadium VI. The wasp always emerges as a third instar of larva, and only from the 6th instar of host larva. Calkins and Sutter (1976) reported the same thing; the parasite emerged from 6th instar armyworm larva, regardless of the host instar that was originally attacked.

The time spent as a pupae ranged from (4-11) days, with a mean = 7.21 and s = .90, with the number of observed individuals = 113. Calkins and Sutter (1976) found that the mean = 6.4 days at 27°C, which does not differ significantly from the result of this study.

The number of cocoons which are constructed by the larvae after they emerge from the body of host larva ranged from 5 to 192, with the mean = 58.56, s = 36.04 and n = 116.

Effects of *A. militaris* on Host Food Consumption - Calkins and Sutter (1976) reported that the most successful parasitism of *Apanteles* is achieved if the female wasps parasitize the third instar larvae. The average percentage of parasitism was 70%. Their figure is similar to the result of this study; 13 out of 19 observed larvae or 68.42% of the larvae were killed by *Apanteles*.

Total food consumption of parasitized larvae and the number of *Apanteles* cocoons emerging from infested larvae is shown in Table 21. The average total food consumption of six unparasitized larvae was 274.06 $\pm$ 24.0 cm^2.

To compare daily food consumption of unparasitized and parasitized larvae, 8 days developmental time were used for parasitized larvae and 15 days for unparasitized data. The average daily food consumption of 8 parasitized and 4 unparasitized larvae is presented in Table 22 and Figure 30.

This study demonstrates that *Apanteles* parasitism reduces the amount of food consumed by individual larva quite significantly. Total food consumption of parasitized larvae is only 15.74% or 16% of the total food consumption of unparasitized larvae if *Apanteles* adults lay eggs on the third instar larvae. Another investigation should be done to determine the reduction of the food consumption of parasitized larvae if *Apanteles* wasps lay eggs on the fourth or fifth instar. However, it is most likely that the result would be quite similar to this study, since the parasitized larvae will be killed in the 6th stadium.

Table 21. Total Food Consumption of Parasitized Larvae by *Apanteles militaris*

Number	Days to Larval Death	Total of Food Consumption (cm^2 barley leaf)	Number of *Apanteles* Cocoons
1	8	47.41	22
2	8	29.15	11
3	8	15.53	11
4	11	89.81	40
5	9	82.96	47
6	8	47.71	28
7	8	45.82	9
8	10	55.03	24
9	11	30.35	16
10	8	16.72	6
11	10	20.33	8
12	8	48.98	35
23	8	30.96	15
Mean	8.85 $\pm$ 1.21	43.14 $\pm$ 23.23	20.92 $\pm$ 13.2

Table 22. Average Daily Food Consumption of Unparasitized Armyworm Larvae Parasitized by _Apanteles_ _militaris_ (in cm^2 barley leaf area)

Day	Parasitized Larvae	Number of Observed Larvae	Unparasitized Larvae	Number of Observed Larvae
1	1.10	8	1.59	4
2	2.99	8	1.57	4
3	4.39	8	5.35	4
4	8.90	8	4.26	4
5	9.38	8	5.93	4
6	9.39	8	16.05	4
7	5.03	8	15.74	4
8	2.25	8	3.39	4
9	0	died	22.62	4
10	-	-	35.15	4
11	-	-	24.21	4
12	-	-	36.32	4
13	-	-	63.35	4
14	-	-	41.36	4
15	-	-	8.42	4
Total	43.34		285.31	

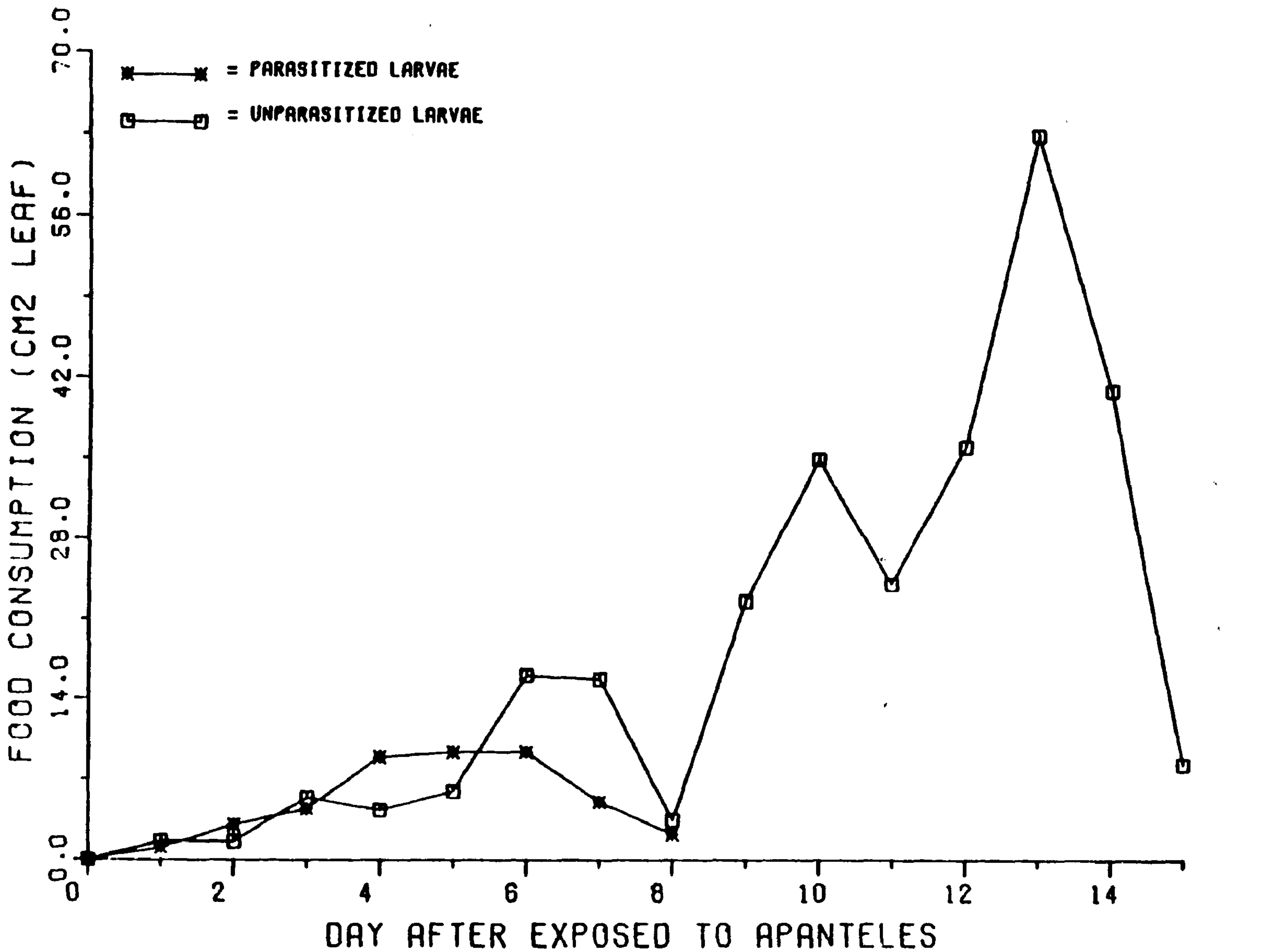

Figure 30. Daily food consumption of unparasitized armyworm larvae and larvae parasitized by *Apanteles militaris*.

Compared with Tachinids, Apanteles is more effective in reducing the amount of defoliation caused by armyworm. It attacks armyworm in the early instars, and this has a large impact on the heavy feeding late stages. Its effectiveness should be considered and utilized in future integrated control strategies.

Effect of Apanteles on Host Growth - Table 22 and Figure 30 indicate that during stadium IV (day 2-day 5) the rate of food consumption of parasitized larvae is greater than unparasitized larvae (although not statistically significant). The parasitized larva has a greater metabolism rate due to what Slonsky (1978) refers to as an "adaptive interest" of the parasite. Parker and Pinnell (1973) also reported that the larvae of Pieris rapae parasitized by Apanteles glomeratus consumed significantly more food than normal larva in the 1st, 4th, and 6th instars. Slonsky (1978) stated that the increased food consumption was caused by: 1) greater duration of the entire larval period, and 2) parasitized larva may have fed at a faster rate.

This study shows that there is no real difference of larval duration between parasitized and unparasitized armyworm larva; the increased food consumption was probably due to parasitized larvae feeding at a greater rate than unparasitized larvae. This case is supported by the fact that total food consumption by parasitized larva has a positive correlation with the number of Apanteles individuals inside the armyworm (Figure 31). The number of parasites per larval body is calculated as a number of Apanteles cocoons emerging from each observed larva (see Table 21). This useful information must be considered in the

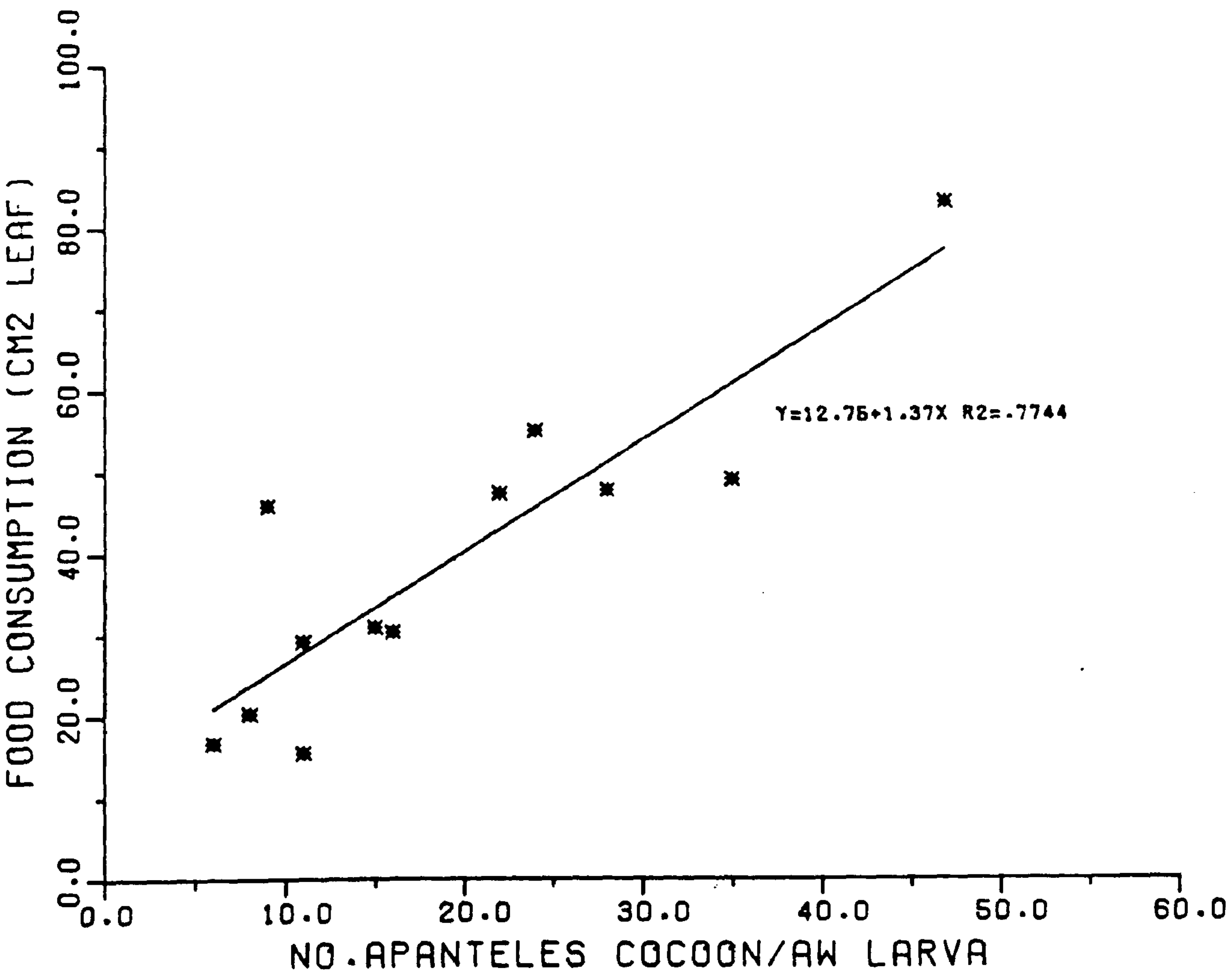

Figure 31. Initial relationship between number of Apanteles cocoons emerged from armyworm larva, and total food consumption of parasitized larva (up to day 6 after eclosion).

development of a model of the interaction between armyworm, parasites, and host plant for a management program.

Field Parasitism Rates

1976 Field Study

Two tachinid parasites, Winthemia rufopicta, and the pupal parasite, Archytas apicifer, were collected from wheat fields in Cass County by quadrat count sampling. Four sets of sampling data gives brief information about the density dependent relationship between populations of armyworm and both parasites (Figure 32). Percentage of parasitism by Winthemia was highest when the armyworm population reached its peak. These parasites must be the mortality factor that reduced the armyworm population in the wheat season. It should be reiterated, that no armyworm population was found in the field after June 27, 1976, which might be due to the low population of armyworm and readiness of the crop to be harvested.

In 1976 Winthemia became the most dominant parasite, which might have been caused by the following conditions: 1) widespread high populations of armyworm which could invite the parasite to move from other available hosts to the armyworm. In this case armyworm was more suitable and available for Winthemia, than other hosts such as Heliothis and other Noctuids. 2) The parasitism was successful because the emergence and occurrence of Winthemia in the field was in synchrony with the phenology of the armyworm. 3) The absence or weakness of interspecific competition especially with Apanteles militaris which attacks armyworm in earlier stages.

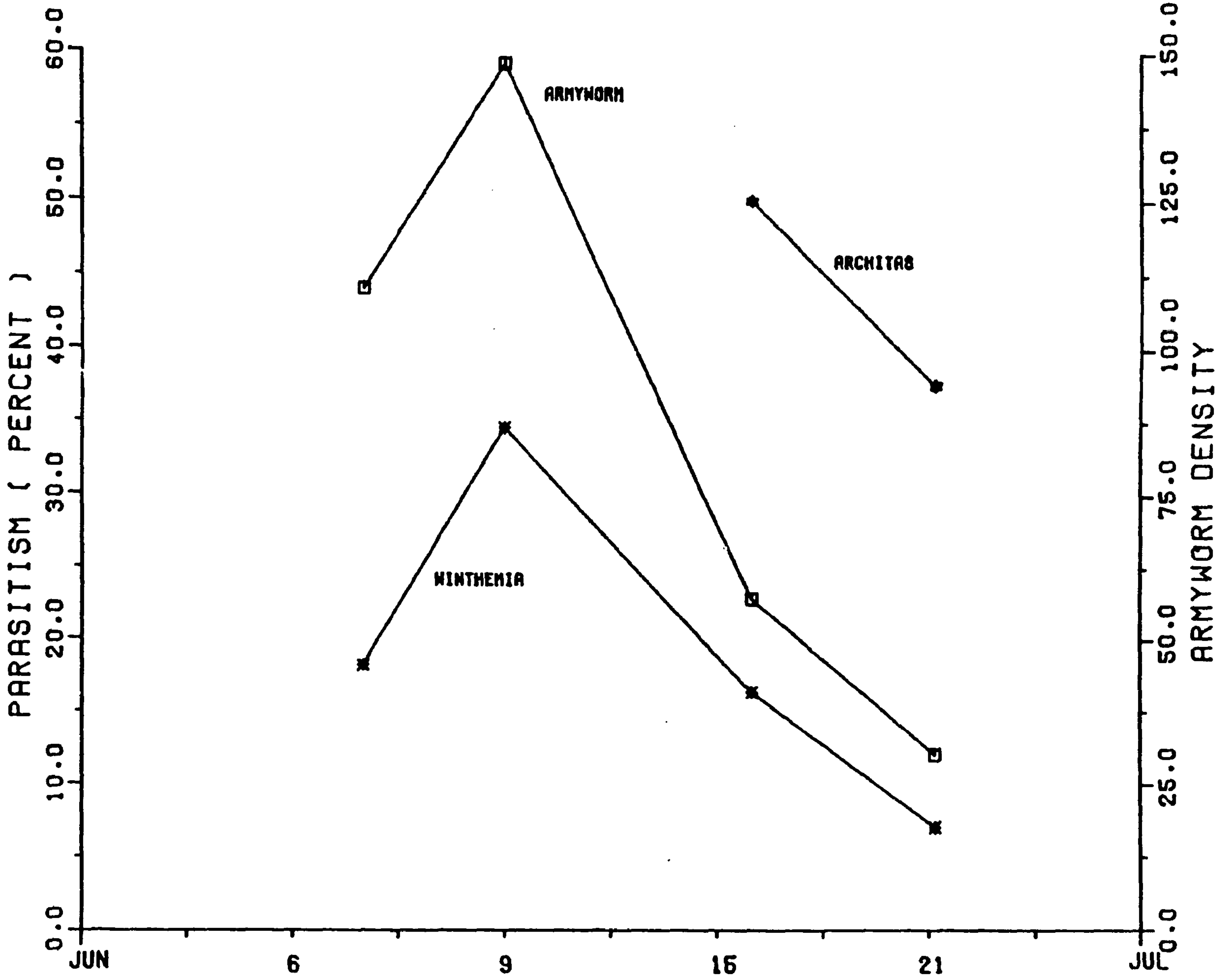

Figure 32. Parasitism of armyworm larvae in wheat (Cass County, 1976).

Figure 33 represents the total catch of _Winthemia_ adults/flies in 3 emergence traps in the same field. The catches coincided with the development of _Winthemia_ on armyworm larva (Figure 32). The peak of parasitism was on June 12, and the peak of fly emergence was on July 6, 1976. The next generation of _Winthemia_, adult females laid their eggs on other available alternate hosts, since the 5th or 6th armyworm instars were not available at that time. If there were not enough alternate hosts available in the field, _Winthemia_ must have experienced a significant population crash in the following generations.

1977 Field Study

Sweep sampling data taken from the wheat field in Cass County shows a different pattern of parasitism. Three parasites were dominant; two Braconids, _Apanteles militaris_ and _Meteorus communis_, and one Tachinid, _Winthemia rufopicta_.

Figure 34 illustrates the relative abundance of the three major parasites and their host over time. Even though the graph does not show the multi-generation's relationship, it demonstrates the character of interspecific competition between the three parasites for the same resource. The two Braconids seemed to co-exist even though mortality was density dependent. _Apanteles_ had the highest parasitism during most of the observation time. _Meteorus_ also showed a significant parasitism which reached 30% on June 1.

Winthemia parasitism was low at the beginning, but it increased significantly at the end of the observation period while the armyworm population and Braconid parasitism was declining. The low parasitism of

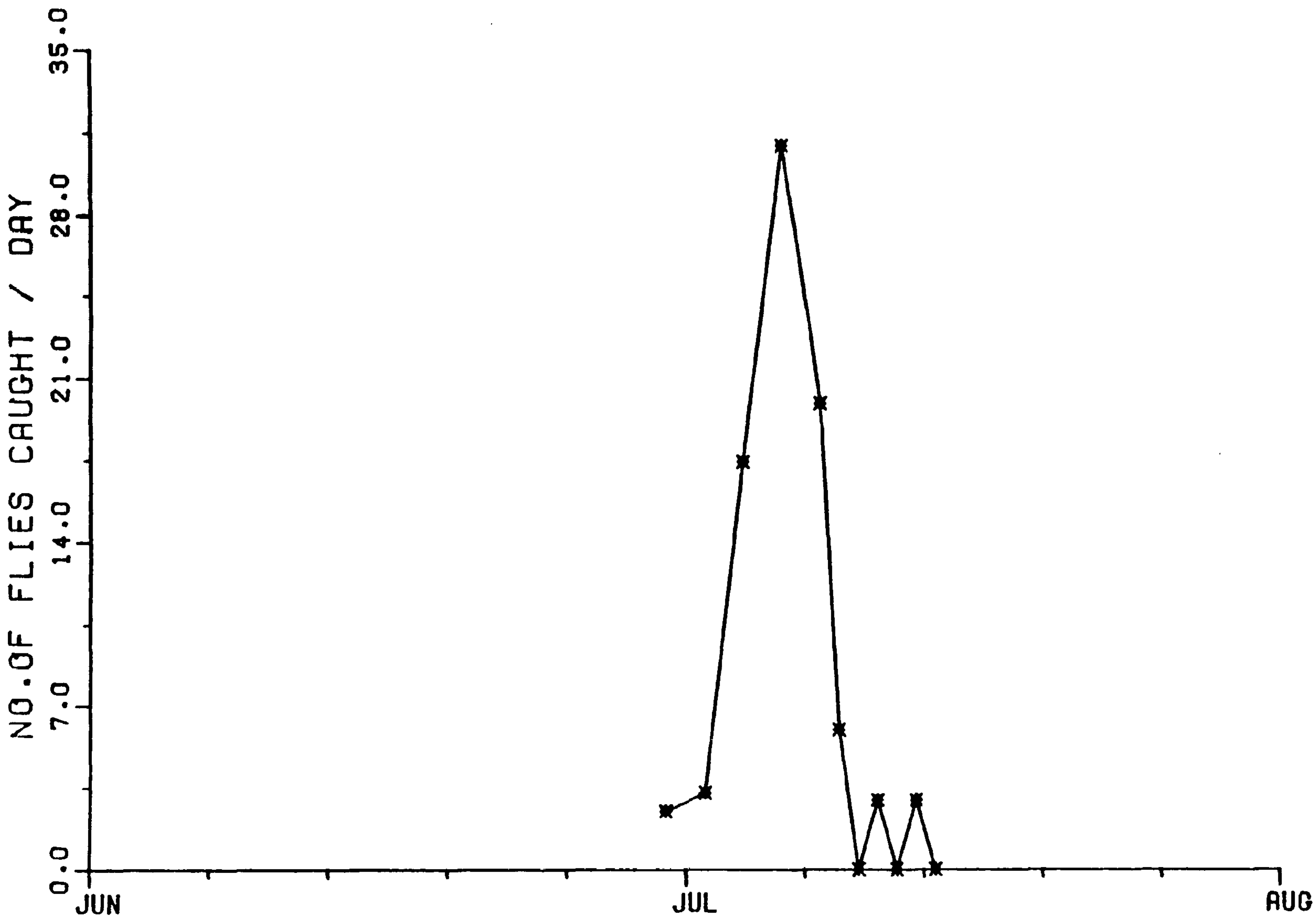

Figure 33. Number of Winthemia adults caught in emergence traps (Cass County, 1976).

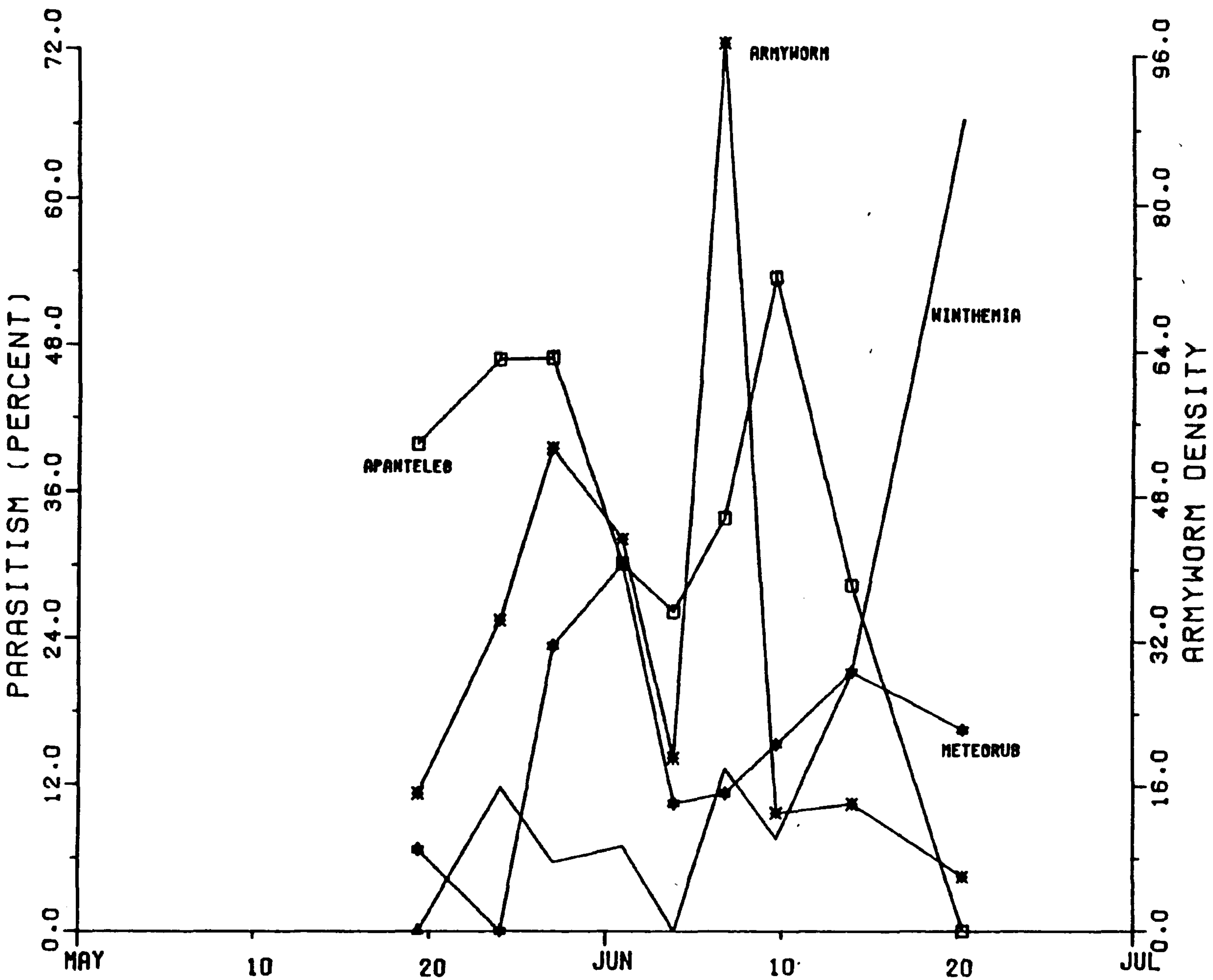

Figure 34. Parasitism of armyworm larvae in a wheat field (Cass County, 1977).

Winthemia might have been caused by several factors: 1) the endemic armyworm population did not attract *Winthemia* females; i.e., they might have laid their eggs on more suitable and available host species, 2) *Winthemia* could not compete successfully with the Braconids which attacked the host earlier, and 3) *Winthemia* development and occurrence in the field did not synchronize with the development of the armyworm; i.e., coming too late, the flies had to find alternate hosts to continue their development.

Bucket Experiment

Larval recovery was high for the early and middle instars of larvae; 50-60% of the 1st through 4th instars were recovered after being exposed for 3-4 days. The recovery rate was low for the 5th and 6th instars (25%). The remaining larvae moved out of the bucket and were not recovered. Apparently, the plants and shade in the bucket did not give enough protection and fresh food for the exposed larvae.

Results of the parasite observations (in the laboratory) is presented in Figure 35. Between June 28 and August 24, all recovered larvae were killed by Nuclear Polyhedrosis Virus, and the parasitism during that time could not be detected.

Figure 35 shows the relationship between the armyworm and its three major parasites. Both Braconids (*Apanteles* and *Meteorus*) compete for the limited number of host. *Winthemia* came later after both Braconids stopped their parasitism of the armyworm larvae. *Winthemia* cannot compete successfully with *Apanteles* and *Meteorus*. This evidence supports the previous analysis of the sweepnet data.

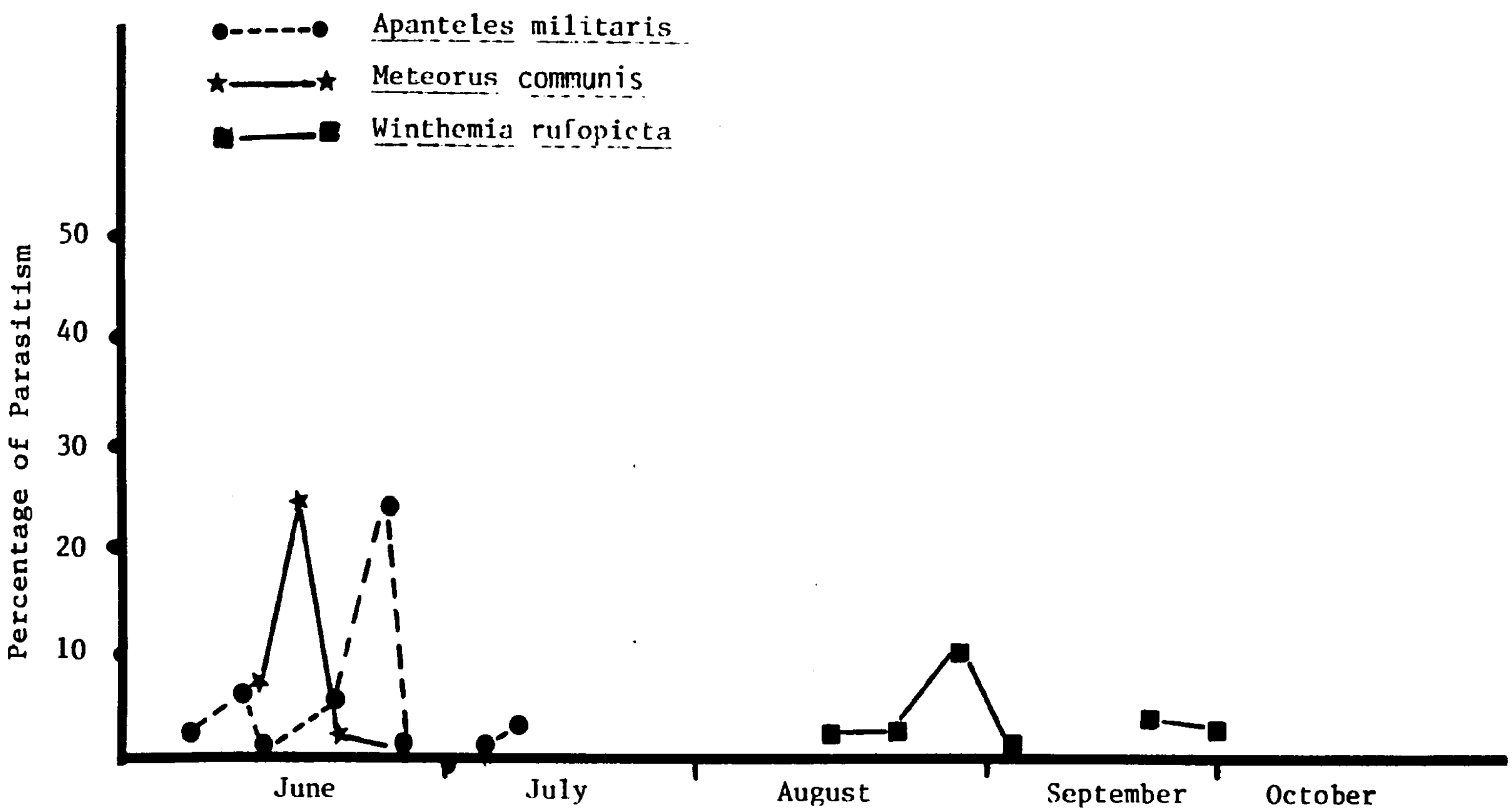

Figure 35. Parasitism of armyworm larvae in a wheat field (bucket experiment, Cass County, 1977).

If this method is used again, more buckets and exposed larvae will be needed to gain a better insight. Another method which can assure the full recovery of the exposed larvae should be investigated to replace the bucket method.

Oviposition Pattern of *Winthemia*

Danks (1975a) stated that parasitism by *Winthemia* may be proportionally greater where the host is locally more abundant. Such behavioral responses to locally higher host densities apparently occur in *Winthemia rufopicta* attacking *Heliothis* spp. within tobacco fields. *Winthemia* adults show a marked response to the spatial distribution of armyworm larvae. Adults would lay more eggs where armyworm larvae are aggregated.

To check the behavioral reponse of *Winthemia* attacking the armyworm within wheat fields, *Winthemia* parasitism data in the wheat field in Cass County in 1976, was plotted and presented in Figures 36 and 37. Figure 36 displays the trend of density dependent relationship between the armyworm and *Winthemia* oviposition, but Figure 37 does not indicate this kind of relationship.

The behavioral response of *Winthemia* attacking the armyworm within asparagus-crabgrass fields is represented by the mapped distribution of armyworm larvae in the field on July 29, 1977 (Figure 38). This figure displays the distribution pattern of parasitized and unparasitized larvae, and the respective instars. If 1 x 1 sq. ft. is used as a unit of observation, all parasitized and unparasitized larvae are recorded, the calculation of *Winthemia* parasitism of 100 units can be plotted and summarized by Figure 39. The figure shows clearly that there is no

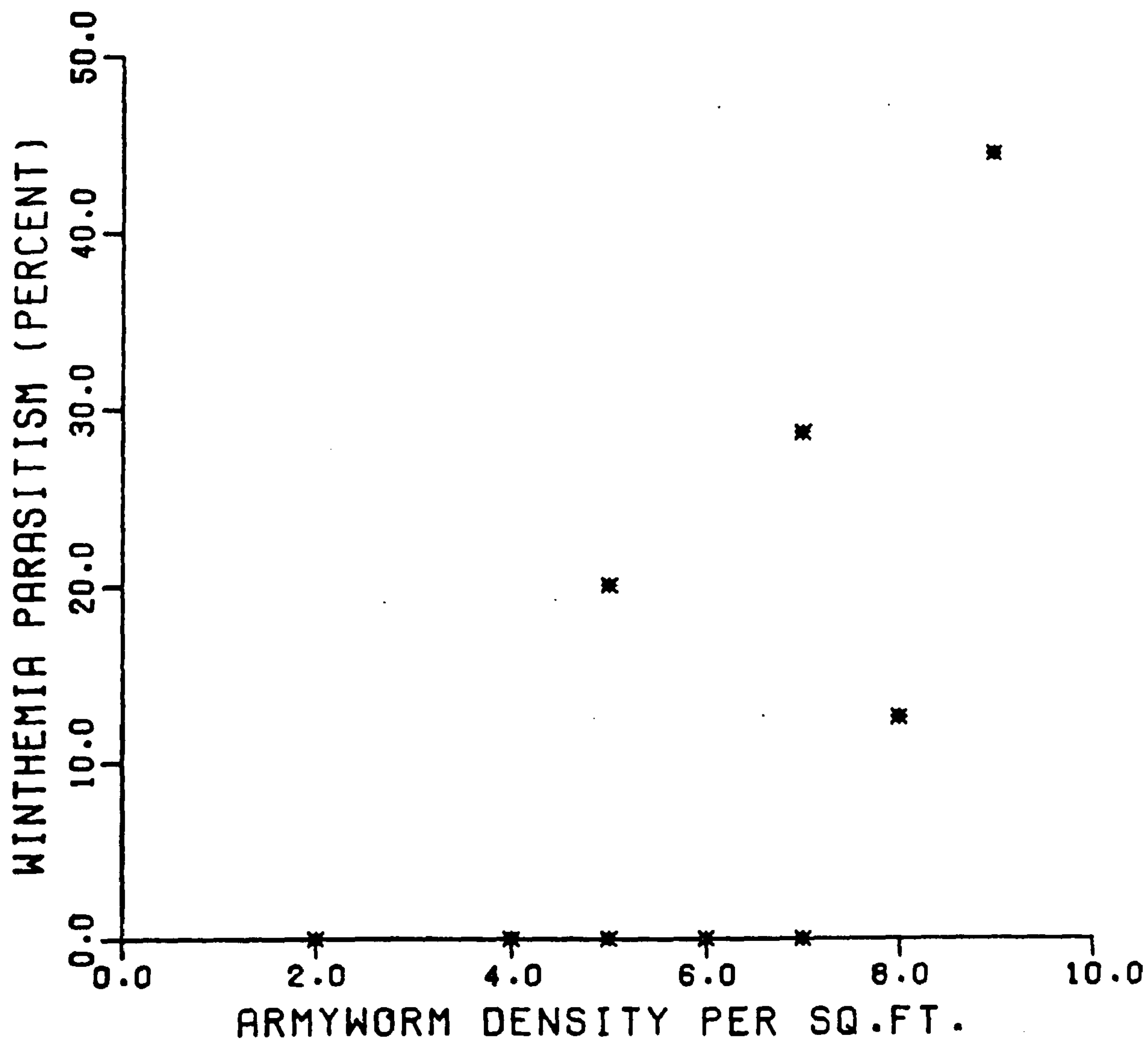

Figure 36. Relationship between armyworm larval density with *Winthemia* parasitism in the wheat field (Cass County, June 19, 1976).

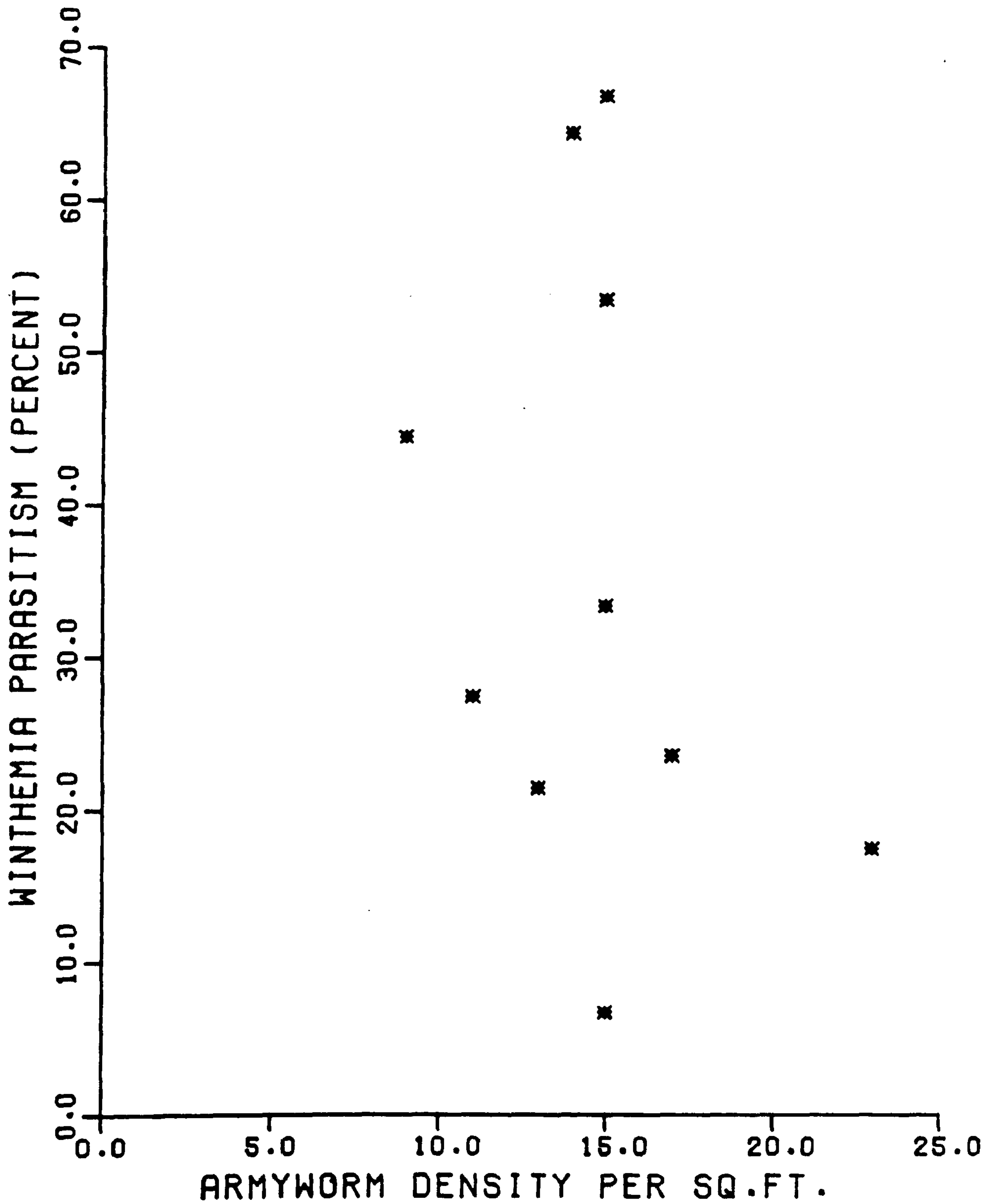

Figure 37. Relationship between armyworm larval density, with <u>Winthemia</u> parasitism in the wheat field (Cass County, June 12, 1976).

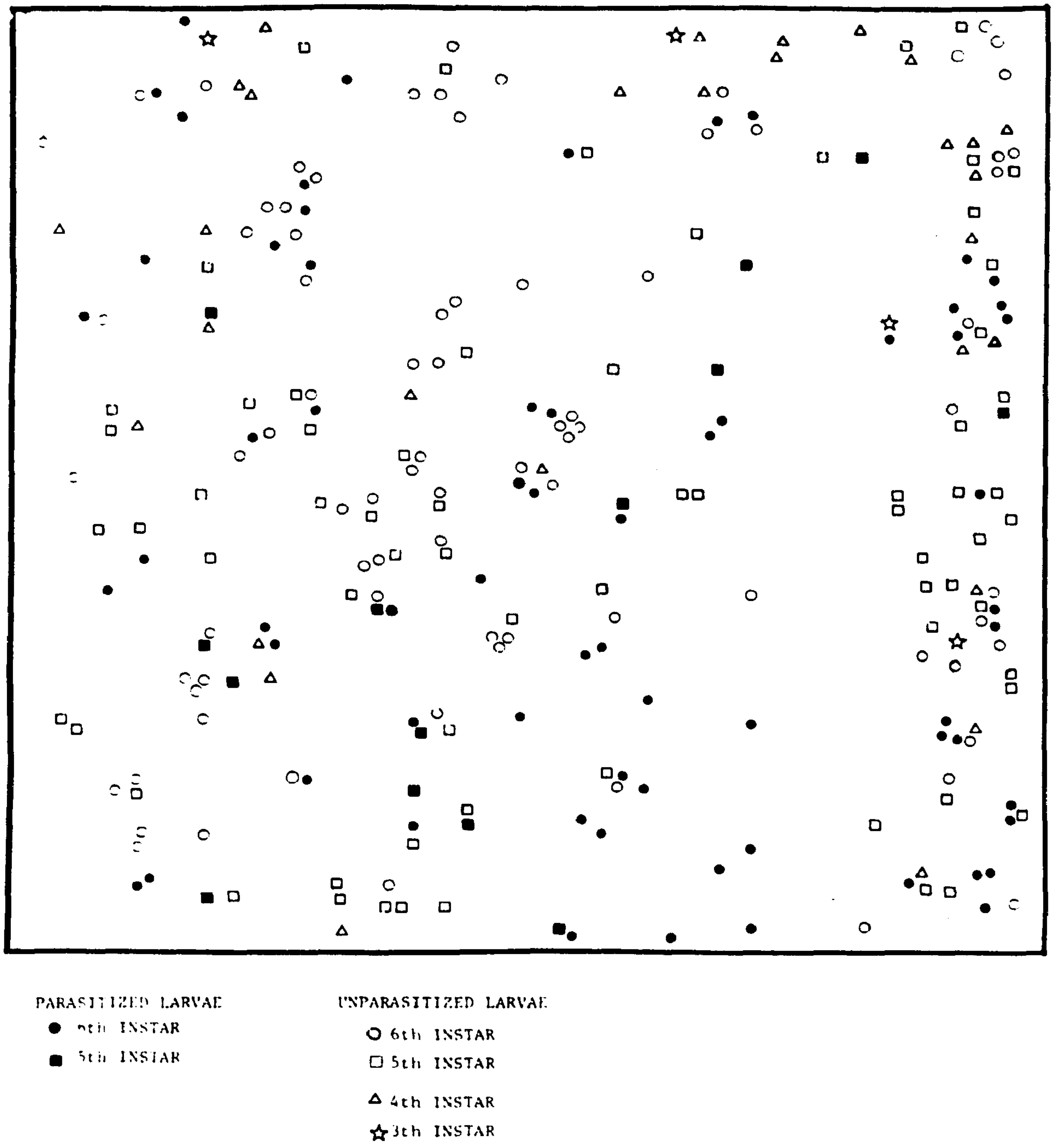

Figure 38. Distribution of parasitized armyworm larvae by <u>Winthemia</u> and unparasitized larvae in 10 x 10 sq. ft. asparagus field (Cass County, July 29, 1977).

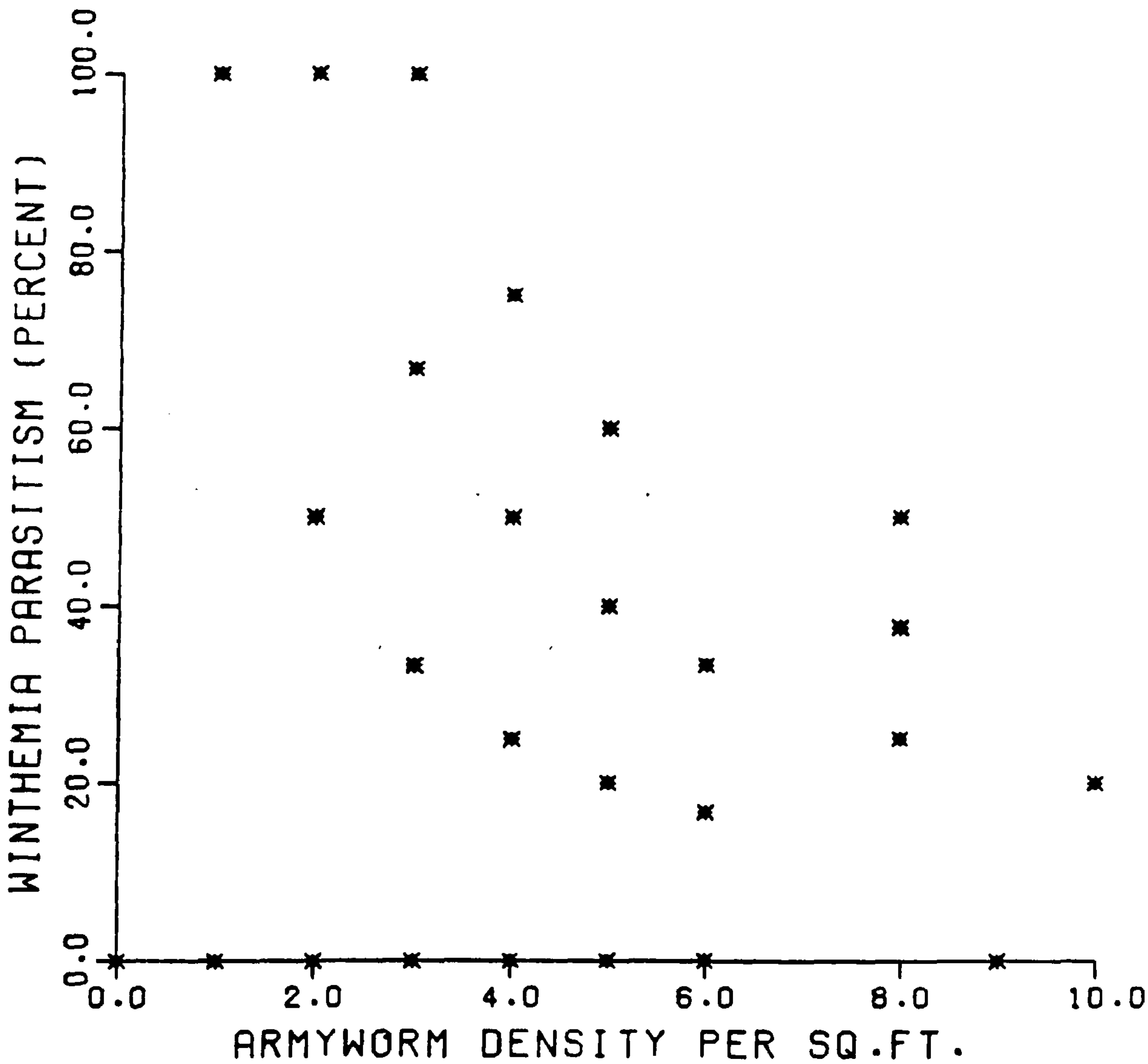

Figure 39. Relationship between armyworm larval density, with Winthemia parasitism in crabgrass-asparagus field (Cass County, July 29, 1977).

relationship between the aggregation of the individual larvae with the success of oviposition by Winthemia. Apparently Winthemia search their hosts and successfully lay their eggs in a random manner.

The basic reason of the difference between Winthemia behavioral response to Heliothis spp. in tobacco, and to the armyworm in a wheat or crabgrass field is the accessibility of the host. The species of Heliothis are common diurnal hosts that often feed exposed, and they are easily attached by Winthemia. Therefore, as Danks (1975a,b) reported, the parasitism of Winthemia on Heliothis has a trend to be density dependent. The armyworm basically is nocturnal. During the day larvae avoid exposure to sunshine by hiding under dry leaves, stones, debries, between soil cracks, inside corn whorls, and in other concealed places. This behavior provides good protection from the parasite attack, especially to Winthemia adults which are active during the day. The asparagus-crabgrass field is a good example of the effective protection of the plants for the armyworm larvae.

The success of egg laying is dependent upon many factors, such as: 1) the amount of protection available, 2) the movement of the host, 3) the density of the host, and 4) the aggregation of the larvae. Even though the distribution of armyworm larvae is clumped, Winthemia parasitism does not respond to the aggregation.

Another method utilized to analyze the data in Figure 38 is by grouping the larvae according to the parasitism and compare their index of dispersion. Table 23 shows the result of the neighbor analysis to 3 different groups of armyworm larvae in the sample plot.

Table 23. Nearest Neighbor Index of Armyworm Larval Groups in Crabgrass Field (Cass County, July 29, 1977)

Group	Mean Nearest Neighbor Distance ($\bar{r}$)	R Index	C Test
All larvae	.23	.76	6.45
Parasitized larvae	.44	.79	3.52
Unparasitized larvae	.29	.77	5.33

Table 23 indicates that the degree of aggregation of the parasitized larvae is lower than the unparasitized larvae and all larvae. The mean distance of the nearest neighbor of the parasitized larvae is farther than the unparasitized larvae. This analysis supports the evidence that Winthemia lays eggs randomly among individuals of armyworm larva in the field.

If the larvae are grouped into instars, there is a difference of aggregation degree between instars 4, 5 and 6 (Table 24). The 4th and 5th instars are distributed randomly while the sixth instar is clumped. This difference might be caused by the higher density of the sixth instar, or the sixth instar moved faster than the fourth and fifth so they found the best places for shelter and food.

Host Preference

Oviposition Rates

Table 25 shows the result of the oviposition experiment A and B (Table 4). Three small grains were tested. Experiment A indicates that more eggs were laid on oat seedlings than on wheat. The moths laid fewer eggs on Downy wheat than on Genesee wheat. It seems that the pubescence character of Downy leaves might reduce the number of eggs laid. Experiment B indicates a different situation. Fewer eggs were found on oats than on wheat, and moths laid more eggs on Genesee than on Downy. Statistically, the differences were not significant. The high variance was due to the fact that some seedlings did not have eggs deposited upon them.

Table 24. Nearest Neighbor Index of Armyworm Larval Instars in Crabgrass Field (Cass County, July 29, 1977)

Group	Mean Nearest Neighbor Distance ($\bar{r}$)	R Index	C Test
Sixth instar	.31	.74	5.79
Fifth instar	.49	.89	1.89
Fourth instar	.75	.81	1.90

Table 25. Number of Armyworm Eggs Laid on Three Host Plants in a Free Choice Test ($\bar{x} \pm$ S.E.)

Plant	Experiment A		Experiment B	
	Egg Masses	Eggs	Egg Masses	Eggs
Downy Wheat (many leaf hairs)	1.0 ± 0.0	3.2 ± 4.3	3.4 ± 1.1	154.8 ± 56.7
Genesee Wheat (few leaf hairs)	1.0 ± 2.0	11.2 ± 19.8	2.6 ± 2.1	100.0 ± 67.0
Oats (no leaf hairs)	2.8 ± 1.9	81.7 ±103.9	1.6 ± 1.5	71.4 ± 82.2

Table 26 presents the result of the oviposition experiments C and D (Table 4). Seven small grains and two grasses were tested. The table shows a tendency for the following conditions:

1) When given a gree choice, the moths showed a preference for small grains over grasses.
2) Oats are less preferred by moths than wheat, barley or rye.
3) Wheat with pubescent leaves reduce the number of eggs laid.
4) Leaf width may be a factor affecting oviposition.

Most eggs were laid in young terminals, which were rolled longitudinally. Requiring a tight place for an oviposition site, the moth will fold the blade and secrete a sticky substance after depositing eggs. This oviposition behavior may explain why moths failed to lay eggs on oats; corn leaves are much wider. In experiment D, eggs laid on corn were found between two leaves that crossed each other. This argument might apply also for oat leaves, but cannot be applied for grasses which have a narrower leaf than small grains. These conclusions need further investigation.

The Developmental Rates

Table 27 shows different small grains (including corn) do not cause a significant difference in the developmental time of larva. Larvae develop slower when fed grasses. Plant hosts do not affect pupal development (Table 28). The relationship between grasses as a food source, weight and mortality of larvae and pupae, is represented by Table 29.

Table 26. Number of Armyworm Eggs Laid on Small Grains and Grasses in a Free Choice Test ($\bar{x} \pm$ S.E.)

Plant	Experiment C		Experiment D	
	Egg Masses	Eggs	Egg Masses	Eggs
Downy Wheat	3.0 ± 2.7	124.0 ± 128.2	2.3 ± 2.2	37.0 ± 104.5
Genesee Wheat	5.3 ± 3.2	376.7 ± 306.3	5.0 ± 2.2	337.2 ± 131.8
Oats	3.3 ± 1.5	96.0 ± 7.0	1.5 ± 1.3	50.5 ± 57.9
Rye (*Secale cereale*)	2.3 ± 1.5	275.3 ± 268.9	2.5 ± 1.0	79.0 ± 79.1
Corn (*Zea mays*)	0	0	1.0 ± 1.7	124.3 ± 215.4
Barley (*Hordeum vulgare*)	0.3 ± 0.6	2.0 ± 3.5	1.3 ± 1.3	134.3 ± 114.1
Timothy (*Phleum pratense*)	0	0	0	0
Sorghum (*Sorghum vulgare*)	1.0 ± 1.7	44.3 ± 76.8	-	-
Brome Grass (*Bromus inermis*)	-	-	0	0

Table 27. Average Longevity of Armyworm Larvae Fed Small Grains and Grasses ($\bar{x} \pm$ S.E.)

Plants	Longevity (Days)	Number of Larvae
Downy Wheat	24.39 $\pm$ 1.72	21
Genesee Wheat	23.41 $\pm$ 1.38	14
Barley	23.97 $\pm$ .91	19
Rye	25.15 $\pm$ 1.02	24
Corn	25.79 $\pm$ .95	18
Oats	24.54 $\pm$ 1.95	11
Timothy	30.33 $\pm$ .87	4
Brome Grass	34.33 $\pm$ 2.89	6

Table 28. Pupal Longevity from Armyworm Fed Small Grains and Grasses ($\bar{x} \pm$ S.E.)

Plant	Longevity (Days)	Number Observed
Downy Wheat	12.75 ± 1.58	18
Genesee Wheat	13.95 ± 1.26	13
Barley	12.79 ± .97	16
Rye	12.65 ± 1.41	19
Corn	12.85 ± .91	13
Oats	13.0 ± 1.0	8
Timothy	11.43 ± .98	10
Brome Grass	12.00 ± 1.07	9

Table 29. Average Weight and Mortality of Larvae and Pupae of Armyworm Raised on Different Small Grains and Grasses ($\bar{x}$ ± S.E.)

Plant	Larval Weight (mg) 10 days	Larval Weight (mg) 15 days	Larval Mortality (%)	Pupa Weight (mg)	Pupal Mortality (%)
Barley	50.6 ± 16.2	418.8 ± 60.6	36.7	304.1 ± 24.71	10.6
Downy Wheat	43.5 ± 2.7	269.6 ± 77.9	50.0	269.0 ± 38.0	16.7
Genesee Wheat	108.5 ± 6.5	307.3 ± 114.7	50.0	235.5 ± 47.8	15.0
Oats	103.6 ± 16.0	234.4 ± 66.4	56.7	209.7 ± 26.0	15.5
Corn	23.1 6.7	161.1 ± 38.9	50.0	297.3 ± 9.0	14.3
Rye	53.5 ± 12.1	418.8 ± 60.7	23.3	262.5 ± 56.0	12.9
Timothy	13.8 ± 2.8	109.6 ± 16.5	66.7	226.6 ± 34.1	23.5
Brome Grass	13.7 ± 61.8	161.8 ± 18.4	60.0	167.2 ± 25.4	37.5

Table 29 indicates that grasses have a different effect on the armyworm development, namely: 1) slower growth, 2) lower larval and pupal weight, and 3) increased mortality. The table shows also that armyworm grow and survive better on rye and barley. There is no significant difference of pubescence of wheat leaves to the growth and survival of the larvae and pupae. For the following reasons this experiment should be duplicated to collaborate the conclusion drawn from the data presented in Table 29.

1. The amount of food (seedlings) that was fed to the larvae was not the same weight. The difference shown in the larval growth and survival might not be caused by the host plant or the quality of food, but it might be caused by the quantity of food consumed.
2. Some larvae were killed by the disease (virus) in late instars. The mortality due to the disease was difficult to separate from mortality due to the host plants. However, assuming that the virus attacked all the larvae at the same rate, the difference of the mortality of larva which were fed different host plants can be assumed as an effect of the host plants.

Food Consumption Rates

Due to some technical constraints, only three plants could be tested completely (barley, Downy wheat, and corn). The average total consumption of one larva on three different crops is presented in Table 30.

Table 30. Average Total Food Consumption of One Armyworm Larva, Reared on Three Plants

Plants	Average Total Food Conumpstion (cm^2 leaf surface)
Corn	293.27
Barley	271.46
Downy Wheat	234.71

The structure of corn leaves (which are smooth and succulent), might be the reason why the larvae consumed more corn leaves than wheat or barley. The effect of leaf pubescence on consumption by the larva needs further investigation.

The average total consumption of one larva also analyzed with respect to the consumption during larval stadia (Table 31) shows the total consumption of larva during six stadia, and the percentage of food consumed by each instar. The percentage of total consumption data show a general character of larval feeding. The total larval consumption (regardless of the host type) was highest during the 5th and 6th instar (Table 31). Detailed data of Tables 30 and 31 are presented in Appendix H.

Table 32 and Figure 40 represent the daily rate of food consumption of armyworm larvae that were fed barley, Downy wheat, and corn. Detailed data about the rate of food consumption for all larvae is presented in Appendix H.

Developmental and Survival Rates

Armyworm

Developmental times of the immature stages of armyworm are readily available in papers by Pond (1960), Guppy (1969), and Kuo et al. (1970) for the oriental armyworm, *Leucania separata* Walk.

The development of each immature stage of the armyworm at constant temperatures from 10 to 31°C is shown in Table 33. Figures 41 and 42 show the rate of development for each of the immature stages, calculated

Table 31. Average Total Food Consumption of Armyworm Larvae

Instar	Downy Wheat Surface Area (cm^2)	Downy Wheat % Total Consum.	Barley Surface Area (cm^2)	Barley % Total Consum.	Corn Surface Area (cm^2)	Corn % Total Consum.
I	.13	.06	.21	.08	.30	.10
II	.26	.11	.23	.08	2.28	.76
III	2.84	1.21	4.06	1.50	3.28	1.09
IV	4.45	1.90	8.84	3.26	15.02	5.04
V	12.49	5.32	34.93	12.86	45.56	15.27
VI	214.54	91.4	223.19	82.22	231.86	77.73
Total	234.71	100.0	271.46	100.0	298.27	100.0

Table 32. Average Daily Rate of Larval Food Consumption of Armyworm

Day	Barley Consumed (cm^2)	Barley Instar	Downy Wheat Consumed (cm^2)	Downy Wheat Instar	Corn Consumed (cm^2)	Corn Instar
1	.06	I	.07	I	.15	I
2	.19	I	.06	I	.13	I
3	.07	II	.09	II	.54	II
4	.13	II	.17	II	.62	II
5	.21	III	1.20	III	1.23	II
6	.75	III	1.64	III	1.16	III
7	1.36	IV	1.58	IV	.30	III
8	1.62	IV	1.81	IV	1.36	III
9	5.51	IV	1.67	IV	2.63	IV
10	3.96	V	4.95	V	3.00	IV
11	10.04	V	4.59	V	3.96	IV
12	13.81	V	3.40	V	4.56	IV
13	8.78	VI	6.98	VI	3.86	V
14	25.38	VI	9.06	VI	15.98	V
15	29.99	VI	9.68	VI	13.12	V
16	37.63	VI	17.22	VI	11.82	.V
17	58.77	VI	32.30	VI	18.95	VI
18	44.22	VI	58.87	VI	19.71	VI
19	20.13	VI	61.40	VI	32.84	VI
20	0	Prepupa	29.10	VI	49.14	VI
21	0	Prepupa	0	Prepupa	66.73	VI
22	0	Pupa	0	Prepupa	43.02	VI
23	0	Pupa	0	Pupa	0	Prepupa
Total	262.61		245.85		295.32	

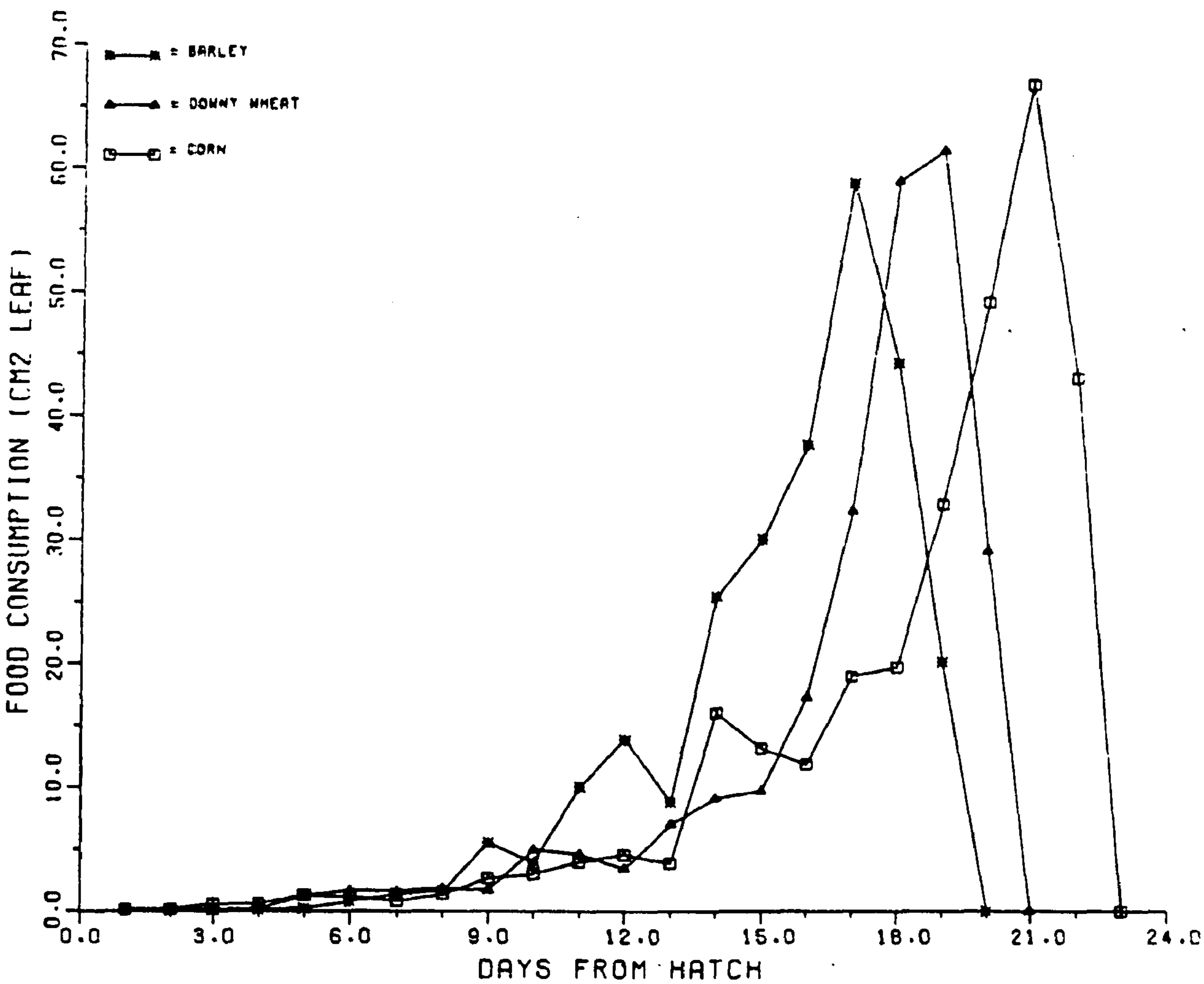

Figure 40. Rate of armyworm larval consumption (barley, wheat and corn).

Table 33. Duration (days) of the Immature Stages of the Armyworm at Constant Temperatures (Guppy, 1969)

Stage	10°	13*	18	17	21	25	29	31
Egg	47.0		18.5	10.4	6.0	4.0	3.3	3.5
Larva	168.0	86.6	76.7	39.9	25.5	18.7	16.3	18.8†
Instar								
I	23.0		12.3	7.3	4.5	3.3	2.5	2.5
II	18.0		9.3	4.5	2.8	2.0	1.5	1.8
III	20.0		8.0	4.8	3.1	2.1	1.7	2.0
IV	21.0		10.0	5.1	3.2	2.2	2.0	2.5
V	25.0		11.3	6.0	3.8	2.7	2.3	4.0
VI	22.0	10.8	25.5	12.8	8.3	6.5	6.4	2.0
VII	39.0†	24.8						6.0
Pupa			45.5	24.0	16.5	11.5	8.8	

*Larvae with seven instars.

†Duration of stage until death of last larvae.

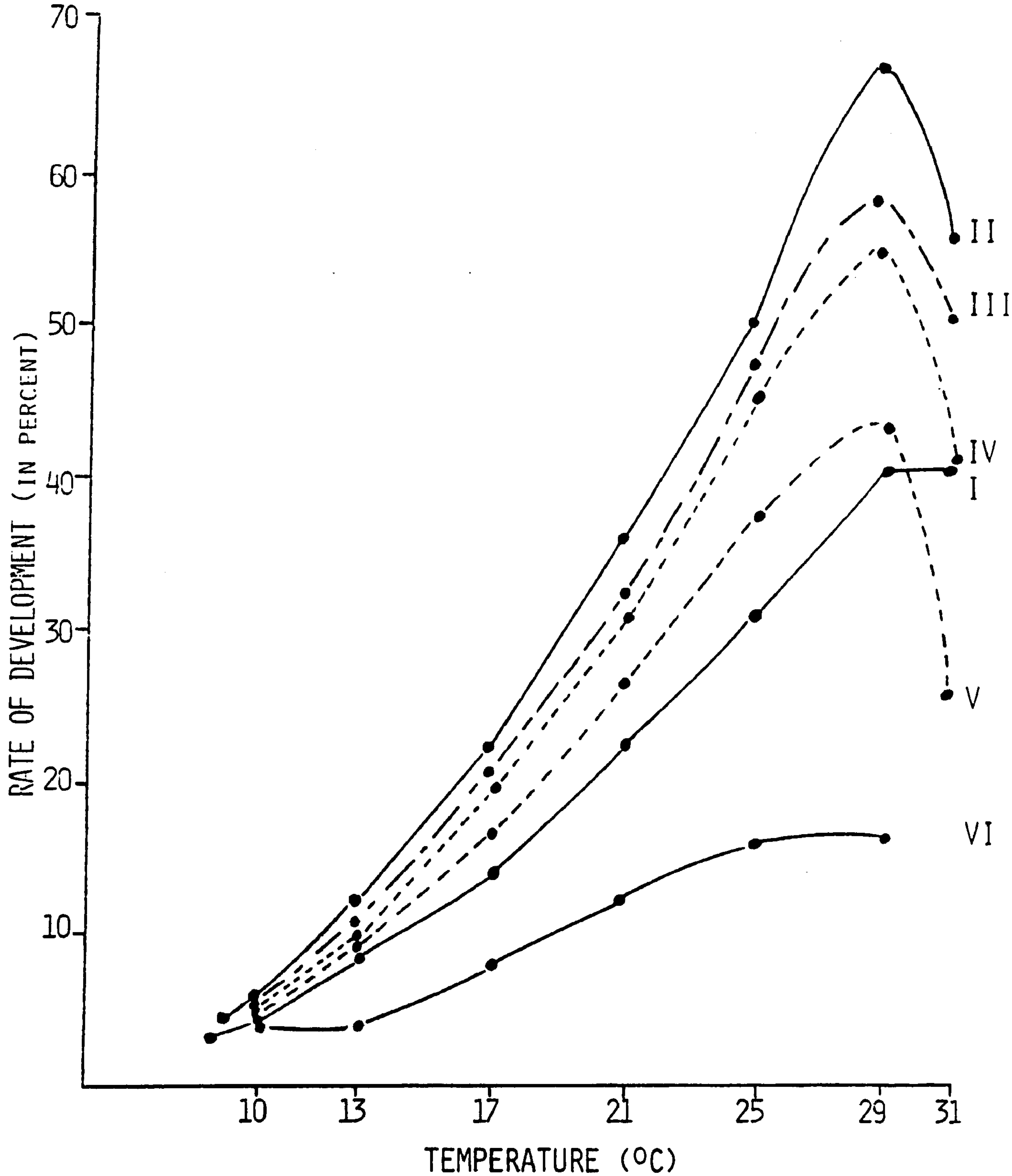

Figure 41. The rate of development of six larva instars of the armyworm at different temperatures (Guppy, 1969).

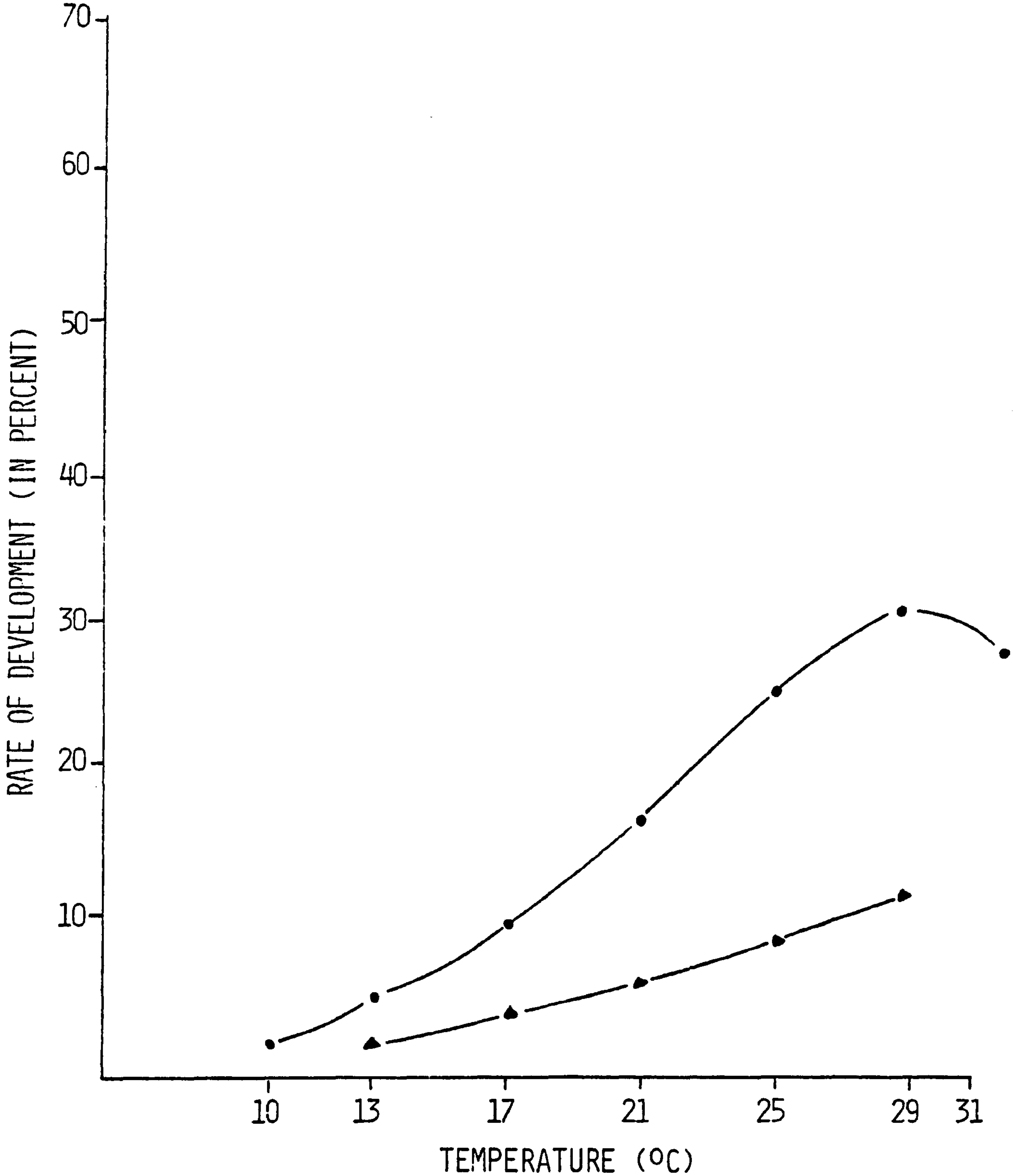

Figure 42. The rate of development of egg and pupa of the armyworm at different temperatures (Guppy, 1969).

as the reciprocal of the duration in days of the stage in question, and plotted against the respective temperatures.

An approximation of the base temperature (developmental zero) can be made graphically by plotting the percent of development per day over different temperatures, finding the point at which the regression line crosses the X axis, and defining that point as the development zero. Figure 43 presents the application of this method in defining base temperatures for armyworm larval stages. The estimated base temperature for each immature instar of the armyworm is presented in Table 34.

There are three main objections to this method: 1) development, in all likelihood, is not a linear process; 2) the developmental zero, in most cases, can be extrapolated far beyond the reasonable limits, and 3) there are probably different developmental zeros for many of the physiological processes involved. Therefore, it is biologically unmeaningful to establish an exact threshold (such as 9.47°C for eggs) on the assumption that no development occurs below that temperature.

Another approach to estimating the developmental zero, is the standard error method. This is accomplished by arbitrarily substituting different thresholds and calculating degree-days from each different constant temperature (Table 33). The mean number of degree-days and standard error was then calculated for all temperatures at each threshold. The point at which standard error is minimized is the best fit estimate of developmental zero for that set of data (see Casagrande, 1971 for similar use).

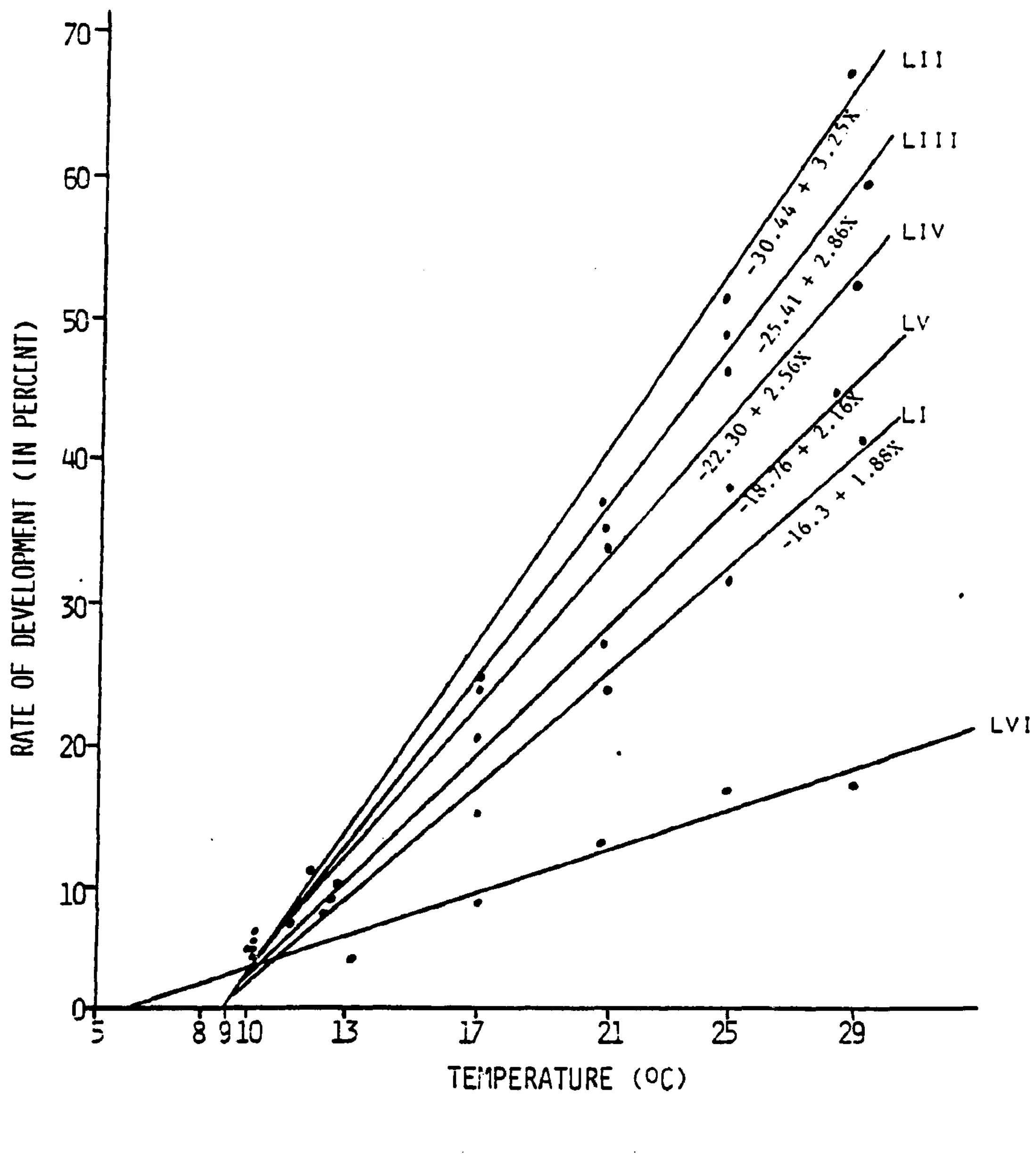

Figure 43. Developmental rate of the six larval instars of the armyworm (Guppy, 1969).

Table 34. Comparison of Regression and Standard Error Method for Developmental Zero of Armyworm Immature Instars (Guppy, 1969)

Instar	Regression Method (0°C)	Standard Errors Method (0°C)
Egg	9.47	8
Larva	8.39	8
L I	8.68	8
L II	9.37	8
L III	8.88	8
L IV	8.71	8
L V	8.69	8
L VI	5.06	8
Pupa	9.65	9

Figure 44 shows standard errors that result from the use of different thresholds in computing degree-day requirements from Table 33. Table 34 is the comparison of developmental zeros estimated utilizing these two methods.

Based on the standard error method, 8°C was used as the developmental zero temperature for all immature instars of the armyworm.

Table 35 shows the ovipositional adult development and number of eggs laid at three different temperatures. The armyworm moth does not lay eggs at 15°C (59.0°F). The difference between 22.8°C and 25.0°C only effects the length of preoviposition period but it does not effect the oviposition period and number of eggs laid.

Unfortunately information about the effect of a wider range of temperatures on the oviposition habit was not obtained due to the failure of the armyworm moth to lay eggs inside the "wooden growth chamber". It seems that the vibration and noise which came from the fan in the chamber obstructed the oviposition of the armyworm moths.

The developmental zero of the armyworm adult based on the available data using standard error method is equal to 16°C (61°F). This figure agrees with Pond's (1960) observations which mentioned that mating did not take place at mean temperatures 40.7, 55.0, and 60°F.

Winthemia rufopicta (Big)

The development period of *Winthemia* at various temperatures was reported by Danks (1975a), and is shown in Table 36.

Developmental zeros (D-O) and rates are used for determination of total degree-days accumulation for each period of growth. Developmental

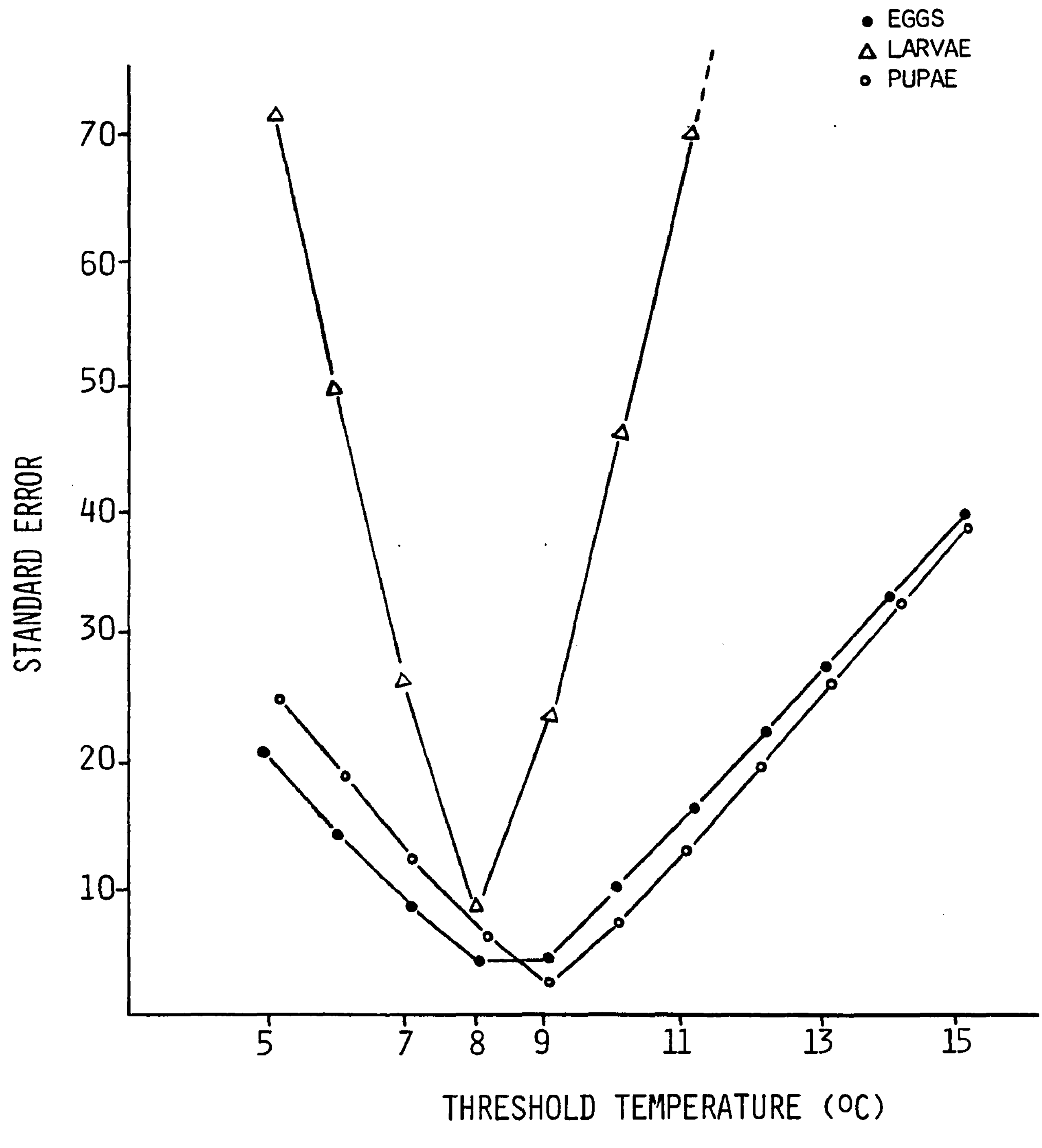

Figure 44. Estimation of developmental zero of immature stages of the armyworm using standard error method (Guppy, 1969).

Table 35. Effect of Three Temperatures on Ovipositional Rate ($\bar{x} \pm$ S.E.)

Temperature (°C)	Preoviposition Period (day)	Oviposition Period (day)	Eggs Laid
15	0	0	0
22.8	10.33 ± 2.31	4.33 ± 2.31	845.00 ± 700.6
25	5.07 ± .58	4.67 ± 3.06	685.67 ± 213.6

Table 36. Duration of Development of *Winthemia rufopicta* at Various Constant Temperatures (Danks, 1975a)

Instar	18.3°C	21°C	24°C	26°C	30°C
Egg	4.6	3.7	3.3	3.2	2.8
Larva	5.7	4.6	2.7	4.0	2.7
Prepupa	2.2	2.3	1.5	1.1	1.2
Pupa					
Male	-	12.0	10.6	9.8	8.6
Female	16.0	18.7	11.6	10.7	9.3

zero estimates are summarized in Table 37 using regression and standard error method. Figure 45 shows the developmental rates and linear regression approximations for each instar. Figure 46 shows standard errors that result from the use of different base temperatures in computing degree-day requirements.

Table 34 indicates that eggs larvae and pupae have a low threshold temperature and prepupae have the highest. This high base temperature is needed because Winthemia overwinters a prepupa. There is no further development until soil temperatures exceed the developmental threshold.

Apanteles militaris Walsh

Calkins and Sutter (1976) provide only limited data of developmental rates of Apanteles inside the armyworm larvae for three constant temperatures (21.1, 26.7 and 27°C). Using the standard error method the threshold temperature of Apanteles larva inside the host is estimated to be 17°C (Figure 47) which is high for an insect. The average rate of development was not significantly different for parasites in the 3rd, 4th and 5th stage of the host larvae.

Related to the high base temperature, Calkins and Sutter (1976) stated that this parasite seems to develop well at moderately high temperatures. But in the field, its slow development at lower temperatures probably would prevent it from becoming a major deterrent factor during the cool spring weather.

Individuals spent 6.4 days as a cocoon at 27°C (Calkins and Sutter, 1976), and 7.2 days at 21°C (based on data observations at the Natural Science Building). Adult longevity was 6-7 days at 27°C, and 10 days at

Table 37. Comparison of Regression and Standard Error Methods for Developmental Zeros of *Winthemia* Stages (Danks, 1975a)

Life Stage	Regression D-0	Standard Error D-0
Egg	-1.93°C	0°C
Larvae	2.28	2
Prepupae	8.14	12
Pupae	2.10	2

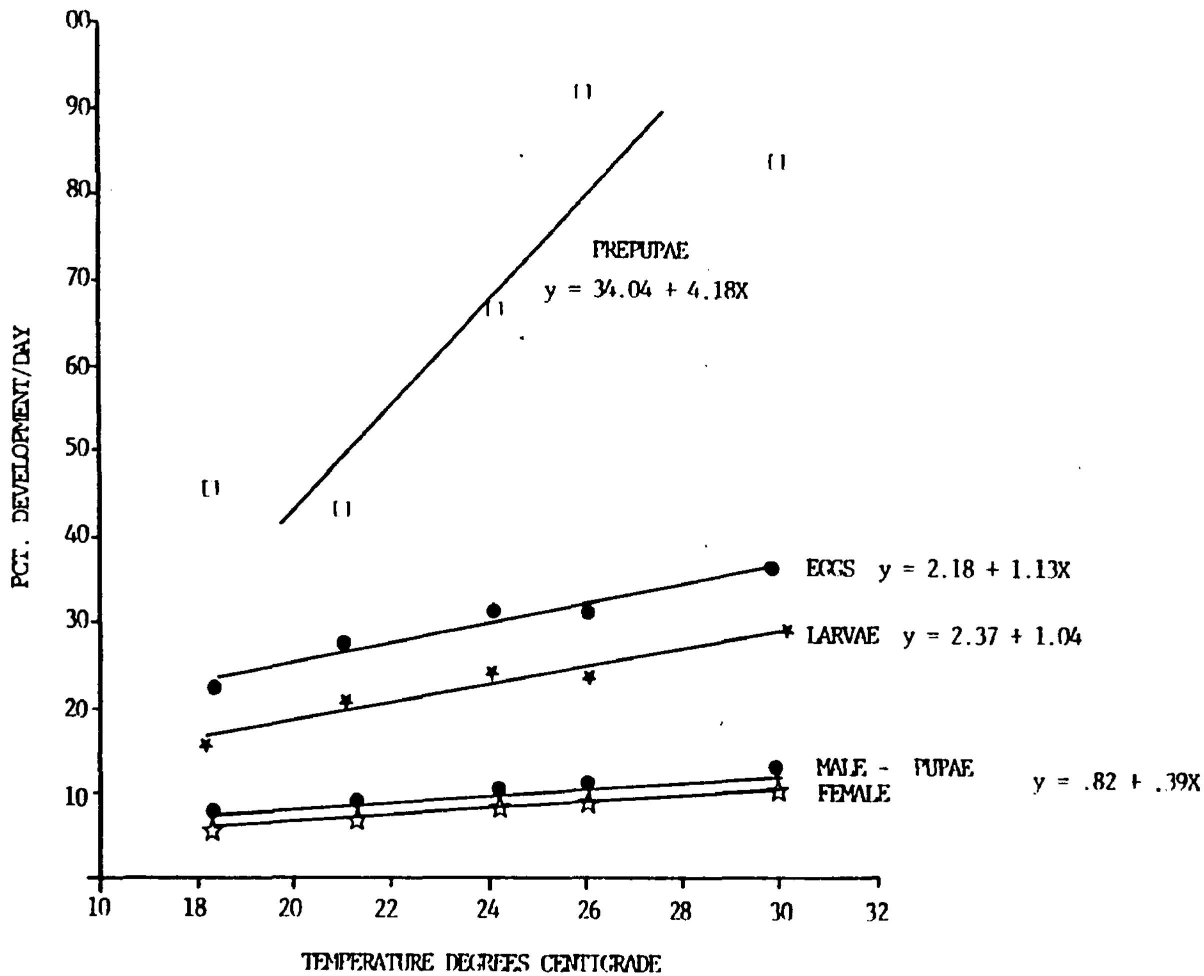

Figure 45. Developmental rate of Winthemia rufopicta life stages.

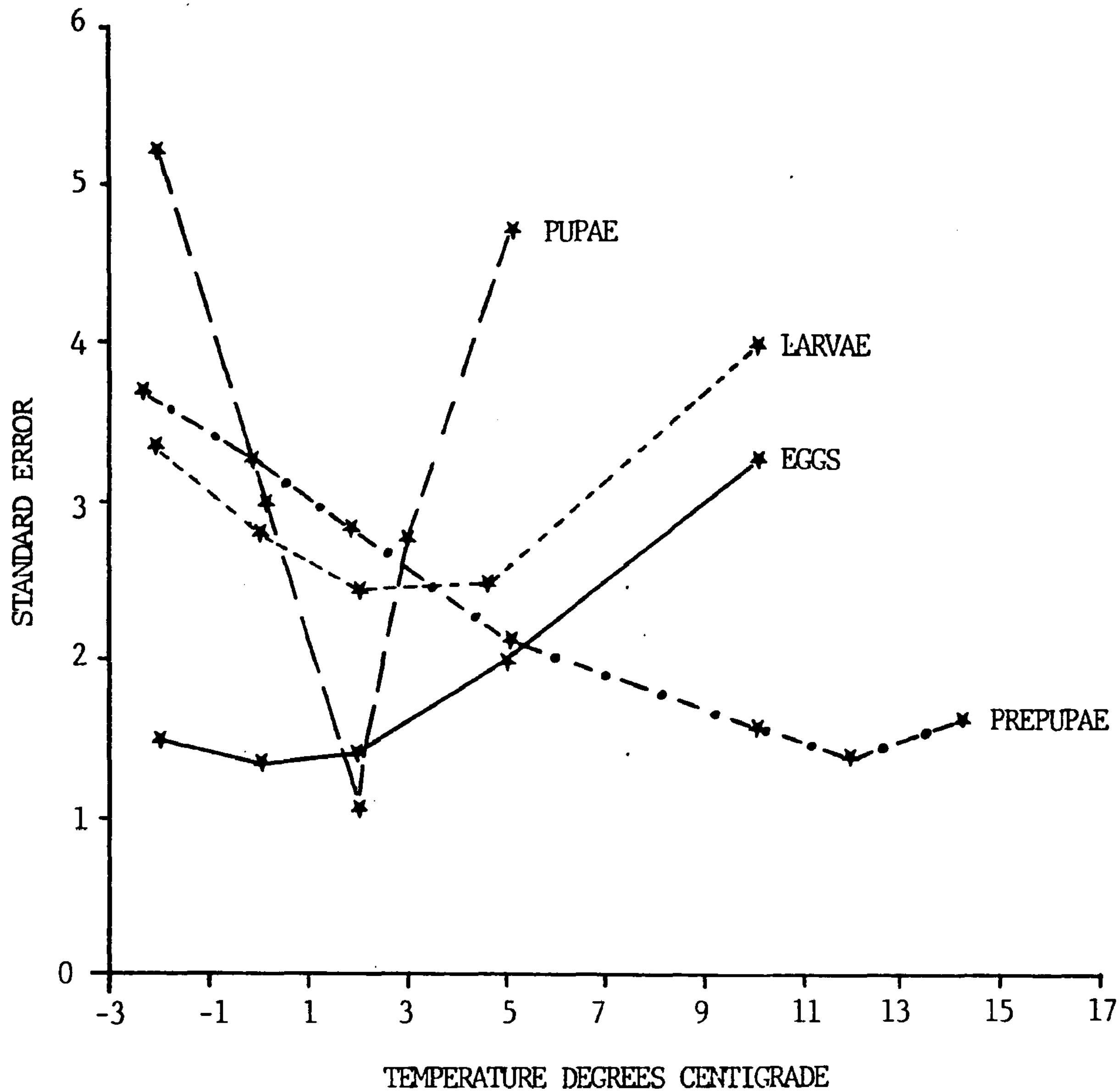

Figure 46. Estimation of developmental zero of *Winthemia* life stages using the standard error method.

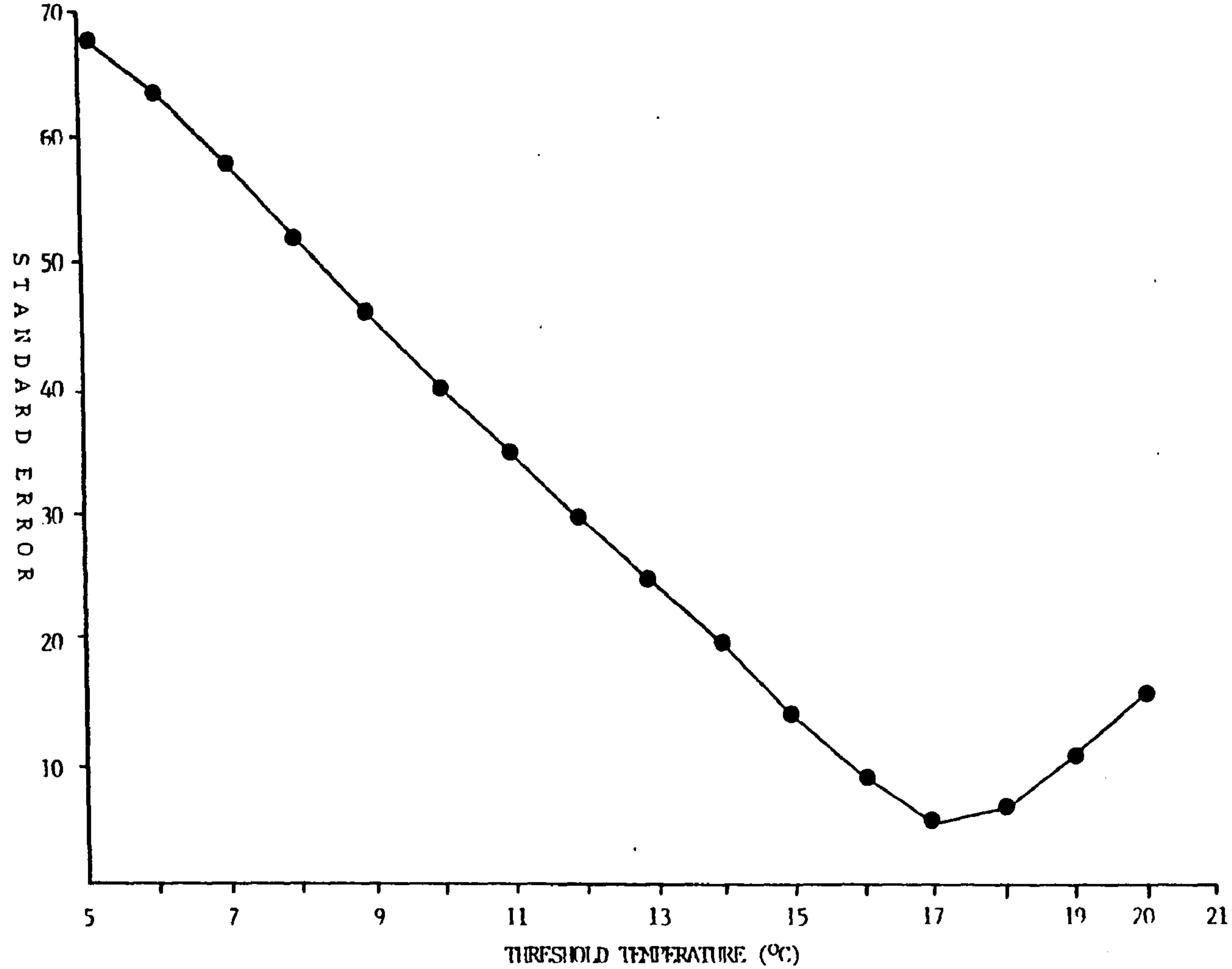

Figure 47. Estimation of developmental zero of Apanteles militaris larvae (Calkins and Sutter, 1976).

10°C; the overall life cycle ranged from 17-30 days, with the average at 19 days. From this data threshold temperatures of cocoons and adults could be approximated.

Effect of Temperatures on Survival

McLaughlin (1962) investigated the effect of temperature upon larval mortality using moderate to high temperatures. Unfortunately, he did not include the first and second instar in his study. Guppy (1969) reported the survival of all larval instars under two temperature extremes (10° and 31°C). Combining this data of both papers, Table 38 was constructed. An average of 96% of first and second instar larvae survived when they were reared at 22.97°C. All sixth instar larvae failed to complete their development at 35°C (McLaughlin, 1962). Based on the available data, Figure 48 was constructed. Figure 49 shows the effect of temperature on eclosion and adult emergence. The data was obtained from Pond (1960), Guppy (1969), Kuo et al. (1970), and observations at 22.7°C.

For the purpose of population modelling, the effect of temperature upon survival is expressed as instantaneous survival rate (Fulton, 1978). This is done because the simulation model is continuous as opposed to a discrete, and the assumption was made that temperature dependent mortalities operated continuously. This implies that:

$$Pt = P_o\, e^{at}$$

where

t = time

Pt = Population at time t

P_o = Initial Population

a = Instantaneous survival rate.

Table 38. Survival of Armyworm Larvae at Different Constant Temperatures in °C (McLaughlin, 1962, Guppy, 1969)

Instar	10°	22.2°	23.9°	25.6°	29.4°	31°	33.3°
I	62.5	--*	--	--	--	94.74	--
II	70.0	--	--	--	--	100.0	--
III	71.43	78.85	--	--	80.70	91.67	66.10
IV	46.67	89.45	--	--	82.97	93.94	51.05
V	71.43	93.57	95.0	--	79.7	70.97	86.27
VI	20.0	63.10	--	60.0	60.7	36.36	16.15

*No data available.

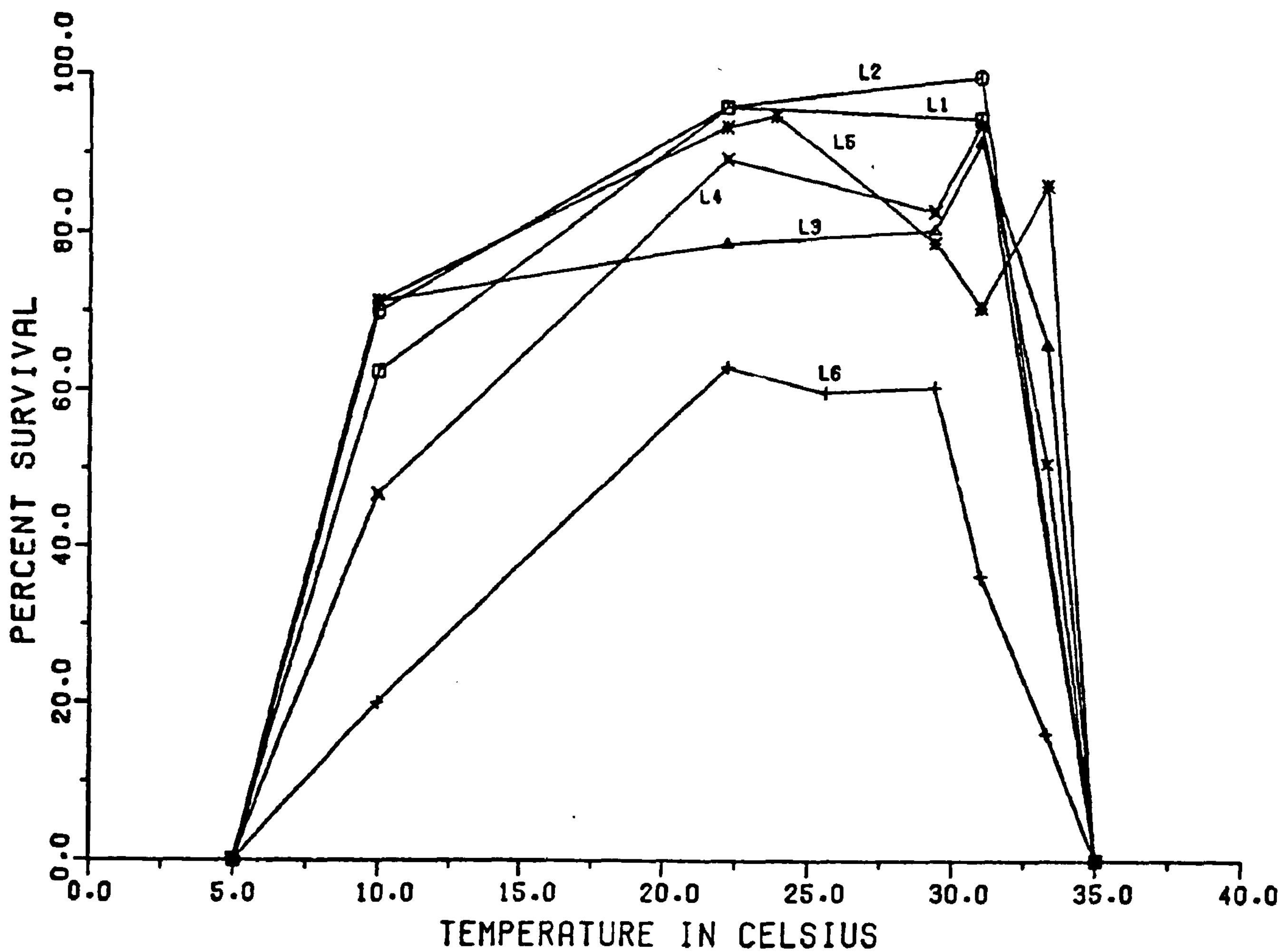

Figure 48. Survival of armyworm larvae as a function of temperature in °C (McLaughlin, 1962 and Guppy, 1969).

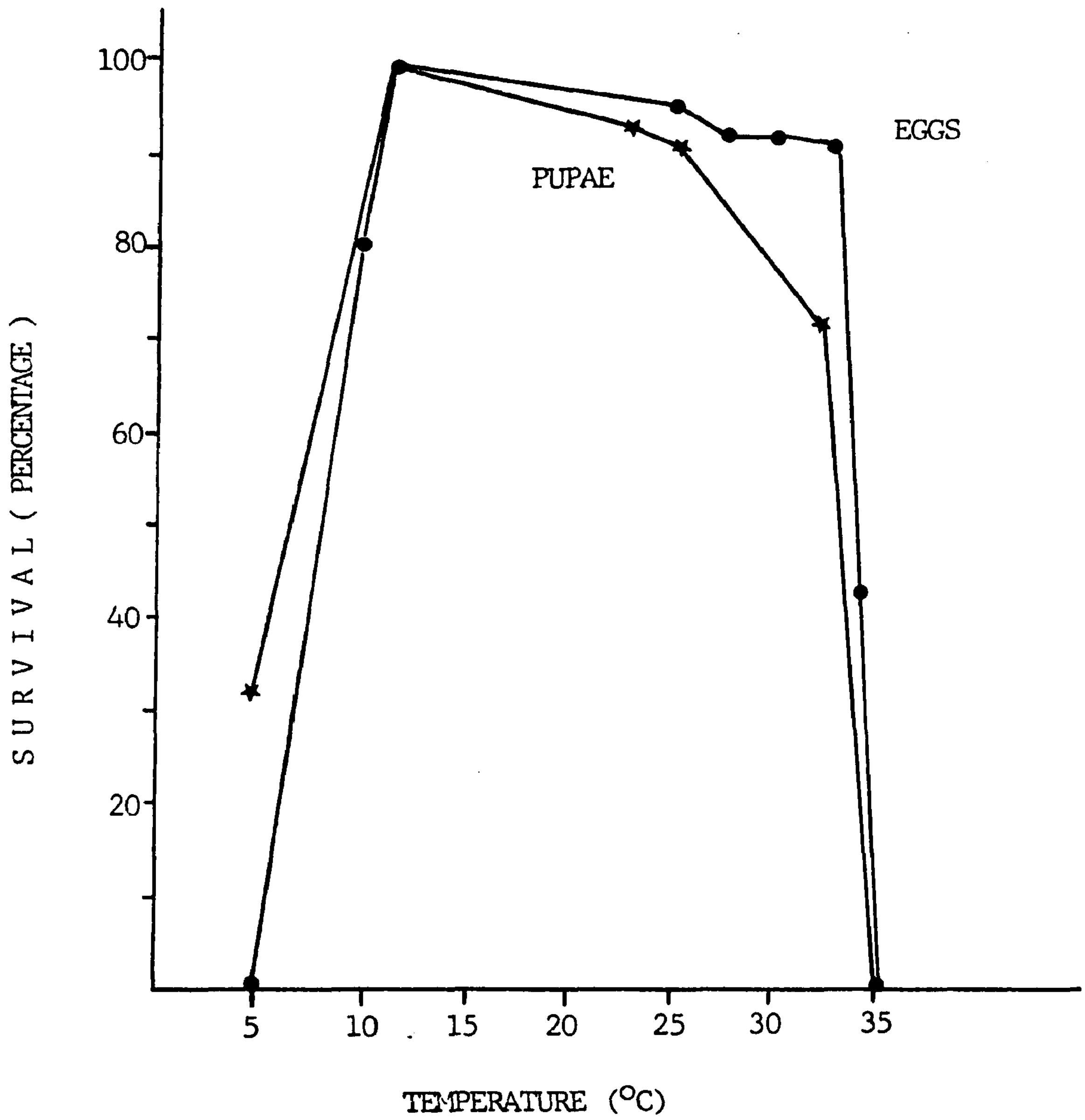

Figure 49. Survival of eggs and pupae as a function of temperature in °C.

There is an interaction between the survival and the time spent in the stage. They both seem to be a function of temperature. This interaction can be removed using the instantaneous survival rate. If DEL is equal to the time the individual remains in one stage then the instantaneous survival rate (a) is calculated as:

$$a = \ln(Pt/Po)/DEL$$

Using the data in Tables 34 and 38, the instantaneous survival rate of armyworm instars were calculated (Figures 50, 51 and 52).

Late Fall Development

The result of observations of the development of armyworm larvae reared in the insectary is presented in Table 39. The table shows that the armyworm keep feeding and changing instars under the low temperature and short day length. This observation indicates that the armyworm does not go to diapause; but spent the winter as a hibernating larvae.

Supercooling Test

Table 40 shows the mortality of armyworm pupae after being refrigerated at 4.4°C (40°F). The table indicates that the armyworm pupae have a low resistance to exposure under low temperatures for a long period of time. This observation supports Breeland's (1958) statement that the armyworm is less likely to overwinter as a pupal stage.

The supercooling point of armyworm instars is presented in Table 41. The table shows a difference in supercooling between instars. The fourth larvae has a supercooling level lower than the fifth and sixth larvae. The difference might be due to the size of individuals.

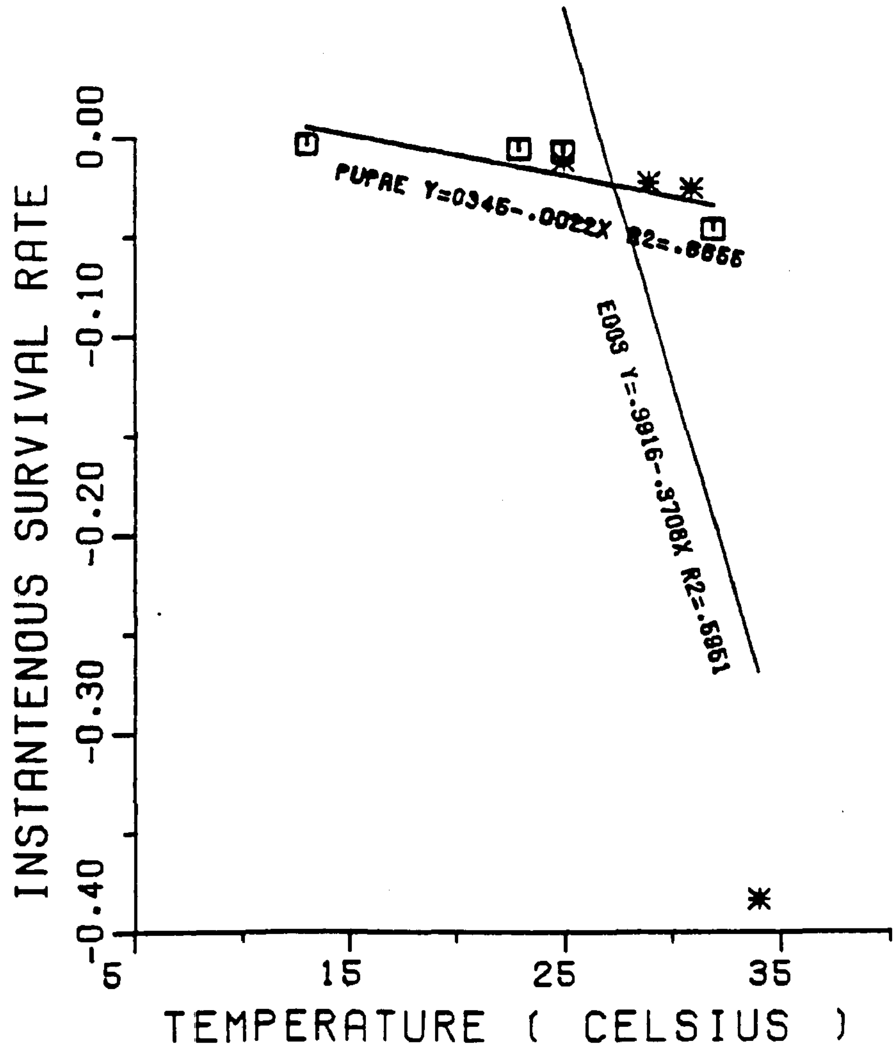

Figure 50. Instantaneous survival rate of eggs and pupae of the armyworm.

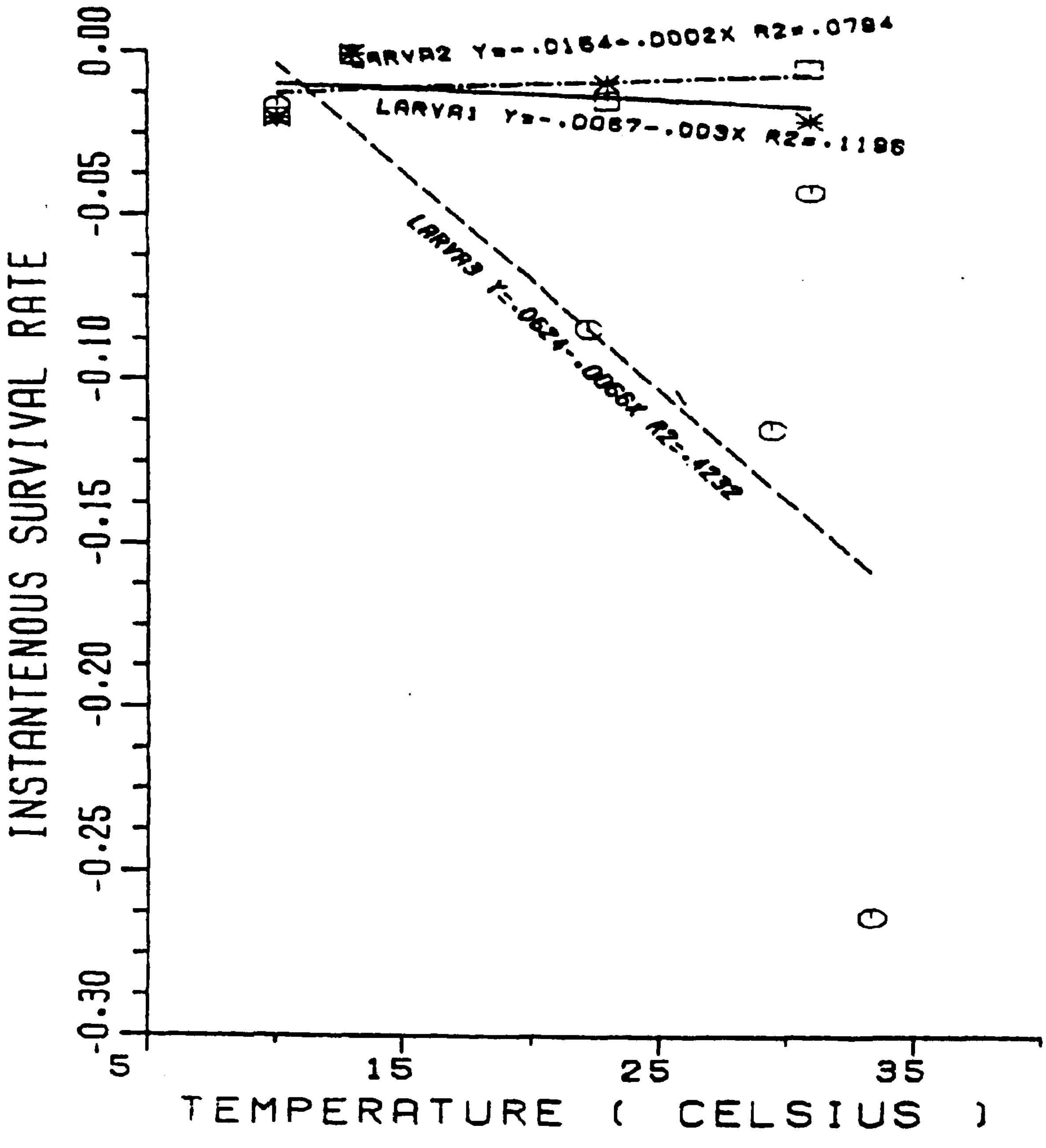

Figure 51. Instantaneous survival rate of 1st, 2nd, and 3rd instars of armyworm larvae.

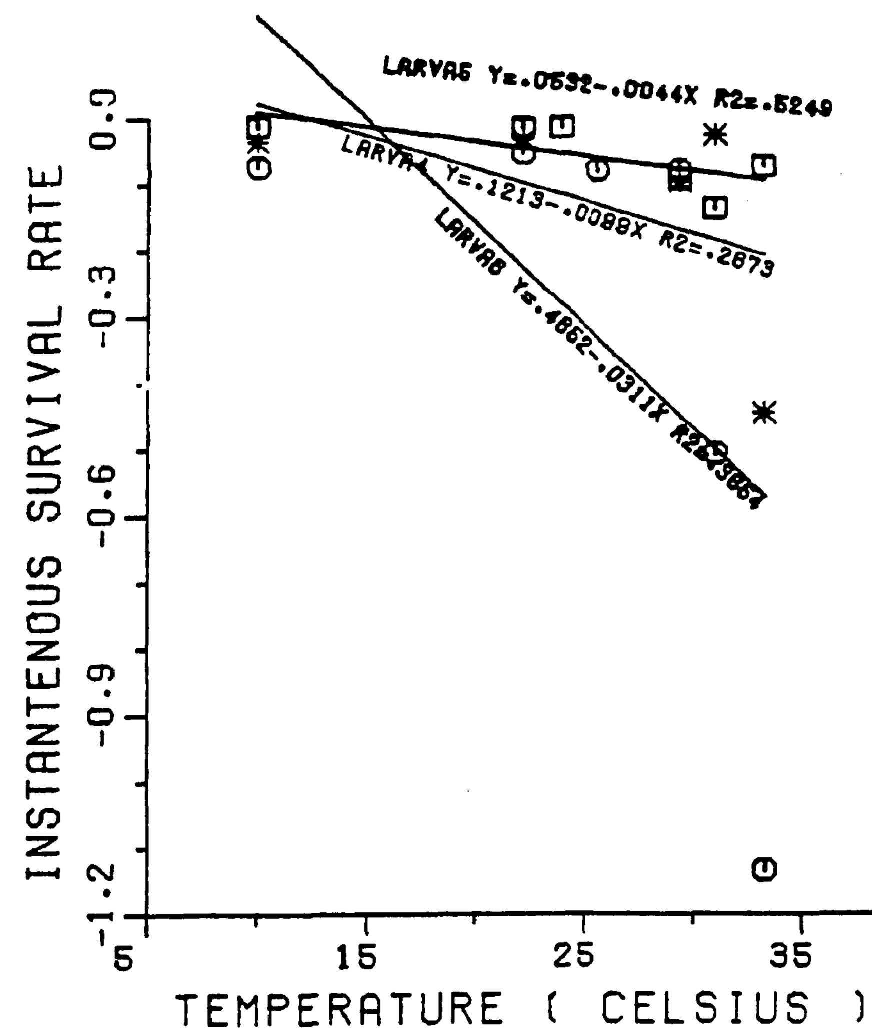

Figure 52. Instantaneous survival rate of 4th, 5th and 6th instars of armyworm larvae.

Table 39. Development of Armyworm Larvae Before the First Frost (East Lansing, 1977)

Instar	Date Started	Total D.D. Accumulation (46°F)	Day Length (hr)
L I	9- 7-77	47.0	13.0
L II	9- 9-77	87.7	13.0
L III	9-16-77	174.0	12.5
L IV	10- 6-77	137.1	12.0
L V	11- 2-77	83.0*	10.25

*Until the first frost on 11-11-77.

Table 40. Number of Pupae Producing Adults After Being Refrigerated at 40°F

Refrigeration Period	Number of Pupae	Number of Moths		Dead Pupae
		Normal	Malfunction	
3 months	143	32	28	83
4 months	117	0	2	115

Table 41. Supercooling of Armyworm Instars Under Natural and Artificial Preconditioning (°F)

Instar	Natural Preconditioned	Mean	Artificial Preconditioned	Mean
4th larva	10 13	11.5	12 11	11.5
5th larva	10, 13 19, 20	15.5	13 12	12.5
6th larva	19, 20 20, 21	20.0	14, 16 15	15.0
Pupa	13	13.0	14	14.0

Salt reported (1964) that the size of the insect reduces its supercooling ability. The natural preconditioned specimens did not have a lower supercooling point, but in fact it was higher than the artificial preconditioned specimens. The pupal supercooling point obtained from this experiment was 13.5°F (-10.28°C) which is different from the result of Roberts et al. (1972). They found the supercooling of the pupae is -24.29°C (-11.72°F).

This experiment was done using feeding larvae. These larvae probably had food particles left in the gut. These particles could initiate and speed-up the formation of ice-crystal nuclei and therefore the larvae would reach the point more quickly. If the period of artificial preconditioning is lengthened by another 2 or 3 days, the supercooling point will eventually drop even further. Salt (1953) using the pale western cutworm, Agrotis orthogana Morr, found that the supercooling point of the feeding larvae was averaging -10.3°C (13.46°F) and ranging from -15.4°C to -6.9°C. The supercooling points of non-feeding larvae were significantly lower than the feeding larvae, averaging -23.6°C (-10.48°F). Salt's data on feeding larvae does not differ from the results of this experiment. It seems that the supercooling points of armyworm instars are close to the supercooling points of Agrotis.

Frost Mortality

The first frost of 1977 was on November 11. On November 14, cups of larvae were checked, and it was found that all exposed larvae were killed by the frost. It seems that the grass cover over the cup was not enough protection from the freezing temperature. The armyworm larvae must over-winter under a thick layer of grass and other concealed sites which can provide them with better insulation.

must over-winter under a thick layer of grass and other concealed sites which can provide them with better insulation.

CONCLUSIONS

This study has been an attempt to initiate the investigation of the distribution and bionomics of the armyworm, Pseudaletia unipuncta (Haw.), which has become increasingly important in Michigan the last four years. The study was performed both in the field and the laboratory during 1976 and 1977.

At the beginning of the season the population of the armyworm was started from two sources. The first group was middle instar of larvae which became active from the over-wintering stage. The second group were migrating adults from the southern states. These two populations produce five or sixth significant peaks of the armyworm flight activity. The investigation of the interrelationship between the two populations, its host crop and parasites' development are highly essential for the management of the armyworm.

Moths lay eggs on green and dry leaves of grasses and small grains. Moths have an ovipositional preference for small grains over grasses, and it is apparent that oats are less preferred than other small grains. The cause of non-preference in laying eggs may be the width of leaves.

The armyworm larvae are polyphagous, feeding on small grains, corn and grasses. From the laboratory observations it was found that larvae fed grass had: 1) a slower development rate, 2) high mortality, and 3) lower larval and pupal weight gain than those fed small grains or corn.

This food preference might explain the behavior of the larvae moving from grassy areas to the small grain or corn fields. The larvae consume more corn leaf area than barley or wheat.

The distribution pattern of larvae in the field is dependent upon the availability and the distribution of food and places to hide during the day; the larval density; and also the age structure. The distribution of larvae in a wheat field in 1976 was random and the trend seems to be uniform, because the high level of the population caused the larvae to move away from each other. Due to the low larval density in 1977, the distribution of larvae in the wheat was random.

The distribution pattern of second generation larvae in the asparagus and crabgrass field was highly clumped. The larvae seems to aggregate in the heavy concentration of crabgrass and avoided asparagus plants as a place to hide. Computer programs have been developed to analyze the distribution data by using nearest neighbor and quadrat count method. There is no significant difference of individual patterns between field plots and observation dates. The study demonstrates the application of Relative Net Precision (Cochran, 1963) to obtain the optimum sampling unit for a certain distribution pattern. For the crabgrass field the optimum sampling unit was approximately 2.5 sq. ft.

The relationship between the armyworm and its parasites *Winthemia rufopicta* (Big), *Apanteles militaris* Walsh, and *Meteorus communis* (Cress.) has been studied but only during the armyworm first generation. *Winthemia* is an active parasite, having a high numerical and functional response, and attacks late instars of armyworm larvae. *Winthemia* parasitism in the outbreak year such as in 1976 was high, and it is highly dependent upon the larval density. Under high density, late instars are migrating to the bordering fields, and are more exposed to Winthemia attacks. Winthemia parasitism in 1977 was lower than the parasitism of Apanteles and Meteorus. This low parasitism might be due to the movement of Winthemia flies to other more suitable hosts, or to the interspecific competition.

Apanteles is a host-specific parasite and it attacks early instars of armyworm larva. Its parasitism was high in 1977 when the armyworm population was low. Even though its presence has always been noticed in the field, this parasite seems to have a low response to the density of armyworm. The specific interrelationship between Apanteles and armyworm populations should be a future area of study. Meteorus parasitism was significant in 1977, and this parasite seems to be able to coexist with Apanteles.

Both parasites, Winthemia and Apanteles, reduce significantly the food consumption of armyworm larvae. Winthemia reduces larval food consumption by 50%, and Apanteles by 84%. There seems to be a positive relationship between the number of Apanteles inside the armyworm and the amount of food consumed by the parasitized larvae.

By analyzing the development and mortality rates data of Guppy (1969) and McLaughlin (1962), 46°F was determined to be the temperature base for the immature stages of the armyworm. From these data the equations for the instantaneous rate of survival of immature stages were derived. Armyworm moths did not lay eggs at 15°C.

The over-wintering study indicated that armyworm over-winters in a hibernation stage rather than a diapause larvae. The supercooling points for a feeding larvae is approximately 15°F, and for a preconditioned (24 hours) larvae is approximately 13°F. This study should be expanded to include a longer preconditioning period. It was apparent that the supercooling points of the armyworm did not differ from the supercooling point of other noctuids such as the pale western cutworm (Salt, 1953).

LITERATURE CITED

LITERATURE CITED

Anscombe, F. J. 1949. The Statistical Analysis of Insect Counts Based on the Negative Binomial Distribution. Biometrics, 5. 165-173.

Anscombe, F. J. 1950. Sampling Theory of the Negative Binomial and Logarithmic Series Distributions. Biometrika, 37. 358-382.

Bliss, C. I. and D. W. Calhoun. 1954. An Outline of Biometry. Yale Co-op. Corp., N-w Haven. 272 pp.

Breeland, S. G. 1958. Biological Studies on the Armyworm, Pseudaletia unipuncta (Haworth) in Tennessee. Journal Tenn. Acad. Sci. 33: 263-347.

Calkins, C. D. and G. R. Sutter. 1976. Apanteles militaris and its Host Pseudaletia unipuncta. Biology and Rearing. Env. Ent. 5(1) 147-150.

Casagrande, R. A. 1971. An Approach to Alfalfa Weevil Management in Michigan. M. S. Thesis. Michigan State University.

Clark, P. J. and F. C. Evans. 1954. Distance to Nearest Neighbor as a Measurement of Spatial Relationships in Populations. Ecology 25: 283-303.

Cochran, W. G. 1963. Sampling Techniques (Second Edition) John Wiley and Sons, Inc., 413 pp.

Cottam, G. and J. T. Curtis. 1956. The Use of Distance Measures in Phytosociological Sampling. Ecology 37: 451-460.

Danks, H. V. 1975. Factors Determining Levels of Parasitism by Winthemia rufopicta (Diptera: Tachinidae) with particular reference to Heliothis spp. (Lepidoptera: Noctiuidae) as Hosts. Can. Ent. 107: 655-684.

Danks, H. V. 1975. Seasonal Cycle and Biology of Winthemia rufopicta (Diptera: Tachinidae) as a parasite of Heliothis spp. (Lepidoptera: Noctuidae) on Tobacco in North Carolina. Can. Ent. 107: 639-654.

Davis, J. J. and A. F. Satterthwait. 1916. Life History Studies of Cirphis unipuncta the True Armyworm. Jour. Agr. Res. 6(21): 799-812.

Dimmoff, K. 1977. Programmer's Guide to Statistical Plotting On-line Command Systems. Pest Management Report, Michigan State University, East Lansing, 108 pp.

Elliott, J. M. 1977. Some Methods for the Statistical Analysis of Samples of Benthic Invertebrates. Freshwater Biol. Ass. Sci. Publ. 25. 160 pp.

Forbes, S. A. 1905. The Armyworm. Ill. Nat. Hist. Survey Ent. Ser. Circ. 7, 9 pp.

Fulton, W. C. 1978. Development of a Model for On-line Control of the Cereal Leaf Beetle (Oulema melanopus (L.)). Pest Management Report No. 17. Ph.D. Dissertation, Department of Entomology, Michigan State University, East Lansing, 130 pp.

Gage, S. H. and D. L. Haynes. 1975. Emergence Under Natural and Manipulated Conditions of Tetrastichus julis, an Introduced Larval Parasite of the Cereal Leaf Beetle, with Reference to Regional Population Management. Environ. Entomol. 4: 425-434.

Greig-Smith, P. 1952. The Use of Random and Contagious Quadrats in the Study of Plant Communities. Annals of Botany N. S. 16: 293-316.

Greig-Smith, P. 1964. Quantitative Plant Ecology (end. ed.). London, 256 pp.

Guppy, J. C. 1967. Insect Parasites of the Armyworm, Pseudaletia unipuncta (Haworth) with notes of species observed in Ontario. Can. Ent. 99: 94-106.

Guppy, J. D. 1969. Some Effects of Temperature on the Immature Stages of the Armyworm Under Controlled Conditions. Can. Ent. 101: 1320-1327.

Harcourt, D. G. 1971. Design of a Sampling Plan for Studies on the Population Dynamics of the Diamond Back Moth, Plutella maculipennis (Curt.). Can. Ent. 93, 820-831.

Harcourt, D. G. 1963. Population Dynamics of Leptinotarsa decemlineata (Say) in Eastern Ontario. I. Spatial Pattern and Transformation of Field Counts. Can. Ent. 95: 812-820.

Harcourt, D. G. 1965. Spatial Pattern of Cabbage Looper, Trichoplusia ni, on crucifers. Ann. Ent. Soc. Amer. 58, 89-94.

Kuo, C. A., F. W. Hsiung, C. C. Hui, and C. H. Chen. 1965. Effect of High Temperatures on the Development and Reproduction of the Armyworm Leucania separata. Walker I. Development and Hatching of the Eggs. Act. Entomol. Sinica 14: 61-76.

McLaughlin, R. E. 1962. The Effect of Temperature Upon Larval Mortality of the Armyworm, Pseudaletia unipuncta (Haworth), J. of Insect Pathol. 4: 279-284.

Morisita, M. 1959. Measuring of the Dispersion of Individuals and Analysis of the Distributional Patterns. Mem. Fac. Sci. of Kyushu Univ., Ser. E2: 215-235.

Morisita, M. 1962. Iδ-Index, a Measure of Dispersion of Individuals. Res. Popul. Ecol. 4, 1-7.

Morisita, M. 1964. Application of Iδ- Index to sampling techniques. Res. Popul. Ecol. 6: 43-53.

Morris, R. F. 1955. The Development of Sampling Techniques for Forest Insect Defoliators, with Particular References to Spruce Budworm. Can. J. Zool. 33: 225-294.

Mukerji, M. K. and J. P. Guppy. 1970. A quantitative Study of Food Consumption and Growth in Pseudaletia unipuncta. Can. Ent. 102: 1179-1188.

Parker, F. D. and R. E. Pinnell. 1973. Effect on Food Consumption of the Imported Cabbageworm When Parasitized by Two Species of Apanteles. Environ. Entomol. 2: 216-9.

Pennington, W. E. 1916. Notes on Rogas terminals Cress. Jour. Econ. Ent. 9(4): 401-406.

Pielou, E. C. 1974. Population and Community Ecology: Principles and Methods. Gordon and Breach, New York, 424 pp.

Pielou, E. C. 1977. Mathematical Ecology. John Wiley, New York, 385 pp.

Pond, D. D. 1960. Life History Studies of the Armyworm, Pseudaletia unipuncta (Lep: Noctuidae) in New Brunswick. Ann. Entom. Soc. Amer., 53: 611-665.

Riley, C. V. 1883. The Armyworm. Third Report of the United States Entomological Commission, pp. 89-156.

Roberts, S. J., E. J. Armbrust, and D. K. Sell. 1972. Supercooling Points of Several Species of Lipidoptera Found on Soybeans. Env. Ent. 1: 671-672.

Salt, R. W. 1953. The Influence of Food on Cold Hardiness of Insects. Can. Ent. 85: 261-269.

Salt, R. W. 1961. Principles of Insect Cold-Hardiness. Ann. Rev. Entomol. 6: 55-74.

Salt, R. W. 1964. Trends and Needs in the Study of Insect Cold-Hardiness. Can. Ent. 96: 400-405.

Slansky, F. 1978. Utilization of Energy and Nitrogen by Larvae of the Imported Cabbageworm, Pieris rapae as affected by Apanteles glomeratus. Environ. Entomol. 7: 197-185.

Tanaka, A., Y. Kuchi, and T. Wakikado. 1960. Ecology of the Armyworm (Leucaniae separata). I. Proc. Assoc. Pl. Prot. Kyushu 16: 37-39.

Tanaka, A. and T. Wakikado. 1974. Ecology of the Armyworm, Mynthimna (Leucania) separata (Walker). V. Food Consumption of Larvae. Proc. Assoc. Pl. Prot. Kyushu 20: 32-4.

Tower, D. G. 1915. Biology of Apanteles militaris. J. Agric. Res. 5: 495-507.

Waters, W. E. 1959. A Quantitative Measure of Aggregation in Insects. Jour. of Econ. Ent. 52: 1180-1184.

Waters, W. E. and W. R. Henson. 1959. Some Sampling Attributes of the Negative Binomial Distribution with Special Reference to Forest Insects. Forest Sci. 5: 397-412.

APPENDICES

APPENDIX A

PROGRAM LISTING OF NEAREST NEIGHBOR ANALYSIS

```
      PROGRAM DISTNC(INPUT,OUTPUT,TAPE1=65,TAPE2=65)
C ----------------------------------------
C THIS PROGRAM IS DEVELOPED IN A COLLBORATION WITH EMMETT LAMPERT
C (PH.D. THESIS,IN PREP. 1979), BASED ON NEAREST NEIGHBOR CONCEPT
C OF CLARK AND EVANS (1954). THE PROGRAM IS DESIGNED FOR A SET OF
C DISTRIBUTION DATA IN A 10 X 10 SAMPLE PLOT.
C ----------------------------------------
      INTEGER FIELD,PLOT,DATE
      DIMENSION X(300),Y(300),DIST(300),NUMB(15),IVAR(2)
      REWIND 1
      PRINT*,"ENTER FORMAT FOR X,Y PAIRS"
      READ 955, (IVAR(I),I=1,2)
955   FORMAT(2A10)
      PRINT*,"ENTER NUMBER OF REPLICATES. "
      READ*,MCOUNT
1     ICOUNT=0
      WRITE (2,906)
      SUM=0.
      SUMSQ=0.
C ----------------------------------
C READ ONE SET OF FIELD DATA
C ----------------------------------
      READ (1,900 ) FIELD,PLOT,DATE,N
      IF(EOF(1))3,4
900   FORMAT(I3,2X,I1,2X,I6,5X,I3)
4     DO 10 I=1,N
      READ(1,IVAR)X(I),Y(I)
945   FORMAT(1X,F10.4,3X,F10.4)
10    CONTINUE
C ---------------------------------------
C SELECT A RANDOM INDIVIDUAL TO START DISTANCE MEASUREMENTS
C ---------------------------------------
2     IND=1+RANF(-1)*N
      ICOUNT=ICOUNT+1
      DO 15 IK=1,15
      NUMB(IK)=0
15    CONTINUE
      DO 20 J=1,N
      DIST(J)=(((X(J)-X(IND))**2.)+((Y(J)-Y(IND))**2.))**.5
20    CONTINUE
      WRITE(2,915)
915   FORMAT(*0*,40(1H-))
      WRITE(2,905)FIELD,PLOT,DATE,N,ICOUNT
      WRITE(2,901)IND,X(IND),Y(IND)
901   FORMAT(*0*,*FOR INDIVIDUAL*,I3,* WHOSE COORDINATES ARE:*
     +* X=*,F5.2,*,Y= *,F5.2,/1X,*THE DISTANCES TO NEIGHBORS*
     +* ARE---1-10, 11-20, ETC.*)
      WRITE(2,902)(DIST(II),II=1,N)
902   FORMAT(10(1X,F6.3))
      SMALL=100.
      DO 40 K=1,N
      IF(K.EQ.IND) GO TO 40
```

OK-

```
C ------------------------------------------
C FIND THE NEAREST NEIGHBOR
C ------------------------------------------
      IF(DIST(K).LT.SMALL)SMALL=DIST(K)
      DO 50 L=1,15
      L1=L
      IF(DIS(K).GE.L-1.AND.DIST(K).LT.L)GO TO 55
50    CONTINUE
55    NUMB(L1)=NUMB(L1)+1
40    CONTINUE
      PRINT*,"NEAREST NEIGHBOR DISTANCE= ",SMALL
      WRITE(2,903)
903   FORMAT(*0*,*NEIGHBOR DISTANCES AND FREQUENCY COUNTS*,/
     +1X,*0-.999,1-1.999, 2-2.999, ETC ---- 10 PER ROW ---* )
      WRITE(2,904)(NUMB(L2),L2=1,15)
904   FORMAT(10(1X,I6))
905   FORMAT(*0*,*NEAREST NEIGHBOR ANALYSIS FOR FIELD*,I4
     +* PLOT*I2,/,1X,*ON*,I7*, NO.  INDIVIDUALS= *I3,*, REPS=*I3)
C ----------------------------------
C CALCULATION OF NEAREST NEIGHBOR STATISTICS
C ----------------------------------
      SUM=SUM+SMALL
      RHO=N/100.
      SUMSQ=SUMSQ+SMALL**2.
      WRITE(2,960) RBAR,S2
960   FORMAT(1X,*MEAN NEIGHBOR DISTANCE =*,F10.6,* VARIANCE=*,F10.6)
      IF(ICOUNT.LT.MCOUNT) GO TO 2
      A=FLOAT(MCOUNT)
      RBAR=SUM/A
      S2=(SUMSQ-((SUM**2.)/A))/(A-1)
      PRINT*,"RBAR DISTANCE= ",RBAR,"VAR= ",S2
C -------------------------------
C TEST OF SIGNIFICANCE OF THE DISTRIBUTION FROM RANDOMNESS
C -------------------------------
      WRITE(2,961)RTEST,CTEST
961   FORMAT(1X,*CLARK AND EVANS R= *,F10.5,*C AND EVANS C =*,F10.6)
      REBAR=1./(2.*SQRT(RHO))
      RTEST=RBAR/REBAR
      DIFR=RBAR-REBAR
      DIFR=ABS(DIFR)
      RHON=A*RHO
      STERR=.26136/SQRT(RHON)
      CTEST=DIFR/STERR
      PRINT*," R= ", RTEST,"  C= ",CTEST
      GO TO 1
3     WRITE(2,906)
906   FORMAT(*1*)
      STOP
      END

OK-
```

APPENDIX B

PROGRAM LISTING OF QUADRAT COUNT ANALYSIS

```
      PROGRAM SPACE(INPUT,OUTPUT,TAPE1=65,TAPE2=65,TAPE3=65)
C ------------------------------------------------------------
C THIS PROGRAM IS WRITTEN IN A COOPERATION WITH EMMETT LAMPERT
C (PH.D.THESIS IN PREP. 1979).IT IS CALCULATING INDICES OF DISPER-
C SION NAMELY,MEAN VARIANCE RATIO,NEG.BINOMIAL K INDEX, AND MORI-
C SITA INDEX/I DELTA ( SEE ELLIOTT,1977 FOR THE EQUATIONS ). THE
C PROGRAM IS DESIGNED FOR A DISTRIBUTION DATA IN 10X10 PLOT.
C ------------------------------------------------------------
      DIMENSION X(150),Y(150),XMEAN(150)
      INTEGER FIELD,PLOT,DATE,XMEAN
      REAL KHAT,IDELTA,MU
      REWIND 1
40    READ(1,10) FIELD,PLOT,DATE,N
10    FORMAT(I3,2X,I1,2X,I6,5X,I3)
      CHECK=0.
      IF(EOF(1)) 77,2
C ------------------------------------------------------------
C READ IN X AND Y COORDINATES
C ------------------------------------------------------------
2     DO 11 I=1,N
      READ (1,45)X(I),Y(I)
45    FORMAT(1X,F10.4,3X,F10.4)
11    CONTINUE
C ------------------------------------------------------------
C FIND X MAX AND Y MAX VALUES
C ------------------------------------------------------------
      XMAX=X(1)
      YMAX=Y(1)
      DO 12 J=2,N
      IF(X(J).GT.XMAX) XMAX=X(J)
      IF(Y(J).GT.YMAX) YMAX=Y(J)
12    CONTINUE
36    PRINT*,"ENTER THE NUMBER OF SAMPLES TAKEN AND UNIT SIZE."
      READ*,NUMB,SAMPLE
      IF(CHECK.NE.0.AND.NUMB.NE.0) WRITE(2,210) NUMB
210   FORMAT(*0*,20X,*NUMBER OF SAMPLES TAKEN EQUALS *,I4,/)
      DEL1=0.
      IF(NUMB.EQ.0)GO TO 302
      SAMPLE=SAMPLE/2.
53    SAMPLE=2.*SAMPLE
      DX=SAMPLE**.5
      DY=DX
      XX=DX/2.
      YY=DY/2.
      ORG=0.
```

```
      XBAR=0.
      S2=0.
      TEST=0.
      SQFTM=0.
      IDELTA=0.
      TVALUE=0.
      TVALUE2=0.
      SUM=0.
      SUMSQ=0.
      IC1=0
      IC2=0
      XRANGE=10.-DX
      YRANGE=10.-DY
      AREA=XRANGE*YRANGE
      IF(XRANGE.LT.5.OR.YRANGE.LT.5.) GO TO 36
      DO47 I2=1,N
      IF(X(I2).GE.XX.AND.X(I2).LE.(10.-XX))GO TO 6
      GO TO 47
6     IF(Y(I2).GE.YY.AND.Y(I2).LE.(10.-YY)) ORG=ORG+1
47    CONTINUE
      MU=ORG/AREA
C -----------------------------------------------------
C FIND RANDOM SAMPLE POINTS
C -----------------------------------------------------
80    DO 13 K=1,NUMB
      TOTAL=0.
      XPT=XRANGE*RANF(-1)
      YPT=YRANGE*RANF(-1)
      DO 14 I1=1,N
      IF(X(I1).GE.XPT.AND.X(I1).LE.XPT+DX) GO TO 5
      GO TO 14
5     IF(Y(I1).GE.YPT.AND.Y(I1).LE.YPT+DY) TOTAL=TOTAL+1.
14    CONTINUE
      SUM=SUM+TOTAL
      SUMSQ=SUMSQ+TOTAL**2.
      XMEAN(K)=TOTAL
13    CONTINUE
C -----------------------------------------------------
C CALCULATE STATISTICS OF SAMPLES
C -----------------------------------------------------
      IF(SUM.EQ.0)GO TO 250
      XBAR=SUM/NUMB
      SQFTM=XBAR/SAMPLE
      S2=(SUMSQ-(SUM**2./NUMB))/(NUMB-1)
```

```
C -----------------------------------------------------------
C K HAT CALCULATION TAKEN FROM ELLIOT(1977) P. 55
C -----------------------------------------------------------
      IF((SUM**2.-SUM).EQ.0)GO TO 90
      IDELTA=NUMB*((SUMSQ-SUM)/(SUM**2.-SUM))
      GO TO 91
90    IDELTA=-9.999
91    IF((S2-XBAR).LE.0.)GO TO 95
      KHAT=XBAR**2./(S2-XBAR)
      GO TO 99
95    KHAT=-9.999
99    TEST=S2/XBAR
      DEX=DEL1/IDELTA
      DEL1=IDELTA
      IF(IDELTA.NE.-9.999)WRITE(3,320)SAMPLE,DEX,NUMB
320   FORMAT(2X,2(F6.3,5X),I3)
      TVALUE=TEST*(NUMB-1)
      TVALUE2=IDELTA*(SUM-1)+NUMB-SUM
      IC1=IFIX(SUM)
      IC2=IFIX(SUMSQ)
250   IF(CHECK.GT.1) GO TO 301
      WRITE(2,200)FIELD,PLOT,DATE,XMAX,YMAX
200   FORMAT(*1*,/////,4X,*TABLE    .  SUMMARY OF SAMPLES *
     +*TAKEN RANDOMLY FROM FIELD*,I4,* PLOT*,I2,*.*,/
     +15X,*ON*,I6,*, X MAX=*,F6.2,*, Y MAX=*,F6.2,*.*)
      WRITE(2,201)
201   FORMAT(*0*,4X,72(1H-))
      PRINT(2,202)
202   FORMAT(*0*,2X,*SAMPLE COUNT  COUNT  MEAN*,19X,*VAR.   CHI*,4X,
     +*I*,5X,*CHI*,5X,*K*,/,3X,*UNIT   SUM*,4X,*SUM*,4X,*PER  MU  *,
     +*MEAN  VAR.   MEAN    SQ*,3X,*DELTA   SQ*,4X,*VALUE*,/,3X,*SIZE*,
     +8X,*SQUARES SQFT*,19X,*RATIO   TST*,10X,*TST*)
      WRITE(2,201)
      IF(CHECK.LT.1)WRITE(2,210)NUMB
      CHECK=5.
301   WRITE(2,204)SAMPLE,IC1,IC2,SQFTM,MU,XBAR,S2,TEST,TVALUE,
     +IDELTA,TVALUE2,KHAT
204   FORMAT(2X,F5.2,2X,I4,1X,I6,3X,2(F4.2),F6.2,F7.2,F6.2,
     +1X,F6.2,F6.2,1X,F6.2,F7.2)
      GO TO 53
302   ENDFILE 3
      PRINT*,"ARE YOU DONE?"
      READ 1051,ANS
1051  FORMAT(A1)
      IF(ANS.EQ.1HY) GO TO 77
      GO TO 40
77    WRITE(2,401)
401   FORMAT(*1*)
1     STOP
      END
```

APPENDIX C

DISTRIBUTION DATA OF LARVAE IN AN ASPARAGUS-CRABGRASS FIELD IN 1976 AND 1977

TABLE C-1 : ARMYWORM DISTRIBUTION IN FIELD 444 PLOT 5 DATE 82876.

NUMBER	X COORDINATE	Y COORDINATE
1	.0778	4.2838
2	.1037	4.0512
3	.2553	4.1609
4	1.2880	6.2270
5	1.0707	2.0904
6	1.8868	4.7322
7	2.1527	9.6887
8	2.0716	6.7269
9	2.9669	8.0711
10	2.1447	2.8589
11	2.8428	2.1105
12	2.4767	1.7198
13	2.7558	1.4498
14	2.3663	.3002
15	3.3159	.2000
16	3.6154	1.9128
17	5.1188	8.0780
18	5.4273	6.2168
19	6.6083	9.7268
20	6.1606	5.5700
21	6.8447	6.3602
22	7.0594	6.5311
23	7.9348	5.7455
24	7.7584	5.4278
25	7.1304	3.4832
26	7.3032	.2259
27	8.1775	4.9004
28	8.6361	3.7365
29	8.7756	3.6260
30	8.5859	3.5653
31	8.7417	2.0471
32	8.7926	1.9124
33	9.9151	8.5192
34	9.6119	8.3118
35	9.7390	8.1035
36	9.7252	3.5625

TABLE C-2 : ARMYWORM DISTRIBUTION IN FIELD 444 PLOT 4 DATE 82376.

NUMBER	X COORDINATE	Y COORDINATE
1	1.4982	8.0991
2	1.3212	5.0948
3	2.2038	4.8297
4	2.7278	4.6157
5	2.4955	4.4296
6	2.9672	.7370
7	5.0304	8.9463
8	5.0193	7.5124
9	5.0798	7.0384
10	4.7363	7.3898
11	4.2165	3.1388
12	4.6341	2.4266
13	4.5350	1.2175
14	4.0747	1.3813
15	3.9692	.9951
16	5.0693	9.0035
17	9.7534	2.9436

TABLE C-3: ARMYWORM DISTRIBUTION IN FIELD 444 PLOT 3 DATE 81776.

NUMBER	X COORDINATE	Y COORDINATE
1	.4291	7.6258
2	.1834	7.5029
3	.3495	7.3660
4	.0764	7.0558
5	.0614	6.8198
6	2.9299	8.0709
7	3.8463	4.0822
8	3.4714	3.8963
9	3.9034	3.8337
10	3.9517	2.9258
11	4.4318	3.3610
12	5.2700	9.2605
13	5.6388	8.7632
14	5.2522	8.7140
15	5.2715	6.5649
16	5.2953	6.3537
17	5.3851	6.3163
18	5.3966	6.1672
19	5.1654	6.2172
20	5.1500	5.9315
21	8.7071	7.9146
22	8.5507	4.8465
23	9.5725	6.8328
24	9.8415	6.6958
25	9.6573	4.8203

TABLE C-4: ARMYWORM DISTRIBUTION IN FIELD 444 PLOT 2 DATE 81276.

NUMBER	X COORDINATE	Y COORDINATE
1	.3458	9.6783
2	.2725	7.3272
3	.2695	6.5685
4	.8614	6.7331
5	.6167	6.5951
6	.6031	6.3960
7	1.4494	9.1988
8	1.7066	9.2498
9	1.3462	9.1236
10	1.7697	8.9392
11	1.9497	8.9525
12	1.9359	8.7161
13	1.8253	6.7006
14	1.2166	2.1827
15	2.4666	9.6540
16	2.2083	9.3518
17	2.2965	8.9045
18	3.4299	2.8280
19	4.8415	8.9047
20	4.6545	3.7421
21	4.2640	2.4590
22	4.5798	1.0178
23	5.7046	6.0483
24	6.3279	7.6932
25	7.6005	7.7244
26	7.4847	7.6865
27	7.2901	7.2378
28	9.4593	6.4525
29	5.6704	3.8466

TABLE C-5: ARMYWORM DISTRIBUTION IN FIELD 444 PLOT 1 DATE 80975.

NUMBER	X COORDINATE	Y COORDINATE
1	.2314	9.5712
2	.4389	9.3569
3	.5957	9.3190
4	.3457	9.2182
5	.1094	9.1803
6	.7374	9.0794
7	.2771	8.9281
8	.5391	8.9155
9	.2355	8.7137
10	.7586	8.6003
11	.5353	8.5498
12	.7962	8.4363
13	.7946	8.2850
14	.4669	8.2850
15	.7281	8.1967
16	.3540	7.5158
17	.2855	4.7289
18	1.3300	7.8689
19	1.2206	7.6671
20	1.4555	7.5662
21	1.6946	6.6204
22	2.5820	8.8398
23	2.9230	8.7768
24	2.2805	8.7516
25	2.6463	8.6391
26	2.6573	8.4353
27	2.3157	8.3607
28	3.2874	9.7856
29	3.5489	9.7226
30	3.3508	9.5839
31	3.1397	9.4451
32	3.8268	8.7264
33	3.4971	8.5372
34	3.6667	8.4615
35	3.9233	8.3985
36	3.6089	6.6961
37	3.6850	6.4565
38	3.3698	6.3934
39	3.3092	5.6116
40	3.3854	5.3846

TABLE C-5: CONTINUED.

NUMBER	X COORDINATE	Y COORDINATE
41	3.4601	3.7579
42	3.7898	2.6986
43	3.6704	2.5599
44	3.8783	2.3960
45	4.3756	9.8235
46	4.6757	9.6974
47	4.5418	9.4199
48	4.1872	9.3569
49	4.4746	9.2686
50	4.6710	9.2434
51	4.1577	9.0415
52	4.4939	7.8310
53	4.2987	7.7306
54	4.4578	7.6671
55	4.5097	7.6166
56	4.3124	7.5410
57	4.4980	6.4943
58	4.4354	5.5233
59	4.5580	4.7163
60	4.4493	4.3506
61	4.4803	3.5561
62	4.3563	1.7276
63	4.5514	1.5889
64	4.7334	1.4502
65	4.4574	1.3745
66	5.5054	8.8272
67	5.3467	8.6885
68	5.3898	7.8058
69	5.2307	7.6293
70	5.4657	7.5410
71	6.9211	1.3493
72	6.3642	.7314
73	6.6379	.5927
74	7.3633	9.7730
75	7.7023	9.6091
76	7.6081	9.3695
77	7.7260	9.3695
78	7.6468	1.8159
79	7.3445	1.7402

TABLE C-5: CONTINUED.

NUMBER	X COORDINATE	Y COORDINATE
80	7.5776	1.4628
81	8.4466	9.3443
82	8.5616	2.8121
83	8.8352	2.6608
84	8.7994	1.7402
85	9.4976	9.5839
86	9.7055	9.4073
87	9.8371	5.7125
88	9.5211	5.5738
89	9.7111	3.6943
90	9.6100	2.7995
91	9.2554	2.7364
92	9.3011	.8449
93	9.4155	.5044

TABLE C-6 : ARMYWORM DISTRIBUTION IN
FIELD 333 PLOT 4 DATE 82876.

NUMBER	X COORDINATE	Y COORDINATE
1	.5231	8.7704
2	.6724	8.4066
3	.0961	7.6992
4	.0290	7.4997
5	.9114	7.1045
6	.1514	3.4237
7	.2642	2.2977
8	.1207	2.1614
9	1.1157	4.2652
10	1.8540	1.8713
11	2.2101	7.9307
12	2.6089	2.4647
13	2.6631	.8392
14	2.8797	.6873
15	6.8400	9.5152
16	6.3469	5.5945
17	6.2798	3.5826
18	6.0277	3.0473
19	7.3070	9.7736
20	8.2882	8.1775
21	8.3592	7.6644
22	9.2117	3.4059

TABLE C-7: ARMYWORM DISTRIBUTION IN
FIELD 333 PLOT 3 DATE 82376.

NUMBER	X COORDINATE	Y COORDINATE
1	.1701	9.0832
2	.4497	8.8434
3	.5486	8.4922
4	.9974	8.4995
5	1.3949	8.5072
6	1.4815	3.1956
7	1.4508	2.6988
8	2.4419	6.8357
9	2.4192	.8708
10	3.4597	8.5675
11	3.9811	5.6599
12	4.4747	1.2816
13	5.6345	5.6214
14	7.4882	8.8475
15	6.8866	5.1920
16	6.9549	4.3552
17	6.3581	3.6600
18	6.6637	3.4652
19	6.4688	3.2071
20	6.9997	2.4678
21	6.5136	.0767
22	7.5151	1.4688
23	7.4871	1.2431
24	7.6966	.4163
25	8.5249	8.6800
26	8.7859	7.8754
27	8.5067	6.9062
28	8.4774	6.5448
29	8.7642	2.0112

TABLE C-8: ARMYWORM DISTRIBUTION IN FIELD 333 PLOT 2 DATE 81276.

NUMBER	X COORDINATE	Y COORDINATE
1	.1835	2.6276
2	.1314	2.5031
3	.3238	2.5156
4	.2571	2.1046
5	.8854	2.1295
6	.3846	2.0050
7	.8975	2.0050
8	.2559	1.9178
9	.5761	1.8680
10	.7549	1.7684
11	.9473	1.7303
12	.6252	1.6936
13	.9081	1.6687
14	.7410	1.5940
15	.9328	1.5193
16	.6246	1.4446
17	.6875	1.2453
18	.7641	1.1955
19	.5839	1.0959
20	.7506	1.0959
21	.9042	1.0585
22	.7628	.9963
23	.5831	.9539
24	.6599	.9465
25	.9033	.9215
26	.7492	.8717
27	.5567	.8468
28	.6716	.7721
29	.9026	.8095
30	.8380	.7223
31	.9531	.6849
32	1.2633	5.0809
33	1.5072	5.1183
34	1.6214	4.9440
35	1.1980	4.8941
36	1.4028	4.8443
37	1.6073	4.7323
38	1.2213	4.5205
39	1.3603	4.2092
40	1.6173	4.2964

TABLE C-8: CONTINUED.

NUMBER	X COORDINATE	Y COORDINATE
41	.9877	2.0797
42	1.0640	1.9801
43	1.0363	1.6563
44	1.2789	1.5068
45	1.0451	1.0336
46	1.7241	.9589
47	1.5569	.8842
48	1.0570	.8966
49	.9924	.8095
50	1.0819	.7721
51	2.6097	5.1059
52	3.8643	.9091
53	4.2398	7.4097
54	4.2508	5.1308
55	4.1591	4.8194
56	4.4027	4.8194
57	4.5568	4.8569
58	4.2469	4.5205
59	4.2832	.1868
60	5.1013	7.8829
61	5.3961	7.7958
62	5.7927	7.6588
63	6.0095	7.4844
64	5.5222	7.4595
65	5.6110	7.3101
66	5.2028	7.2727
67	5.5456	7.1108
68	7.2380	9.1283
69	7.3910	8.9913
70	7.8230	8.3811
71	7.6684	8.2690
72	7.9937	5.0187
73	7.7757	5.0062
74	8.0698	4.8941
75	7.9415	4.8817
76	8.1200	4.7198
77	7.9146	4.6824
78	7.9842	3.5367
79	7.3443	3.7111

TABLE C-8: CONTINUED.

NUMBER	X COORDINATE	Y COORDINATE
80	7.7913	3.4371
81	8.7360	8.8169
82	8.6449	8.6052
83	8.2716	8.3685
84	8.5015	8.2316
85	8.9231	8.0075
86	8.6652	7.7709
87	8.4060	7.3350
88	8.1613	5.1681
89	8.1602	4.9938
90	8.2365	4.8941
91	8.2229	4.7696
92	8.9913	4.6451
93	8.4422	2.9763
94	8.1295	2.2042
95	8.1405	1.9303
96	8.9119	.2491
97	8.7061	.1494
98	8.8081	.0623
99	9.8539	9.2030
100	9.1909	7.7833
101	9.5883	7.7709
102	9.7166	7.7958
103	10.0114	7.7833
104	10.1065	4.6202
105	9.5554	4.1968
106	9.4106	4.0598
107	9.3070	3.8854
108	9.4856	3.9103
109	9.4473	3.7733
110	9.5875	3.6498
111	9.3438	3.6364
112	9.4847	3.6115
113	9.7150	3.5367
114	9.5824	2.8518
115	9.2625	2.9514

TABLE C-9: ARMYWORM DISTRIBUTION IN FIELD 333 PLOT 1 DATE 80976.

NUMBER	X COORDINATE	Y COORDINATE
1	.3138	8.7989
2	.5743	1.7395
3	.3265	1.6271
4	.3737	1.1092
5	.6709	.9436
6	1.4495	9.4497
7	1.1984	4.6783
8	1.6253	4.4994
9	1.4887	3.7551
10	2.3048	9.2434
11	2.1968	8.7894
12	2.4312	8.8640
13	2.5374	8.9011
14	2.7041	8.8752
15	2.4946	8.6869
16	2.1686	8.5497
17	2.3367	8.4604
18	2.5443	8.4467
19	2.3478	9.2583
20	2.3070	8.0565
21	2.2793	7.8673
22	2.5132	7.8737
23	2.6164	7.8024
24	2.4335	7.6897
25	2.1868	7.6910
26	2.3155	7.5641
27	2.2135	6.4782
28	2.5252	6.3383
29	2.6012	6.1359
30	2.3156	6.1499
31	2.2738	5.8345
32	2.6247	5.8580
33	2.3894	5.6950
34	2.6228	5.6559
35	2.1802	5.5319
36	2.3552	4.7861
37	2.7298	3.1302
38	2.8240	2.0691
39	4.2364	7.4281
40	4.1298	7.1382

TABLE C-9: CONTINUED.

NUMBER	X COORDINATE	Y COORDINATE
80	3.4451	1.8134
81	3.7172	1.7489
82	3.4177	1.6620
83	3.2231	1.6883
84	3.5860	1.5981
85	3.3907	1.5485
86	3.2343	1.4362
87	3.6753	1.4208
88	3.4668	1.3461
89	3.3349	1.1195
90	3.0998	.9818
91	3.3692	.6143
92	5.4749	6.5254
93	7.3434	9.2053
94	7.4596	8.8007
95	7.5387	6.4013
96	7.2906	6.2511
97	7.2285	5.1403
98	7.4702	4.5835
99	7.3385	4.3821
100	7.3965	.7581
101	8.2528	9.2336
102	8.4724	.5380
103	8.7053	.4358
104	9.7706	7.6274
105	9.5732	7.3380
106	9.3130	4.9782
107	9.8242	4.9504
108	9.6808	4.8880
109	9.4984	4.8258
110	9.3954	.7480

TABLE C-9: CONTINUED.

NUMBER	X COORDINATE	Y COORDINATE
41	4.4292	7.2125
42	4.3436	6.3670
43	4.1987	6.1404
44	4.3766	5.7102
45	4.3345	5.3695
46	4.1719	4.6254
47	4.3418	4.7392
48	4.2216	4.3725
49	4.3370	4.2079
50	4.3305	3.5009
51	4.3423	1.9351
52	4.2373	1.8220
53	4.5099	1.8080
54	4.4327	1.6693
55	4.2518	1.6578
56	4.1063	1.6964
57	3.0318	9.2145
58	3.6639	8.7441
59	3.1178	8.6711
60	3.4792	8.4294
61	3.0072	7.9394
62	3.4358	7.9372
63	3.1491	7.8250
64	3.0441	7.7119
65	3.2380	7.6099
66	3.4580	7.5204
67	3.1710	7.3830
68	3.3732	7.3138
69	3.3557	4.8442
70	3.4177	4.5156
71	3.5194	4.2752
72	3.2463	4.2387
73	3.1480	3.4184
74	3.3359	2.6599
75	3.3582	2.2558
76	3.2136	2.0671
77	3.9749	1.9501
78	3.6147	1.9009
79	3.1858	1.8652

TABLE C-10: ARMYWORM DISTRIBUTION IN FIELD 222 PLOT 2 DATE 81776.

NUMBER	X COORDINATE	Y COORDINATE
1	2.8988	7.4648
2	8.1922	8.4478
3	8.7377	6.3917
4	8.5312	6.2428
5	8.6722	6.0930
6	9.5558	4.9451
7	9.3441	3.4512

TABLE C-11: ARMYWORM DISTRIBUTION IN FIELD 222 PLOT 3 DATE 82976.

NUMBER	X COORDINATE	Y COORDINATE
1	.3033	3.1389
2	.6679	2.1669
3	1.7445	8.8583
4	2.7787	2.1881
5	3.1711	.4184
6	5.8762	5.7482
7	6.1057	9.0103
8	6.1177	5.9672
9	7.3107	5.9278
10	7.4006	5.0866
11	7.4600	4.8162
12	8.9484	9.2961
13	8.5414	2.8942

TABLE C-12: ARMYWORM DISTRIBUTION IN FIELD 111 PLOT 1 DATE 81276.

NUMBER	X COORDINATE	Y COORDINATE
1	.6097	7.4752
2	.6590	6.6924
3	.1686	5.6513
4	.3087	5.2283
5	.2420	4.2472
6	.5868	3.5747
7	.2260	3.0299
8	.6097	2.4814
9	1.6475	6.6999
10	2.6225	6.4714
11	4.0377	7.6694
12	3.7292	7.5094
13	3.3420	6.6915
14	3.8496	4.4157

TABLE C-13: ARMYWORM DISTRIBUTION IN FIELD 222 PLOT 1 DATE 81276.

NUMBER	X COORDINATE	Y COORDINATE
1	1.8103	5.5624
2	1.8517	4.8005
3	2.2288	6.2948
4	2.5432	5.8797
5	2.7673	4.4043
6	5.2123	5.6034
7	5.0990	3.7443
8	5.0207	2.6215
9	5.3631	2.3934
10	9.7964	9.0782
11	9.8456	7.9291
12	9.6663	5.9085

TABLE C-14: ARMYWORM DISTRIBUTION IN FIELD 111 PLOT 2 DATE 81776.

NUMBER	X COORDINATE	Y COORDINATE
1	.8631	9.8022
2	.5497	6.5760
3	.9319	1.9530
4	1.1751	1.8418
5	2.0728	8.4672
6	2.6362	5.6860
7	2.4165	5.1669
8	2.9322	5.4141
9	2.6063	2.5216
10	2.7738	2.4475
11	3.1308	9.5056
12	3.2597	9.5426
13	3.2596	9.4190
14	3.4516	8.4549
15	3.5674	8.3065
16	3.4377	7.6257
17	6.4156	8.4920
18	7.1771	9.4314
19	8.7239	9.7528
20	9.9995	9.6292
21	9.9849	8.3189
22	9.9930	4.5365
23	9.9380	1.9036

TABLE C-15: ARMYWORM DISTRIBUTION IN FIELD 111 PLOT 3 DATE 82976.

NUMBER	X COORDINATE	Y COORDINATE
1	.1324	8.0651
2	.2862	7.1215
3	.6884	3.3120
4	.9776	2.9549
5	.2789	2.3847
6	.3093	.9647
7	.4976	.8164
8	.4111	.5233
9	1.4404	9.5957
10	1.4233	9.5978
11	1.5409	9.6092
12	1.5414	9.4746
13	1.6447	8.6293
14	1.5452	8.4709
15	2.9828	8.9255
16	2.3128	7.5314
17	2.8633	7.4208
18	2.8322	5.6952
19	2.8759	4.0425
20	2.8642	3.8345
21	2.4015	3.7400
22	2.3273	3.4958
23	3.0834	7.4681
24	4.0035	7.0453
25	3.2970	5.2267
26	3.1896	3.8444
27	3.4666	3.4017
28	4.9496	1.7507
29	5.7983	9.0517
30	5.1927	.3413
31	6.3622	8.8639
32	6.8127	8.8729
33	6.3635	8.5212
34	6.7942	7.1472
35	6.6696	7.0012
36	6.8825	6.9629
37	6.9709	6.7542
38	6.7901	4.8951
39	6.8043	4.4421
40	7.0379	5.5664

TABLE C-15: CONTINUED.

NUMBER	X COORDINATE	Y COORDINATE
41	7.0510	5.4072
42	7.2902	5.0333
43	7.4674	4.5106
44	7.6051	4.5096
45	7.5055	4.3757
46	7.6682	4.3623
47	7.5334	3.6166
48	7.8780	1.8271
49	7.1320	.5229
50	8.6444	1.0381
51	9.2544	5.2442
52	9.5120	4.7771
53	9.1726	.3733

TABLE C-15: ARMYWORM DISTRIBUTION IN FIELD 555 PLOT 1 DATE 72977.

NUMBER	X COORDINATE	Y COORDINATE
1	.3970	2.6010
2	.5455	2.5480
3	.8505	4.0980
4	.7793	4.7140
5	.5099	5.3820
6	.8966	5.8800
7	.8850	6.0470
8	.8408	7.1240
9	.6301	7.1250
10	.3869	8.0620
11	.2434	9.1140
12	1.5880	10.4700
13	1.7980	10.2900
14	1.1630	9.6360
15	1.2870	9.6220
16	1.8450	9.7080
17	1.5580	9.3380
18	1.8370	8.0550
19	1.2280	7.7630
20	1.8350	7.6830
21	1.8320	7.1700
22	1.8310	6.9650
23	1.1320	5.8790
24	1.3920	5.7490
25	1.7850	5.1450
26	1.1630	4.7250
27	1.8430	4.4010
28	1.8400	3.6440
29	1.7770	3.4520
30	1.6140	3.1200
31	1.8000	3.0810
32	1.7620	2.9910
33	1.7980	2.6700
34	1.1220	1.4170
35	1.1610	1.8270
36	1.1840	1.3910
37	1.1710	1.2380
38	1.8160	1.3880
39	1.2810	.8524
40	1.1560	.7633

TABLE C-15: CONTINUED.

NUMBER	X COORDINATE	Y COORDINATE
41	1.8490	.5931
42	2.1220	.6430
43	2.7850	1.9600
44	2.6580	1.3450
45	2.4560	3.0900
46	2.0840	3.0020
47	2.4830	3.4620
48	2.3340	3.4500
49	2.3850	3.6540
50	2.9120	5.0110
51	2.8040	5.7930
52	2.4330	5.8340
53	2.2590	5.7700
54	2.1340	5.5660
55	2.2490	6.1420
56	2.6950	6.2680
57	2.8440	6.2670
58	2.8550	6.0890
59	2.8010	7.5370
60	2.8260	7.6780
61	2.4770	7.1410
62	2.2420	7.3220
63	2.4330	8.3590
64	2.5940	8.3710
65	2.7760	7.5880
66	2.7540	8.0760
67	2.7810	8.5750
68	2.9060	8.7290
69	2.7330	8.8450
70	2.2410	9.5910
71	2.1300	9.7070
72	2.3810	10.3900
73	2.7360	9.5630
74	3.1710	9.7790
75	3.8520	9.6470
76	3.8500	6.6600
77	3.8230	6.2880
78	3.7450	5.5960
79	3.9310	5.5820

TABLE C-15: CONTINUED.

NUMBER	X COORDINATE	Y COORDINATE
80	3.8400	4.7500
81	3.4540	4.3280
82	3.1480	5.0090
83	3.4320	4.8410
84	3.6400	4.4300
85	3.5040	4.3410
86	3.3550	4.3160
87	3.2040	3.9960
88	3.4770	3.9820
89	3.4760	3.8280
90	3.6370	3.7510
91	3.8540	2.6080
92	3.8830	1.8390
93	3.8260	1.8010
94	3.8240	1.4420
95	3.8720	1.1720
96	3.1390	.7531
97	3.6100	.7379
98	3.1380	.5224
99	3.5960	.4944
100	3.7450	.4680
101	3.1730	.2145
102	4.2030	.4734
103	4.4310	1.4390
104	4.3940	1.5540
105	4.2250	2.4780
106	4.0900	2.6460
107	4.6890	3.4120
108	4.7630	3.5010
109	4.6110	2.6690
110	4.8260	3.7440
111	4.4940	4.1820
112	4.1730	4.4660
113	4.1370	4.6070
114	4.1390	4.9790
115	4.1020	5.1460
116	4.8970	5.4240
117	4.9420	4.6160
118	5.0120	6.1280

TABLE C-15: CONTINUED.

NUMBER	X COORDINATE	Y COORDINATE
119	4.4200	6.7080
120	4.1340	6.6200
121	5.0320	5.1790
122	4.1490	7.1450
123	4.2490	7.3120
124	4.9320	7.4880
125	4.2640	10.1700
126	4.7330	9.7830
127	4.3590	9.3880
128	4.1370	9.6200
129	4.1380	9.8760
130	4.8940	9.7700
131	5.8840	9.6490
132	5.5710	8.9460
133	5.3480	8.9210
134	5.8310	6.4830
135	5.1850	6.0630
136	5.3950	5.9980
137	5.2830	5.8700
138	5.4570	5.8820
139	5.3540	5.1010
140	5.1200	5.4220
141	5.2180	5.1910
142	5.9110	5.0720
143	5.8730	4.8420
144	5.7080	4.0480
145	5.8180	3.7520
146	5.7260	2.7140
147	5.4940	3.3180
148	5.7350	2.0600
149	5.8960	1.9950
150	5.8460	1.8420
151	5.4600	1.4850
152	5.6320	1.3430
153	5.2300	.2168
154	5.3790	.1904
155	6.3950	.1082
156	6.8700	.9391
157	6.1030	1.2510

TABLE C-15: CONTINUED.

NUMBER	X COORDINATE	Y COORDINATE
158	6.1600	2.8270
159	6.5060	5.0950
160	6.6420	5.0940
161	6.7570	5.7860
162	6.8820	5.9780
163	6.8100	6.4780
164	6.1590	7.5590
165	6.6080	8.0690
166	6.7240	9.1580
167	6.8240	9.3110
168	6.8880	9.5190
169	6.6900	9.6200
170	6.6650	9.6580
171	6.3950	10.2000
172	7.4980	10.2100
173	7.4220	9.9880
174	7.1960	9.3730
175	7.2080	9.2070
176	7.8510	8.8960
177	7.1510	7.6940
178	7.1700	4.0150
179	7.1380	2.5270
180	7.4970	2.5510
181	7.1560	1.1810
182	7.1630	.2325
183	7.1650	.5274
184	8.2540	.2525
185	8.8880	.6724
186	8.8400	.8906
187	8.6900	.7503
188	8.3960	1.4310
189	8.8520	3.3010
190	8.9150	3.5950
191	8.8430	4.0570
192	8.8540	3.8520
193	8.6240	4.8790
194	8.6120	5.0710
195	8.4810	6.1230
196	8.5480	7.0590

TABLE C-15: CONTINUED.

NUMBER	X COORDINATE	Y COORDINATE
197	8.2840	8.8680
198	8.7480	9.9550
199	8.6870	10.1700
200	8.2170	10.3200
201	9.2340	10.3500
202	9.4810	10.3400
203	9.5800	10.1700
204	9.1950	10.0000
205	9.3320	10.1800
206	9.6150	9.7710
207	9.0780	9.0050
208	9.3880	9.0290
209	9.6990	9.1940
210	9.3500	8.8490
211	9.5850	8.8740
212	9.7710	8.8990
213	9.7420	7.9630
214	9.5600	8.7710
215	9.3830	7.9520
216	9.3470	8.2600
217	9.3080	7.9650
218	9.2580	7.7600
219	9.5300	7.7460
220	9.5410	7.4510
221	9.1440	7.2220
222	9.5530	7.2330
223	9.6140	7.1050
224	9.5750	6.8350
225	9.4270	6.9390
226	9.2790	7.0040
227	9.1260	6.2220
228	9.2410	6.7860
229	9.3400	6.7730
230	9.6340	6.1690
231	9.6300	5.3480
232	9.1260	6.0810
233	9.1990	5.8500
234	9.4590	5.8620
235	9.1710	5.1580

TABLE C-15: CONTINUED.

NUMBER	X COORDINATE	Y COORDINATE
236	9.4060	5.1440
237	9.5790	5.1180
238	9.7140	4.7840
239	9.3530	4.5670
240	9.1030	4.0690
241	9.3760	4.0420
242	9.4990	4.0150
243	9.4000	3.8490
244	9.4860	3.8360
245	9.3860	3.6830
246	9.5220	3.6310
247	9.5340	3.5020
248	9.1740	3.4270
249	9.1480	3.1970
250	9.6560	3.0530
251	9.7050	2.8860
252	9.3310	2.4520
253	9.0460	2.5690
254	9.0040	1.5820
255	9.1410	1.6710
256	9.2880	1.4520
257	9.0930	1.9280
258	9.1000	.9405
259	9.6610	1.6810
260	9.6730	1.4890
261	9.8100	1.5780
262	9.4840	.8615
263	9.3350	.8496
264	9.0990	.6456
265	9.4320	.5029
266	9.7550	.5013

TABLE C-16: ARMYWORM DISTRIBUTION IN FIELD 555 PLOT 2 DATE 80577.

NUMBER	X COORDINATE	Y COORDINATE
1	.6768	1.4430
2	.3820	6.4000
3	.2769	8.7050
4	.9455	9.2110
5	1.7110	9.3710
6	1.9730	9.1860
7	1.4420	8.6560
8	1.9890	8.1870
9	1.2300	5.8940
10	1.9000	5.2030
11	1.2280	2.7990
12	1.2980	2.3060
13	1.2680	1.7140
14	2.8540	5.3020
15	2.5340	7.4720
16	2.8120	7.7440
17	2.1480	7.7190
18	3.5860	7.3980
19	3.5540	6.6340
20	3.1470	5.9060
21	3.8560	5.2530
22	3.4260	4.8460
23	3.7640	4.8460
24	3.8380	4.6490
25	3.2100	4.5250
26	3.2030	2.8110
27	3.2780	.8015
28	4.5910	.5179
29	4.5010	1.6650
30	4.4220	2.7250
31	4.5430	3.6370
32	4.6250	4.4020
33	4.5780	4.7230
34	4.9210	5.2400
35	4.9150	4.5500
36	5.4940	.6289
37	5.4000	2.7990
38	5.3170	3.3170
39	5.1960	3.7850
40	5.7660	7.3490

TABLE C-16: CONTINUED.

NUMBER	X COORDINATE	Y COORDINATE
41	5.3320	7.8550
42	6.2580	7.7190
43	6.4070	4.7230
44	6.8800	2.8980
45	6.6770	2.6260
46	6.8580	1.8370
47	7.2350	.5055
48	7.6360	4.7970
49	7.2690	5.7830
50	7.6880	6.4490
51	7.8160	6.7690
52	8.6100	8.6440
53	8.8230	8.6680
54	9.2360	2.9350

TABLE C-17: ARMYWORM DISTRIBUTION IN FIELD 555 PLOT 3 DATE 81277.

NUMBER	X COORDINATE	Y COORDINATE
1	.3834	1.5920
2	.5636	7.1180
3	.5560	9.1350
4	1.2570	9.8220
5	1.2710	6.2180
6	1.1990	5.1590
7	1.5030	4.5240
8	1.7790	4.5770
9	1.7880	2.1790
10	1.3690	.1063
11	2.7750	.2870
12	2.4980	3.8620
13	4.5660	8.4070
14	5.8460	8.8440
15	5.8360	1.5990
16	4.3330	.2854
17	6.7590	.5053
18	7.9500	7.2510
19	7.8710	8.2100
20	7.8460	4.8270
21	7.7970	1.1360
22	7.7880	.2995
23	8.5280	.4949
24	8.4890	.8018
25	8.9150	7.8630

TABLE C-18: ARMYWORM DISTRIBUTION IN FIELD 555 PLOT 4 DATE 81677.

NUMBER	X COORDINATE	Y COORDINATE
1	.6839	9.4870
2	.6242	7.5170
3	.6131	6.4600
4	1.5710	5.5370
5	1.5720	4.5050
6	1.5480	3.5080
7	2.5670	3.4730
8	2.6980	8.4690
9	4.5460	.5346
10	4.6610	7.5230
11	5.6070	6.4660
12	5.5470	4.5210
13	5.5480	3.5370
14	8.5560	2.4590
15	8.5800	3.4680
16	8.5910	4.4650

APPENDIX D

DEGREE-DAY ACCUMULATIONS FOR CASS, BAY AND LENAWEE COUNTIES
FROM APRIL 1, 1976 TO SEPTEMBER 30, 1976

Table D-1: Degree-Day Accumulations for Paw Paw, Cass County 1976.

°D >46°F

DAY	APRL	MAY	JUNE	JULY	AUG	SEPT
1	0.0	253.5	610.4	1310.2	2119.4	2843.5
2	3.3	255.2	623.5	1329.2	2135.9	2856.1
3	12.5	255.2	639.2	1347.2	2152.4	2879.1
4	14.6	261.6	660.7	1368.7	2173.9	2904.6
5	16.7	282.6	683.2	1393.7	2199.9	2918.6
6	22.2	282.6	705.7	1419.2	2219.9	2935.3
7	24.9	283.5	727.2	1444.2	2233.4	2958.3
8	25.2	287.4	752.7	1469.2	2248.9	2988.8
9	28.2	300.9	780.2	1497.2	2269.9	3006.3
10	35.6	317.4	811.2	1535.7	2293.9	3016.9
11	35.6	322.9	839.7	1571.7	2323.4	3035.4
12	36.5	328.8	865.7	1589.2	2354.9	3057.4
13	43.0	342.2	899.2	1605.9	2384.4	3080.4
14	60.5	362.2	932.7	1640.4	2407.4	3106.9
15	85.0	380.7	966.7	1673.4	2425.4	3124.4
16	111.0	401.2	981.7	1695.9	2440.2	3139.4
17	138.0	408.7	1003.2	1713.9	2457.7	3161.9
18	165.0	413.2	1030.2	1739.9	2478.2	3178.9
19	177.5	420.5	1047.2	1769.4	2504.7	3198.4
20	189.0	439.5	1064 2	1804.4	2530.7	3213.9
21	205.0	452.5	1082.2	1835.4	2558.7	3220.0
22	217.5	461.1	1107.2	1859.4	2558.7	3226.2
23	224.7	469.1	1129.7	1891.4	2619.2	3238.2
24	231.8	477.8	1149.7	1921.9	2647.7	3245.7
25	231.8	487.2	1171.7	1946.4	2675.7	3255.7
26	231.8	498.9	1198.2	1976.9	2706.2	3263.2
27	231.8	513.9	1227.2	2005.4	2739.7	3276.2
28	234.4	531.4	1255.7	2028.4	2769.2	3281.4
29	239.8	547.4	1276.2	2052.9	2783.2	3292.0
30	246.2	567.9	1292.2	2077.9	2796.5	3306.5
31		590.4		2100.0	2822.5	

Table D-2: Degree-Day Accumulations for Saline, Ohio, 1976.

° D >46°F

DAY	APRL	MAY	JUNE	JULY	AUG	SEPT
1	0.0	237.8	565.7	1239.6	1988.3	2607.8
2	2.1	245.1	579.2	1260.6	2004.3	2618.3
3	6.1	250.2	593.7	1277.6	2018.8	2633.8
4	10.4	265.7	608.9	1299.1	2034.6	2659.3
5	13.5	265.9	626.3	1328.1	2057.1	2675.3
6	18.7	273.2	649.3	1354.1	2073.6	2687.9
7	21.7	384.6	673.8	1380.1	2088.1	2706.3
8	21.7	273.2	702.3	1404.4	2103.1	2734.3
9	23.4	284.6	729.3	1422.1	2120.6	2755.3
10	28.9	298.1	755.8	1453.6	2139.8	2766.2
11	28.9	308.1	787.3	1480.6	2161.3	2786.2
12	30.2	314.3	808.8	1502.6	2193.3	2806.2
13	34.4	323.3	835.8	1519.2	2220.8	2824.7
14	46.2	337.3	868.8	1546.7	2242.3	2843.4
15	69.2	355.3	898.8	1577.2	2260.3	2858.4
16	94.2	371.8	920.3	1604.2	2274.4	2873.4
17	118.2	383.3	934.6	1619.8	2290.8	2891.4
18	141.7	390.6	957.6	1640.3	2308.6	2907.9
19	163.7	398.4	978.6	1664.3	2327.1	2923.5
20	175.2	412.5	996.6	1690.8	2347.1	2938.0
21	188.2	426.5	1014.6	1717.3	2368.1	2943.8
22	201.2	433.1	1036.1	1740.8	2392.1	2948.5
23	207.7	439.7	1057.1	1770.3	2418.6	2958.8
24	212.8	447.3	1077.1	1797.8	2444.1	2964.6
25	212.8	454.8	1102.6	1817.3	2466.6	2972.8
26	212.8	464.1	1125.1	1840.8	2493.1	2979.3
27	213.1	474.6	1151.6	1870.8	2522.6	2989.8
28	217.2	488.2	1177.6	1895.3	2548.6	2995.5
29	222.0	503.2	1205.6	1921.3	2560.2	3004.2
30	228.8	523.7	1223.6	1945.8	2571.4	3016.7
31		545.2		1971.3	2589.3	

Table D-3 : Degree-Day Accumulations for Standish, Bay County 1976.

°D >46° F

DAY	APRL	MAY	JUNE	JULY	AUG	SEPT
1	0.0	184.6	457.6	1122.0	1813.0	2415.1
2	1.8	187.2	467.6	1142.0	1825.0	2424.1
3	3.1	187.2	479.5	1161.0	1844.0	2439.6
4	3.1	187.2	496.5	1181.5	1860.5	2458.6
5	5.6	205.5	512.5	1205.5	1876.5	2471.6
6	9.5	205.5	530.5	1234.0	1889.0	2483.8
7	9.5	206.3	555.5	1253.5	1901.9	2504.8
8	9.5	210.9	583.5	1270.0	1917.4	2532.8
9	11.5	223.7	615.0	1289.5	1936.9	2548.8
10	14.8	235.5	642.0	1319.5	1955.9	2559.8
11	14.8	238.1	674.0	1352.5	1984.9	2580.8
12	15.3	243.8	691.5	1371.0	2013.9	2601.3
13	12.4	252.1	720.5	1389.0	2042.9	2621.8
14	33.5	270.1	752.5	1414.5	2059.4	2642.8
15	48.6	280.2	781.5	1439.0	2072.4	2654.8
16	72.1	292.3	799.5	1461.0	2087.0	2668.8
17	95.6	299.3	821.5	1482.0	2106.5	2689.3
18	117.1	303.7	845.0	1501.5	2125.5	2709.3
19	134.6	312.4	862.5	1524.5	2146.5	2730.3
20	141.2	328.8	880.0	1547.0	2173.5	2742.8
21	147.6	341.5	899.0	1567.5	2197.5	2747.6
22	154.2	347.0	920.5	1592.0	2226.0	2751.4
23	157.9	349.8	942.5	1617.5	2246.5	2756.3
24	157.9	354.1	962.0	1636.0	2263.5	2762.0
25	157.9	359.6	988.0	1655.0	2284.5	2764.5
26	157.9	367.3	1013.5	1682.5	2307.5	2767.6
27	158.9	380.1	1050.5	1711.5	2338.5	2773.9
28	163.9	394.1	1077.0	1732.5	2362.5	2778.9
29	169.8	405.6	1094.5	1754.0	2375.2	2788.0
30	175.8	421.6	1107.5	1777.0	2385.0	2798.1
31		443.6		1796.0	2402.6	

APPENDIX E

RESULTS OF THE NEAREST NEIGHBOR ANALYSIS OF 1976 AND 1977 DATA

Table E-1: Nearest Neighbor Statistics of Field Data in Cass County 1976

FIELD-PLOT	N	DATE	NEIGHBOR DISTANCE MEAN	NEIGHBOR DISTANCE VARIANCE	CLARK AND EVANS C TEST	CLARK AND EVANS R TEST
111-3	5	82976	.4201	.0417	1.6608	.6117
111-2	5	81776	.7285	.3960	1.2887	.6997
111-1	5	81276	.6701	.0705	2.1327	.5014
222-1	5	81276	1.1288	.6955	.9329	.7819
222-2	5	81776	2.3955	2.8678	1.1446	1.2676
222-3	5	82976	1.1318	.7518	.7864	.8162
333-1	5	80976	.3840	.1602	.8217	.8056
333-2	5	81276	.1547	.0015	2.8580	.3319
333-3	5	82376	.9166	.1395	.0453	.9894
333-4	5	84876	.8975	.2412	.6763	.8419
444-1	5	80976	.2524	.0069	2.1952	.4868
444-2	5	81276	.4161	.1335	2.3605	.4482
444-3	5	81776	.3951	.0560	3.0153	.2951
444-4	5	82376	.4341	.0974	2.7463	.3580
444-5	5	82876	1.0530	1.1970	1.1277	1.2636
111-3	10	82976	.5794	.1933	.9459	.8438
111-2	10	81776	.4574	.2068	3.3956	.4387
111-1	10	81276	.6080	.0342	3.2973	.4550
222-1	10	81276	.8463	.1062	2.5026	.5863
222-3	10	82976	1.8462	1.7170	2.0045	1.3313
333-1	10	80976	.3593	.0847	1.4898	.7537
333-2	10	81276	.3170	.0611	1.9361	.6800
333-3	10	82376	.9635	.4125	.2284	1.0378
333-4	10	82876	.8737	.3522	1.0913	.8196
444-1	10	80976	.3100	.0520	2.4331	.5978
444-2	10	81276	.4567	.1255	3.0742	.4818
444-3	10	81776	.7367	.5040	1.5930	.7367
444-4	10	82376	.8257	.6813	1.9304	.6809
444-5	10	82876	.6059	.1544	1.6512	.7271
111-3	20	82976	.5398	.1968	1.8308	.7860
111-2	20	81776	.9642	.6408	.6432	.9248
333-1	20	80976	.4468	.0791	.5368	.9376
333-2	20	81276	.1818	.0047	5.2204	.3899
333-3	20	89276	1.0942	.4220	1.5275	1.1785
333-4	20	82876	.8356	.7498	1.8483	.7838

444-1	20	80976	.4126	.0797	1.7476	.7957
444-2	20	81276	.8566	.5180	.6623	.8226
444-3	20	91776	.5374	.3420	3.9582	.5374
444-5	20	82876	.9195	.5183	.8845	1.1034
111-3	30	92976	.4526	.1419	3.4213	.6735
333-1	30	80976	.2351	.0133	5.3110	.4831
333-2	30	81276	.1573	.0028	6.9422	.3375
444-1	30	80976	.2601	.0164	5.2226	.5016
444-5	30	82876	.5976	.2710	2.9644	.7171
111-3	40	82976	.4748	.1313	3.7345	.6916
333-1	40	80976	.2936	.0334	4.6483	.6159
333-2	40	81276	.2736	.0589	4.9984	.5869
444-1	40	80976	.3893	.0465	4.4142	.6352
111-3	50	82976	.4692	.1337	4.2865	.6831
333-1	50	80976	.3049	.0337	5.0110	.6296
333-2	50	81276	.2467	.0265	6.3708	.5290
444-1	50	80976	.3263	.1155	5.0146	.6293
333-1	76	80976	.2395	.0751	4.1094	.7519

Table E-2: Nearest neighbor statistics of collected field data in Cass County 1977

FIELD-PLOT	N	DATE	NEIGHBOR DISTANCE MEAN	NEIGHBOR DISTANCE VARIANCE	CLARK AND EVANS C TEST	CLARK AND EVANS R TEST
555-1	5	72977	.3572	.0599	.7065	1.1652
555-2	5	80577	.4796	.0104	1.2623	.7049
555-3	5	81277	.8900	.1754	.4708	.8900
555-4	5	81677	1.0907	.0344	.5450	.8726
555-1	10	72977	.2403	.0081	1.3084	.7837
555-2	10	68577	.6453	.1463	.3125	.8483
555-3	10	81277	1.1843	.3207	1.1152	1.1843
555-4	10	81677	1.0512	.0170	.9621	.8410
555-1	20	72977	.3135	.0713	.1925	1.0225
555-2	20	80577	.5669	.0606	1.4269	.8332
555-3	20	81277	.8416	.1357	1.3552	.8416
555-1	30	72977	.2175	.0168	3.0456	.7893
555-2	30	80577	.5676	.0875	1.7365	.8342
555-1	40	72977	.2403	.0176	2.6145	.7839
555-2	40	80577	.6059	.0760	1.3247	.8905
555-1	50	72977	.2818	.0283	1.0946	.9191
555-2	50	80577	.5673	.0566	2.2484	.8338
555-1	60	72977	.2445	.0230	2.9796	.7989
555-1	75	72977	.2766	.0291	1.6217	.9021
555-1	100	72966	.2335	.0154	4.5615	.7616
555-1	125	72977	.2675	.0311	2.7253	.8726
555-1	150	72977	.2531	.0229	4.0851	.8257
555-1	175	72977	.2763	.0377	2.4969	.9013
555-1	200	72977	.2802	.0333	2.3283	.9139

APPENDIX F

DISTRIBUTION STATISTICS OF FIELDS 111-3 AND 333-2

Table F-1: Distribution Statistics of Field 111-3, date 8-29-76

No. of Run	Total Catch	Var/Mean	I Delta	Chi Sqr. Test	Distr.
Number of samples: 5					
1	6	2.67	2.33	10.67	C
2	3	.50	.01	2.00	R
3	-	-	-	-	-
4	2	.75	.01	3.00	R
5	2	2.00	5.00	8.00	R
6	2	.75	0.0	3.00	R
7	3	1.33	1.67	5.33	R
8	0	-	-	-	-
Mean and S.D.		1.33± .85	2.25±4.01		
C.V.		63.85	177.78		
Number of samples: 10					
1	6	1.56	2.0	14.0	R
2	3	3.0	10.0	27.0	C
3	8	2.17	2.50	19.5	C
4	7	1.92	2.39	17.88	C
5	3	.78	0.0	7.00	R
6	6	.82	.67	7.33	R
7	9	2.09	2.22	18.78	C
8	6	2.67	4.00	24.00	R
Mean and S.D.		1.88± .80	3.4 ±3.07		
C.V.		42.38	90.30		

No. of Run	Total Catch	Var/Mean	I Delta	Chi Sqr. Test	Distr.
Number of samples: 70					
1	30	2.74	5.15	189.3	C
2	94	7.10	5.53	489.8	C
3	119	8.47	5.37	585.1	C
4	97	8.04	6.06	554.7	C
5	39	2.22	3.21	153.1	C
6	76	6.75	6.29	465.6	C
7	69	8.37	8.47	577.2	C
8	68	5.69	5.81	391.1	C
Mean and S.D.		6.17±2.46	5.74±1.45		
C.V.		39.92	25.33		
Number of samples: 100					
1	131	6.69	5.33	662.1	C
2	111	5.60	4.92	553.9	C
3	101	7.61	7.54	753.5	C
4	97	6.30	6.46	623.6	C
5	101	4.37	4.37	432.7	C
6	119	7.06	6.08	698.7	C
7	97	6.03	6.19	596.8	C
8	109	4.30	4.03	425.9	C
Mean and S.D.		6.56±1.62	5.62±1.17		
C.V.		24.66	20.87		

No. of Run	Total Catch	Var./Mean	I Delta	Chi Sqr. Test	Distr.
Number of samples: 30					
1	15	1.34	1.71	39.0	R
2	38	3.86	3.24	112.0	C
3	30	14.34	14.34	416.0	C
4	31	3.04	2.97	88.0	C
5	36	3.64	3.19	105.7	C
6	11	1.60	2.73	46.3	C
7	32	4.13	3.93	119.9	C
8	29	4.53	4.66	131.3	C
Mean and S.D.		4.56±4.12	4.6 ±4.03		
C.V.		93.28	87.63		
Number of samples: 50					
1	46	4.34	4.64	212.7	C
2	52	3.81	3.70	186.5	C
3	58	9.79	8.56	479.9	C
4	67	6.99	5.45	342.7	C
5	71	8.74	6.42	428.3	C
6	58	7.72	6.76	378.2	C
7	60	7.75	6.61	380.0	C
8	30	2.18	2.99	106.7	C
Mean and S.D.		7.58±3.61	5.64		
C.V.		47.59	32.29		

Table F-2: Distribution Statistics of Field 333-2, date 8-12-76

No. of Run	Total Catch	Var./Mean	I Delta	Chi Sqr. Test	Distr.
Number of samples: 5					
1	2	.80	5.0	8.0	R
2	0	-	-	-	-
3	19	72.20	5.0	76.0	C
4	7	9.80	1.5	28.0	C
5	5	1.50	5.0	6.0	R
6	9	16.20	5.0	36.0	C
7	7	9.8	5.0	28.0	C
8	0	-	-	-	-
Mean and S.D.		6.0 ±27.0	4.42±1.43		
C.V.		449.9	32.3		
Number of samples: 10					
1	7	.97	.95	8.71	R
2	8	1.06	1.07	9.5	R
3	9	1.35	1.39	12.11	R
4	9	2.58	2.78	23.22	C
5	27	20.91	7.89	188.20	C
6	13	4.62	3.72	41.62	C
7	10	2.67	2.67	24.00	C
8	3	.78	-	7.00	R
Mean and S.D.		8.8 ±19.34	2.92±2.4		
C.V.		219.8	155.8		

No. of Run	Total Catch	Var./Mean	I Delta	Chi Sqr. Test	Distr.
Number of samples: 70					
1	30	1.46	2.09	100.7	C
2	34	2.07	3.24	143.1	C
3	25	1.32	1.87	90.8	C
4	33	2.13	3.45	147.3	C
5	32	1.38	1.83	94.9	C
6	36	1.62	2.22	111.8	C
7	23	1.92	3.87	132.2	C
8	27	1.98	3.59	136.3	C
Mean and S.D.		1.74± .33	2.77± .85		
C.V.		18.81	30.58		
Number of samples: 100					
1	62	1.85	2.37	183.2	C
2	39	1.60	2.56	158.4	C
3	69	1.48	1.71	146.9	C
4	51	1.64	2.27	162.7	C
5	55	1.67	2.22	165.0	C
6	57	1.78	2.38	176.3	C
7	43	1.65	2.58	163.9	C
8	57	1.41	1.77	135.2	C
Mean and S.D.		1.64± .14	2.23± .32		
C.V.		8.76	14.49		

No. of Run	Total Catch	Var./Mean	I Delta	Chi Sqr. Test	Distr.
Number of samples: 30					
1	17	2.03	2.87	58.9	C
2	17	3.12	4.85	90.7	C
3	11	.66	.78	19.0	R
4	13	1.91	2.54	55.3	C
5	19	1.41	2.50	41.0	R
6	15	1.34	1.71	39.0	R
7	21	1.59	1.86	36.1	C
8	7	1.08	1.42	31.6	R
Mean and S.D.		1.64± .74	2.32±1.23		
C.V.		45.19	52.91		
Number of samples: 50					
1	21	2.04	3.57	100.4	C
2	29	1.27	1.47	62.4	R
3	29	1.69	2.17	83.1	C
4	34	1.41	1.60	68.9	C
5	32	1.77	2.21	86.8	C
6	23	1.25	1.45	61.3	R
7	15	.85	.48	41.7	R
8	21	2.24	4.04	109.9	C
Mean and S.D.		1.57± .46	2.12±1.17		
C.V.		29.09	55.33		

APPENDIX G

CALCULATIONS OF RELATIVE NET PRECISION FOR 1976 DATA

Field 111-3 Date: 8-29-76

Unit Size	Su^2	RNP
.4	.41	14.45
.6	.50	24.00
.8	.59	28.55
1.0	1.23	16.26
1.2	1.59	18.11
1.4	1.75	21.13
1.6	1.20	37.43
1.8	2.26	22.40
2.0	2.56	22.01
2.2	1.91	34.71
2.4	2.30	33.39
2.6	1.88	43.85
2.8	3.38	27.61
3.0	3.55	27.86
3.2	4.25	25.63
3.4	4.19	28.44
3.6	4.71	26.71
3.8	5.23	26.30
4.0	5.21	28.44

Field 111-2 Date: 8-17-76

Unit Size	Su^2	RNP
.4	.05	118.52
.6	.17	70.59
.8	.25	67.37
1.0	.35	57.14
1.2	.28	102.86
1.4	.44	84.05
1.6	.32	140.35
1.8	.72	70.31
2.0	.31	181.74
2.2	.65	102.00
2.4	.71	108.71
2.6	1.23	67.02
2.8	1.25	74.57
3.0	.78	126.80
3.2	.92	118.41
3.4	1.59	74.95
3.6	1.06	118.70
3.8	1.40	98.23
4.0	1.56	94.97

Field 222-2 Date: 8-17-76

Unit Size	Su^2	RNP
.4	.13	45.58
.6	.01	*)
.8	.05	336.84
1.0	.15	133.33
1.2	.11	261.82
1.4	.15	246.54
1.6	.31	144.88
1.8	.23	220.11
2.0	.28	201.21
2.2	.09	736.68
2.4	.26	295.38
2.6	.24	343.50
2.8	.26	358.97
3.0	.49	201.84
3.2	.25	435.74
3.4	.48	248.28
3.6	.33	381.29
3.8	.37	371.69
4.0	.63	235.16

Field 222-3 Date: 8-29-76

Unit Size	Su^2	RNP
.4	.09	65.84
.6	.06	200.0
.8	.11	153.11
1.0	.16	125.00
1.2	.13	221.54
1.4	.22	168.10
1.6	.28	160.40
1.8	.29	174.57
2.0	.24	234.74
2.2	.30	221.00
2.4	.36	213.33
2.6	.27	305.33
2.8	.32	291.67
3.0	.39	253.59
3.2	.45	242.08
3.0	.57	209.08
3.6	.70	179.75
3.8	.63	218.29
4.0	.58	255.43

Field 444-3 Date: 8-9-76

Unit Size	Su^2	RNP
.4	.01	*)
.6	.44	27.27
.8	.11	153.11
1.0	.29	68.97
1.2	.77	37.40
1.4	.85	43.51
1.6	.32	140.35
1.8	.70	72.32
2.0	1.36	37.22
2.2	1.10	60.27
2.4	1.58	48.61
2.6	2.37	34.78
2.8	1.99	46.90
3.0	2.04	48.48
3.2	1.67	65.23
3.4	1.36	87.63
3.6	2.36	53.32
3.8	2.11	65.18
4.0	3.20	46.30

Field 444-4 Date: 8-17-76

Unit Size	Su^2	RNP
.4	.11	53.87
.6	.14	88.71
.8	.28	60.15
1.0	.31	64.52
1.2	.32	90.0
1.4	.35	105.66
1.6	.74	60.49
1.8	.41	123.48
2.0	.51	99.26
2.2	.71	93.38
2.4	.63	121.90
2.6	.78	105.69
2.8	.94	99.29
3.0	.70	141.29
3.2	1.10	99.03
3.4	.82	145.34
3.6	1.52	82.78
3.8	1.44	95.50
4.0	1.68	88.18

*) only one individual count.

Field 333-1 Date: 8-9-76

Unit Size	Su^2	RNP
.4	1.52	3.90
.6	2.54	4.72
.8	3.85	3.73
1.0	5.36	12.91
1.2	2.23	4.85
1.4	7.63	5.51
1.6	8.15	5.09
1.8	9.94	2.86
2.0	19.70	4.25
2.2	15.60	4.21
2.4	18.26	5.16
2.6	15.97	5.36
2.8	17.44	2.96
3.0	33.44	6.70
3.2	16.25	4.16
3.4	28.62	3.55
3.6	35.49	2.55
3.8	32.62	4.22
4.0	37.53	3.92

Field 333-2 Date: 8-12-76

Unit Size	Su^2	RNP
.4	1.31	4.52
.6	2.89	4.15
.8	8.83	1.91
1.0	7.25	2.76
1.2	5.01	5.75
1.4	27.42	1.35
1.6	6.85	6.56
1.8	26.41	1.92
2.0	15.44	3.65
2.2	9.42	7.04
2.4	19.10	4.02
2.6	9.48	8.70
2.8	13.23	7.05
3.0	20.13	4.91
3.2	17.49	6.23
2.4	24.75	4.82
3.6	28.84	4.36
3.8	23.87	5.76
4.0	13.78	10.75

Field 333-3 Date: 8-23-76

Unit Size	Su^2	RNP
.4	.12	8.33
.6	.18	66.67
.8	.35	48.12
1.0	.37	54.05
1.2	.38	75.79
1.4	.49	75.49
1.6	.45	99.81
1.8	.58	87.28
2.0	.53	106.30
2.2	.63	105.24
2.4	.85	90.35
2.6	.81	101.78
2.8	.93	100.36
3.0	1.18	83.81
3.2	1.01	107.86
3.4	1.28	93.11
3.6	1.18	106.63
3.8	1.29	106.61
4.0	1.08	137.71

Field 444-2 Date: 8-17-76

Unit Size	Su^2	RNP
.4	.34	17.43
.6	.32	37.50
.8	.78	21.59
1.0	1.11	18.02
1.2	.28	102.86
1.4	.67	55.20
1.6	.92	48.82
1.8	1.06	47.76
2.0	.65	77.88
2.2	2.95	22.48
2.4	1.47	52.24
2.6	1.18	69.86
2.8	1.70	54.90
3.0	1.87	52.89
3.2	1.20	90.78
3.4	2.29	52.04
3.6	2.87	43.84
3.8	1.39	100.38
4.0	1.67	88.71

Field 333-4 Date: 8-28-76

Unit Size	Su^2	RNP
.4	.05	118.52
.6	.15	80.0
.8	.20	84.21
1.0	.15	133.33
1.2	.18	160.00
1.4	.18	205.45
1.6	.26	172.74
1.8	.40	126.56
2.0	.50	112.68
2.2	.44	150.68
2.4	.38	202.11
2.6	.62	132.97
2.8	.56	166.67
3.0	.58	170.52
3.2	.71	153.43
3.4	.51	233.68
3.6	.57	220.75
3.8	.63	218.29
4.0	.96	154.32

Field 444-1 Date: 8-9-76

Unit Size	Su^2	RNP
.4	.57	10.40
.6	1.53	7.84
.8	1.51	11.15
1.0	2.47	8.10
1.2	1.84	15.65
1.4	4.85	7.62
1.6	3.37	13.33
1.8	4.81	10.52
2.0	6.59	8.55
2.2	5.99	11.07
2.4	6.81	11.28
2.6	6.55	12.59
2.8	7.49	7.84
3.0	12.35	8.01
3.2	9.06	12.02
3.4	8.29	14.38
3.6	14.50	8.68
3.8	13.94	9.87
4.0	9.95	14.89

Field 444-2 Date: 8-12-76

Unit Size	Su^2	RNP
.4	.34	17.43
.6	.32	37.50
.8	.78	21.59
1.0	1.11	18.02
1.2	.28	102.86
1.4	.67	55.20
1.6	.92	48.82
1.8	1.06	47.76
2.0	.65	86.67
2.2	2.95	22.48
2.4	1.47	52.24
2.6	1.18	69.86
2.8	1.70	54.80
3.0	1.87	52.89
3.2	1.20	90.78
3.4	2.24	53.20
3.6	2.87	43.84
3.8	1.39	98.94
4.0	1.67	88.71

Field 444-5 Date: 8-28-76

Unit Size	Su^2	RNP
.4	.18	32.92
.6	.30	40.0
.8	.32	52.63
1.0	.38	52.63
1.2	.32	90.0
1.4	.87	42.51
1.6	.59	76.12
1.8	.72	70.31
2.0	.95	59.30
2.2	.65	10.20
2.4	1.11	69.16
2.6	1.28	64.41
2.8	1.54	60.61
3.0	1.59	62.20
3.2	1.33	81.91
3.4	1.29	92.38
3.6	1.73	72.73
3.8	1.36	101.12
4.0	1.44	102.88

APPENDIX H

FOOD CONSUMPTION RATES OF INDIVIDUAL LARVA FED WITH BARLEY, DOWNY WHEAT, AND CORN LEAVES

Table H-1: Rate of food consumption of armyworm larvae fed on barley leaves (cm^2 leaf area)

INSTAR/DAY	NUMBER OF INDIVIDUALS							AVERAGE
	1	2	3	4	5	6	7	
Instar I								
1	.05	.05	.12	.04	.12	.06	0	.06
2	.17	.20	.15	.24	.16	.15	.27	.19
Instar II								
3	.08	.05	.08	.06	.13	.02	.06	.07
4	.07	.31	.10	.10	.04	.16	.15	.13
Instar III								
5	.20	.22	.17	.16	.14	.15	.46	.21
6	.76	.50	.55	.35	1.05	1.00	1.07	.75
Instar IV								
7	1.03	1.10	1.20	1.70	1.70	1.65	1.15	1.36
8	1.46	1.46	1.35	2.20	1.22	1.44	2.22	1.62
9	5.26	4.87	6.20	5.01	7.19	5.01	5.09	5.51

Table H-1 (continued)

Instar V								
10	2.53	4.72	3.28	2.91	2.66	6.26	5.34	3.96
11	10.15	9.32	9.68	9.21	9.27	12.18	10.52	10.04
12	15.60	19.36	15.73	14.27	5.62	14.48	11.58	13.31
Instar VI								
13	11.07	10.04	9.05	8.02	4.55	9.07	9.07	8.78
14	32.03	27.77	26.57	23.38	9.04	27.97	30.85	25.38
15	30.81	28.66	30.02	30.35	29.73	30.30	30.07	29.99
16	46.37	42.58	44.07	42.37	43.26	44.87	41.15	37.63
17	57.01	56.18	56.21	57.21	59.68	62.81	62.30	58.77
18	41.95	44.71	39.45	44.16	41.75	56.90	40.57	44.22
19	16.50	15.88	14.73	18.71	14.91	43.86	16.32	20.13
Prepupa								
20	0	0	0	0	0	0	0	
21	0	0	0	0	0	0	0	
TOTAL								262.61

Table H-2: Leaf Area Consumed by Armyworm Larvae (cm^2 barley leaf area)

No.	Instar I	II	III	IV	V	VI	TOTAL
1	.19	.21	1.55	7.15	39.67	275.62	324.39
2	.17	.15	.96	7.75	28.28	235.74	173.05
3	.25	.36	.72	7.43	33.40	225.84	268.
4	.27	.18	.72	8.75	28.69	220.10	258.71
5	.28	.16	.51	8.91	26.39	224.20	260.45
6	.27	.27	.45	10.88	29.38	260.23	301.48
7	.28	.17	1.19	10.11	17.55	202.82	232.12
8	.21	.18	1.15	8.10	32.92	275.78	318.34
9	.21	.17	.41	10.44	21.98	227.40	260.61
10	.27	.21	1.53	8.61	27.44	230.93	268.99
11	.12	.12	6.94	6.74	43.46	209.79	267.17
12	.31	.51	14.32	9.53	46.03	183.56	254.26
13	.24	.33	10.83	9.24	65.35	208.25	294.24
14	.31	.24	6.94	9.82	44.19	183.08	244.58
15	.12	.20	12.66	9.17	39.16	184.49	245.8
Mean	.21	.23	4.06	8.84	54.93	223.19	271.46
%	.08	.08	1.50	3.26	12.86	82.22	100

Table H-3: Rate of Food Consumption of Armyworm Larvae Fed on Downey Wheat Leaves (cm^2 leaf area)

INSTAR/DAY	NUMBER OF INDIVIDUALS			AVERAGE
	1	2	3	
Instar I				
1	.07	.07	.07	.07
2	.06	.06	.06	.06
Instar II				
3	.09	.09	.09	.09
4	.17	.17	.17	.17
Instar III				
5	1.20	1.20	1.20	1.20
6	1.64	1.64	1.64	1.64
Instar IV				
7	2.12	1.13	1.50	1.58
8	1.97	1.57	1.90	1.81
9	1.35	1.88	1.77	1.67
Instar V				
10	3.41	8.17	3.28	4.95
11	5.73	3.48	4.57	4.59
12	4.88	1.55	3.78	3.40
Instar VI				
13	5.94	8.18	6.83	6.98
14	3.86	13.49	9.87	9.07
15	5.68	11.71	18.84	9.68
16	17.82	13.42	20.41	17.22

Table H-3 (continued)

Instar VI (continued)

17	29.60	32.17	35.12	32.30
18	61.68	59.0	55.94	58.87
19	60.07	60.72	63.41	61.40
20	55.30	8.45	23.55	29.10
21	Prep.			

Table H-4: Total Leaf Area Consumed by Armyworm Larvae per Instar Fed on Downy Wheat Leaves (cm^2 leaf area)

NO.	INSTAR						TOTAL
	I	II	III	IV	V	VI	
1	.13	.26	2.84	5.44	14.02	239.94	262.64
2	.13	.26	2.84	4.58	13.20	207.14	228.15
3	.13	.26	2.84	5.17	11.63	233.97	254.00
4	.13	.26	2.84	2.66	8.98	214.92	229.77
5	.13	.26	2.84	5.57	15.72	190.47	214.99
6	.13	.26	2.84	3.29	11.37	200.78	218.67
AVERAGE	.13	.26	2.84	4.45	12.49	214.54	234.71
%	.06	.11	1.21	1.90	5.32	91.4	100.

Table H-5: Rate of Food Consumption of Armyworm Larvae Fed by Corn Leaves

INSTAR/DAY	NUMBER OF INDIVIDUALS				AVERAGE
	1	2	3	4	
Instar I					
1	.20	.15	.06	.19	.15
2	.14	.16	.09	.14	.13
Instar II					
3	.50	.58	.49	.58	.54
4	.53	.84	.45	.63	.62
5	.71	1.29	1.53	1.38	1.23
Instar III					
6	1.69	1.36	.51	1.11	1.16
7	.84	.79	.56	1.02	.80
8	.79	1.26	1.90	1.48	1.36
Instar IV					
9	2.90	1.30	3.82	2.50	2.63
10	2.57	.65	1.97	6.81	3.00
11	3.94	4.02	3.32	4.55	3.96
12	5.26	8.37	2.57	2.05	4.56
Instar V					
13	2.33	2.72	4.79	5.61	3.86
14	19.61	22.41	8.71	13.50	15.98
15	15.90	21.22	7.95	7.42	13.12
16	13.46	14.64	13.59	5.64	11.83

<u>Instar VI</u>

17	16.72	23.35	17.71	18.02	18.95
18	6.97	28.80	11.43	31.64	19.71
19	30.04	17.11	33.51	50.71	32.84
20	29.80	34.71	64.40	66.63	49.14
21	49.19	71.24	69.60	76.87	66.73
22	46.31	54.40	56.29	15.09	43.02
23	PREPU	PREPU	PREPU	PREPU	
TOTAL					295.32

Table H-6: Corn Leaves Consumed by Instar of Armyworm Larvae (cm^2 leaf area)

NO.	INSTARS						TOTAL
	I	II	III	IV	V	VI	
1	.34	1.74	3.32	14.67	51.30	179.03	250.40
2	.31	2.71	3.41	14.34	60.99	230.61	312.37
3	.15	2.47	2.97	11.68	34.74	232.94	304.95
4	.33	2.59	3.61	15.91	32.17	258.96	313.57
5	.35	1.88	2.92	18.51	48.59	237.77	310.02
AVERAGE	.30	2.28	3.25	14.02	45.56	231.86	298.27
%	.1	.76	1.09	5.04	15.27	77.73	100.