REARING AND DYNAMICS OF LABORATORY POPULATIONS OF THE YELLOW-STRIPED ARMYWORM, PRODENIA ORNITHOGALLI GUENÉE, AND THE RELATIONSHIPS OF ITS NATIVE PARASITES WITH SYMPATRIC HELIOTHIS SPP.

By

DALE GEORGE BOTTRELL

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1963

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
May, 1968

REARING AND DYNAMICS OF LABORATORY POPULATIONS OF THE YELLOW-STRIPED ARMYWORM, PRODENIA ORNITHOGALLI GUENÉE, AND THE RELATIONSHIPS OF ITS NATIVE PARASITES WITH SYMPATRIC HELIOTHIS SPP.

Thesis Approved:

R R Walton
Thesis Adviser

Jerry W. Young

R S Matheson

William A. Drew

N. Durham
Dean of the Graduate College

PREFACE

The yellow-striped armyworm, Prodenia ornithogalli Guenée, bollworm, Heliothis zea (Boddie), and tobacco budworm, H. virescens (Fabricius), sometimes occur sympatrically on several cultivated plants in Oklahoma. The yellow-striped armyworm frequently feeds on cotton, but it seldom causes the damage that the bollworm and budworm are capable of doing. Little has been published on P. ornithogalli, and virtually no information is available on native parasites attacking Heliothis in Oklahoma. Hence, this study was undertaken to learn more about the biology and dynamics of the yellow-striped armyworm and to evaluate the relationships of native parasites attacking the three sympatric insects.

I am grateful to members of the Department of Entomology and Zoology, Clemson University, Clemson, South Carolina, for directing my first year of graduate studies on a National Defense Educational Act Fellowship.

Dr. D. E. Bryan, now with the Entomology Research Division, U. S. Department of Agriculture, Tucson, Arizona, was major adviser during my first year in graduate school at Oklahoma State University. Dr. R. R. Walton, Professor of Entomology, served as major adviser during the remaining time. Dr. J. H. Young, Professor of Entomology, was a committee member and directed my graduate research program. Dr. W. A. Drew, Associate Professor of Entomology, and Dr. R. D. Morrison, Professor of

Mathematics and Statistics, served as committee members. I am thankful for the assistance of these individuals.

I appreciate the help from members of the Oklahoma Cotton Research Station, Chickasha, and the Irrigation Research Station, Altus, Oklahoma. Superintendents Ed Oswalt and Bill Webb and personnel were most cooperative in providing facilities and assistance during my residence at their stations.

I acknowledge the Oklahoma Cotton Research Foundation and U. S. Department of Agriculture Regional Project S-59 for providing financial support.

I am grateful to R. H. Adams for his concern and assistance throughout the study.

D. C. Arnold provided many larval collections for parasite records. Dr. Twee Hormchong assisted in laboratory rearing and offered many suggestions. I appreciate the cooperation of each.

I acknowledge the following persons for assisting in parasite identification: Dr. D. M. Wood, Dr. W. R. M. Mason, Dr. O. Peck, and G. S. Walley, Entomology Research Institute, Ottawa, Ontario, Canada; and Dr. C. W. McComb, Maryland State Board of Agriculture, College Park.

Dr. H. H. Shorey, University of California, Riverside, provided a strain of yellow-striped armyworms for biological studies. G. M. Thomas, Invertebrate Pathology Laboratory, University of California, Berkeley, determined pathogens reported in the section on diseases of P. ornithogalli and Heliothis. Dr. W. H. Anderson, Chief, Insect Identification and Parasite Introduction Research Branch, Entomology Research Division, U. S. Department of Agriculture, Beltsville, Maryland, provided references to literature on Chelonus texanus Cress.

Dr. J. W. Gentry, Chief Staff Officer, Survey and Detection Operations, Plant Pest Control Division, U. S. Department of Agriculture, Hyattsville, Maryland, furnished distribution records on the yellow-striped armyworm. Messrs. J. A. Reinert, J. T. Pitts, J. P. Keathley, C. M. Bush, and L. D. Abernathy assisted in collecting research data. I appreciate the valuable help of these individuals.

Thanks to Eldon Hardy for making illustrations used in the thesis and to Connie Burke for typing the manuscript.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

The yellow-striped armyworm, Prodenia ornithogalli Guenée, is a common noctuid, the phytophagous larva selecting a large group of cultivated and wild host plants distributed within the Western Hemisphere. It is an amenable laboratory animal, and its maintenance and biology have been reported by past and contemporary researchers. However, there has been little written on the population dynamics of laboratory cultures or its native parasites.

The most plausible explanation for the scarcity of published information appears due to the insect's inability to maintain an economic threshold on most cultivated plants. Often it is reported attacking crops such as tobacco, cotton, vegetables, and several others, but then usually as only a benign pest compared with many of its familial relatives. For example, it sometimes occurs sympatrically with the bollworm, Heliothis zea (Boddie), and the tobacco budworm, Heliothis virescens (Fabricius), on cotton, but it infrequently attains the magnitude of importance that the latter congeneric species have proved capable. Its high reproductive potential and euryecious distribution would suggest the reverse as being true. Thus, research on the yellow-striped armyworm was conducted with the following objectives:

1. To gain a better understanding on the biology and dynamics of laboratory populations and to incorporate the findings into

the most suitable rearing procedures for producing large numbers of insects.

2. To study the influence of larval density on a selected group of biological phenomena.
3. To evaluate the relationships of the native parasites attacking sympatric populations of the yellow-striped armyworm and Heliothis.

The study is intended to expand information on parasites of the three aforementioned noctuids and to produce a mass rearing technique for P. ornithogalli. This technique might allow future workers to evaluate the yellow-striped armyworm as a reservoir for propogating parasites in biological control studies with Heliothis.

CHAPTER II

REVIEW OF LITERATURE

Biology and Rearing of the Yellow-Striped Armyworm

Prodenia ornithogalli is distributed from the most southern countries of South America to Maine in North America.[1] Crumb (1929) reported its distribution to be in the Lower Austral Life Zone of Merriam (1898). He suggested that cold temperature probably discouraged heavy abundance in the extreme north temperate zones.

Crumb (1929) offered one of the most comprehensive accounts available on the biology and description of the yellow-striped armyworm. He reared it on a natural diet of plants and listed descriptive characters for each larval instar. He described only six instars and gave no mention of recording but this number in the species. Its host plants are listed in his treatise.

There are few works available on P. ornithogalli. Other than Crumb's (1929) work, most accounts on the species are fragmentary. A few publications note the moth's appearance in light trap catches (Walkden and Whelan, 1942) or comment on the unusual egg-laying habits of the female (Porter and Hughes, 1950; Sullivan and Thompson, 1959).

---

[1] Personal communications with Dr. J. W. Gentry, Chief Staff Officer, Survey and Detection Operations, USDA, ARS, Plant Pest Control Division, Hyattsville, Md.

And many incidental reports list host plants for the species. Descriptions of the insect's hosts and habits suggest that it is often present as part of the insect complex on many plants but seldom demands control (Webster, 1915; Berger, 1920; Jones, 1920). Only occasionally has the literature presented this insect as an economic pest (Morrill, 1917; Gowdey, 1923; Lowry and Calhoun, 1952; Miskimen, 1960).

A thorough investigation on P. ornithogalli was made by contemporary researchers Shorey and Hale (1965). They reported the biology and mass-rearing of the insect on artificial diet.

The Effects of Larval Density on Life Phenomena

Varied population density has been reported to exert correspondingly variable effects on the morphology, physiology, and biology of lepidopterous larvae. Long (1953) studied the biology of several caterpillars at varied larval density. Drooz (1966) reported that females of the elm spanworm, Ennomos subsignarius (Hübner), displayed lowered pupal weight and decreased fecundity at densities greater than one larva per container of pignut hickory leaflets. Zaher and Moussa (1961) reported that crowding had pronounced effects on larval development, pupal weight, adult weight, and fecundity of Prodenia litura Fabricius.

Several researchers have attempted to explain why varied density produces such differences in the same animal. Unfortunately, most workers have been interested in only one of the several criteria involved and have presented findings without regard to ecological implications. Allee (1931) considered density as an ecological phenomenon and presented a thorough account of the principles involved.

The Life Table as an Aid in Population Dynamic Studies

One of the most useful aids for population studies is the life table, a device that records facts with respect to the age distribution of mortality. A voluminous bibliography is available on life tables for animal populations; two of the best general treatises are by Dublin and Lotka (1925) and Pearl (1940). Deevey (1947) reviewed the life table as a tool in the study of natural populations. Morris (1963) emphasized the importance of the life table and presented it as one of the most informative of all tactics in the explanation of the dynamics of the spruce budworm in Canada.

A useful feature of the life table is that its columns lend themselves readily to graphic representation. By abstracting data from the table and plotting them, ordinate against abscissa, graphs may be constructed to show a curve descriptive of a cohort during its chronological history.

Parasites and Pathogens of *Prodenia ornithogalli* and *Heliothis* spp.

Little has been written on the parasites and pathogens of *Prodenia ornithogalli*, *Heliothis zea*, and *H. virescens* in Oklahoma. Bryan (1962) recognized that *Heliothis* may be represented as a complex of two species, *H. zea* and *H. virescens*, in cotton at certain times of the year and under certain environmental conditions. Workers in other states have noted the occurrence of the complex in cotton (Brazzel et al., 1953; Snow, 1964; Sundman and Hanna, 1963; Henry and Adkisson,

1965; Brazzel and Newton, 1963). But for the most part, full accounts of the parasites and pathogens of these insects are not available. Bibby (1943) compiled a list of parasites of the bollworm in Texas. Quaintance and Brues (1905) emphasized the importance of several parasites of the bollworm, and Winburn and Painter (1932) found several parasites attacking H. zea.

Only fragments of information on the parasites and diseases of P. ornithogalli are available. The most complete work was by Crumb (1929).

CHAPTER III

LABORATORY REARING AND BIOLOGY OF THE YELLOW-STRIPED ARMYWORM

Laboratory research on the yellow-striped armyworm was conducted at various times over a 2-year period. Preliminary research demanded methods of handling large numbers of insects and studies on the basic biology of laboratory cultures. The basic studies were necessary for a more thorough understanding of the dynamics of the insect in the artificial ecosystem of the laboratory.

General Laboratory Rearing

Several cultures from various origins were maintained in the laboratory throughout the research. Different cultures received different handling techniques; thus, there is need for clarifying terminology employed with reference to the strains of insects and rearing procedures.

Experimental Strains

A strain, as used here, refers to a population of armyworms established from field collections in a particular geographical location or a population cultured from pairings, each sex representing a different origin. A wild strain refers to the first laboratory generation of insects provided by field-collected adults or adults reared through

from field-collected larvae. A P_1 generation designates the first adult laboratory generation reared from progenies provided by field-collected moths or from moths reared through from field-collected larvae. A P_1 generation also represents the first parental generation from progenies of a combination strain mating. Thus, the F_1 generation of an Altus strain denotes the first filial generation produced by P_1 moths. The P_1 moths had been reared from moths collected at Altus, Oklahoma or from moths reared through from larvae collected at Altus. A mixed strain defines a population provided by an oviposition chamber housing progenitors of several possible origins.

Rearing Procedures

Approximately 10 pairs of pupae were sexed with characters illustrated by Butt and Cantu (1962) and placed in a breeding chamber similar to that described by Shorey and Hale (1965). Emerging adults deposited eggs on paper toweling fitted to the walls of the chamber and occasionally on cotton wicks in the feeding vials or on the chamber's nylon top. Egg masses were collected as demanded and held in empty diet cups until hatching. Newly-emerged larvae were transferred with a small artist's brush to 1-oz. transparent plastic cups (Premium Plastics, 465 Cermak Road, Chicago, Ill. 60616), each supplied with approximately 15 cc of wheat germ diet developed by Adkisson et al. (1960) and modified by Berger (1963). Methods of diet preparation and dispensing were described by Adams (1966). A pressurized device was used to dispense liquid diet into empty cups. The device consisted of an 8-qt. pressure cooker fitted with a pressure gauge at the air inlet. A kitchen sink hose with spray assembly was fitted to the pressure

cooker's lid. The hose extended to a metal funnel welded to a flat base. Freshly-mixed diet in the liquid state was poured into the funnel, and the funnel was bathed in hot water. The pressure cooker was supplied with compressed air to force diet out the hose. The amount of diet dispensed was regulated by the spray system's nozzle.

Different experiments required a certain larval density or a combination of larval densities. Larval density, as used here, refers to the number of larvae confined within a cup of diet. Densities from 1 to 10 were established for different experiments.

Larvae used only for stock in continuing strain cultures were housed three to four per cup fitted with a paper lid. A small air hole was made in the lid's center by inserting a no. 3 insect pin. All rearing was done in the laboratory at approximately 80°F without controlled light or humidity.

Biology and Actuarial Data

Materials and Methods

The F_1 generation of a California strain[1] provided information reported here. Newly-emerged larvae were placed on diet at one per cup; new diet was furnished when appearing deteriorated. Cups were observed once daily; and recordings were made on death, molting, and entry into the prepupal and pupal stages.

Consecutive molts usually were detected by cast skins or head capsules appearing in the cups. Often the larger larvae devoured these

---

[1]California strain supplied by Dr. H. H. Shorey, Dept. of Entomology, Univ. of Calif., Riverside.

products making it impossible to determine the stadial number. One way to avoid overlooking a molt was to examine the fecal material (generally extruded as one or more pellets) for shed body parts. The wheat germ diet, when not adulterated with eaten body parts, passed through the larva's gut as a material nearly the same color as when eaten. Therefore, an ingested body part appeared in the feces as a distinct inclosion and served as an indication of an earlier molt.

Another method to confirm a molt was by using a "fire orange" Day Glo® daylight pigment (Switzer Bros., 4732 St. Clair Ave., W., Cleveland, Ohio 44113). A small amount of the powdered pigment was applied to each larva's dorsum. The pigment disappeared with the skin at ecdysis; when the skin was eaten, the pigment retained its bright color and appeared as a distinct constituent in the feces. More pigment was applied with successive molts. Before incorporating the technique as an aid in collecting biological data, several larvae were treated with the pigment and compared with untreated larvae to check for possible toxic properties. No difference in treated and untreated insects was detected in developmental periods or survival in larvae or pupae.

The prepupal stage was spent in a burrow dug in the diet by the last-instar larva just previous to cessation of feeding. Thus, a new burrow served as an index for entry into the prepupal stage. Pupation occurred in the same burrow.

Pupae were removed from the burrows, sexed, weighed in grams, measured (length in cm), and held individually in empty diet cups until adult emergence. To reduce variation in weight and length of pupae with time, recordings were made when pupae were 5 days old.

Several dead larvae and pupae with symptoms of disease were sent to

the University of California's Invertebrate Pathology Laboratory for diagnoses.

Results and Discussion

Table I presents biology and actuarial data for one cohort of F_1 larvae followed daily from hatching through eclosion or death of the last pupa.

Both males and females passed through six, seven, or eight larval instars before pupating. Six was the most frequent for each sex. Regardless of the number of instars demonstrated, more time was spent in the terminal than in any other.

The female had both shorter larval and pupal periods and produced a slightly longer and heavier pupa than the male.

Mortality was highest in the pupal stage (33.3%), and 71.0% of the original cohort died before adulthood. Death in the immature stages was unusually high in this experiment (cf. to less than 50% usually observed in routine rearing). Diagnoses by microbiologists at the University of California revealed that most mortality was attributed to septicemia caused by Streptococcus sp. This organism usually attacks laboratory cultures exposed to abnormal environmental conditions.[2] The abnormal conditions may have provided selection pressure which favored certain members and confounded inferences about a population as a whole. Conditions which favored the invading pathogen are speculative. Fluctuations in temperature or variation in the

---

[2]Personal communications with G. M. Thomas, Technician I, Univ. of Calif., Invertebrate Pathology Laboratory, Berkeley.

artificial diet could have served as factors in its spread.

Differences in Progenies from Combination Matings of Different Strains

Materials and Methods

An experiment was conducted to examine possible differences in developmental period, survival, and pupal weight in progenies from several combinations of matings of moths representing various strains. Matings providing the progenies were: P_6 Altus X P_6 Altus (P_6A X P_6A), P_2 California X P_2 California (P_2C X P_2C), P_2 California X P_6 Altus (P_2C X P_6A), P_6 Altus X P_2 California (P_6A X P_2C), and wild Stillwater X wild Stillwater (WS X WS). The male of the mating is listed first in each pair.

Three hundred newly-emerged larvae from each mating were established individually in cups of artificial diet. The larvae were divided at random into three groups of 100. Each group was assigned a replication (holding shelf height - high, medium, or low), and the treatments (matings) were arranged in a randomized complete block design. The treatments were examined in 25 days; and the percent larvae, prepupae, and pupae were recorded. Pupae (not sexed) were selected from treatments and weight in grams. There was considerable variation in the number of pupae (0-66) in the experimental units; hence, the pupal weight data were not analyzed with statistics. All other data were statistically analyzed. The null hypothesis of no difference due to the five matings was tested for each of the following: percent in pupal stage; percent combined in prepupal and pupal stages; and percent

alive (larval, prepupal, or pupal stage). Duncan's new multiple range test was used to study mean differences at the .05 level of probability (Duncan, 1955). It was used only on data providing significant F values at the .05 level in the analyses of variance.

Results and Discussion

Analyses of variance are shown in Tables II, III, and IV. The null hypothesis was rejected for no differences due to matings in the percent combined in prepupal and pupal stages and for percent alive. The hypothesis of no difference due to matings in percent in pupal stage was not rejected.

Table V presents data on progenies obtained from the matings. Results show that there was considerable variation in the time required to attain the prepupal and pupal stages, in pupal weight, and in survival. The P_8 Altus strain mating (P_8A X P_8A) provided the smallest pupae and least survival. When either sex of the mating was crossed with the opposite sex from the P_2 California strain mating (P_2C X P_2C), heavier pupae and increased survival were obtained as displayed by P_2C X P_8A and P_8A X P_2C matings.

Information from this experiment suggests that precaution should be taken when making inferences about laboratory data from yellow-striped armyworms assumed homogeneous but actually from several unrelated strains. Responses by such insects might reflect the inherent genetic makeup of the individual colony or the physiological differences accompanying selection pressure in the laboratory for several generations.

Correlation of the Joint Relationship of Several Biological Variables in the Larval and Pupal Stages

Materials and Methods

Data from the F_1 generation of a California strain reported under Biology and Actuarial Data were used in this section. The possibilities were examined that one or both of the variables, pupal weight and number of days in the pupal stage, were related to the number of days in the larval stage or pupal weight was related to the number of days in the pupal stage.

A sample correlation coefficient (r) was computed from data for each set of the random variables: days in larval stage, days in pupal stage; days in larval stage, pupal weight in grams; and days in pupal stage, pupal weight in grams, to establish a measure of the intensity of association in the variables together. Sex was not differentiated.

Results and Discussion

Table VI presents sample correlation coefficients for each set of variables. Each coefficient is small; nonsignificant t values suggest that no joint relationship existed in any combination of the variables.

The number of days in the pupal stage and the pupal weight were unrelated to the number of days in the larval stage. And pupal weight was unrelated to the number of days in the pupal stage.

Sex Ratio of Pupae

Materials and Methods

One sample of pupae was selected from each of 28 different cultures at various times. A culture represented one generation in one of several strains maintained in the laboratory. Biology of the F_1 California strain suggested that females had a shorter larval period and, thus, pupated earlier than males. To avoid a biased sample of predominately females, pupae were selected at random after all members in the culture providing the sample had pupated. The samples ranged in size from 6 to 182, totaling 1,257 (642 males and 615 females).

The total collection produced sexes distributed about 1:1, but individual samples varied considerably in the proportion of males and females. Thus, the question arose as to how the data from several samples should be combined. How much did each sample contribute to the information relative to the hypothesis under test (1:1 ratio)?

The hypothesis of a 1:1 ratio of males to females was tested by a chi-square test (Ostle, 1963). A chi-square was computed for each sample. The 28 shi-squares were summed to provide a pooled chi-square. The original data (642 males, 615 females) were lumped into one large sample, and a total chi-square was computed. The total chi-square was substracted from the pooled chi-square to obtain the difference or heterogeneity chi-square. This statistic served as a measure of the lack of consistency among the 28 samples.

Results and Discussion

Sex ratios of the pupal samples and chi-squares are presented in

Table VII. Ratios ranged from 1:1.1 to 1:5 (male:female) in individual samples. The combined samples provided a ratio of nearly 1:1, and the chi-square value failed to reject the hypothesis under test. However, the pooled chi-square which accumulated components of information supplied by the independent samples was significant to reject the hypothesis of a 1:1 sex ratio. The heterogeneity chi-square further substantiated the lack of consistency among the 28 samples in providing the hypothesized ratio.

The 28 samples of pupae were selected at random from several cultures of armyworms reared essentially in the same environment. Thus, the large lumped sample of 642 male and 615 female pupae probably allows a good estimate of the sex ratio of the parent population. Even though the ratio of males to females varied considerably from sample to sample, the sex ratio (about 1:1) is fixed in the parent population. Hence, males and females had equal chances of appearing in each sample, regardless of its size. Random effects of sampling prevented each sample from exactly duplicating the population ratio of 1:1. The significant pooled chi-square and heterogeneity chi-square values merely showed lack of consistency from sample to sample. And they do not produce information sufficient to reject the hypothesis under test with the parent population.

Summary

General procedures in the laboratory rearing of the yellow-striped armyworm are described.

A technique employing a Day Glo® daylight pigment was very useful in detecting larval molts.

Biology and actuarial data showed that larvae of both sexes passed through six, seven, or eight instars before pupating. Mortality was highest in the pupal stage, and 71% of the original cohort died before adulthood. Most mortality was attributed to Streptococcus sp.

Data on progenies from combination matings of different strains showed that at least one mating provided progenies responding differently from progenies of other matings in developmental rate and survival.

Number of days in the pupal stage and the pupal weight were unrelated to the number of days in the larval stage. Pupal weight was not related to the number of days in the pupal stage.

The sex ratio of 28 samples of pupae combined was approximately 1:1. However, individual samples produced ratios varying from 1:1.1 to 1:5 (male:female).

CHAPTER IV

EFFECTS OF LARVAL DENSITY ON VARIOUS LIVE PHENOMENA OF THE YELLOW-STRIPED ARMYWORM

Preliminary investigations on the laboratory rearing of the yellow-striped armyworm indicated that larvae reared solitarily behaved differently than larvae reared at more than one per cup of diet. Contradictory results were obtained when studying the biology at different densities. A hidden interaction seemed to exist and unless density was controlled in the sample population, this interaction could lead to misinterpretation of the data.

Research in this chapter was undertaken with the following objectives considered:

1. To select the proper rearing density in the mass production of yellow-striped armyworms.
2. To define the critical periods in intraspecific competition at different densities.
3. To study the effects of larval density on development and morphometrics.

Selection of Larval Density in a Mass Rearing Program

Materials and Methods

Newly-emerged larvae were placed in cups of artificial diet at

densities 1, 2, 3, 4, 5, and 10. At each density approximately 25 cups (range = 21 to 25) were established with one small air hole in each of the cups' lids, and an equivalent number of cups was established without air holes. The air hole was made by probing a no. 3 insect pin in the lids' center. Insects living in containers without air holes received a limited amount of air which was present previous to fitting the cups with lids. Preliminary investigations, however, suggested that the proper supply of air was not admitted by lids without air holes.

The test was replicated four times using progenies from strains listed below:

Rep. 1. F_3 and F_4 Altus

2. F_5 Altus

3. F_5 Altus

4. F_1 California

Sometimes it was impossible to obtain enough larvae from the same strain at a given time to establish approximately 25 cups for each treatment. When enough larvae from one strain were not available to complete a full replication, those larvae available were partitioned into the six densities at both levels of air; as more larvae became available, the same procedure was practiced until the replication was complete. This accounted for the use of two strains in the first replication.

The treatments were observed weekly, and the number of living insects, regardless of developmental stage, was recorded. Pupae were removed when first detected and counted as being alive on consecutive observation dates.

Results and Discussion

Bar graphs present survival at the various larval densities after 1, 3, 4, 5, and 6 weeks, respectively, in Figures 1-5.

At the end of 1 week survival was greatest in insects maintained at medium densities (3 and 4), possibly describing Allee's (1931) group-survival principle at this age. His premise states that animals living in intermediate-sized clusters often produce greater survival values than those living as solitaries or at densities higher than the intermediate range.

Insects in cups which were provided with air holes produced an average survival rate higher than insects in cups with no air holes at each density on every observation date. Averaged over density, there was 5.7% greater survival in insects provided with air at the end of 6 weeks. At that time difference in air and no air was most noticeable in insects reared at density 1. At that density, cups with air holes produced 11% more live insects than cups without air holes.

This simple air-hole technique would be extremely valuable in a mass rearing program demanding 100,000, for example, pupae for an experiment. Fifty percent of the yellow-striped armyworms placed on diet as first-instar larvae in cups with air holes were alive at the end of 6 weeks. This compares to 39% in cups without air holes. Assuming that only pupae were alive at the end of 6 weeks, cups without air holes would have required an initial 256,410 first-instar larvae to produce 100,000 pupae. Whereas, cups with air holes

would have required only 200,000 first-instar larvae to produce 100,000 pupae. This means that 56,410 cups of diet could be conserved by employing the air-hole technique.

Difference in survival became most noticeable between densities in 3 and 4 weeks. This was pronounced in consecutive observations after 4 weeks in cups provided with air. But at both 5 and 6 weeks, there were more insects at density 4 without air than insects at density 3 with air.

This experiment indicates that selection of larval density is very important in the mass rearing of the yellow-striped armyworm. Proper selection of density depends on the time when the insects are demanded. Proportionally fewer pupae would be expected at increasing densities. But a high-density population would be more economical when utilizing a limited number of young larvae for a short period of time. Regardless of density selected, the air-hole technique should not be overlooked.

Critical Periods in Intraspecific Competition at Various Larval Densities

Ecologists are not in full agreement about the essential characters and the significance of competition. But most agree that it is mediated by two density dependent components: exploitation and interference (Park, 1962). Exploitation operates when organisms draw upon a particular resource (e.g., food) which is present in limited supply. Interference exists when interactions between organisms affect their reproduction or survival. Thus, competition between larvae of the yellow-striped armyworm sharing the same environment (i.e., intraspecific competition) could consist of one or both of these components.

The pattern taken by each depends on larval density.

Research reported here was conducted with the following objectives:

1. To determine critical periods in chronology of growth where intraspecific competition in larvae is most critical.
2. To determine the influence of larval density on the distribution of developmental stages in time.
3. To determine if larvae living crowded for an initial interval of time and then living solitarily at a later time respond differently than larvae living either crowded or solitarily throughout life.

Materials and Methods

Newly-emerged larvae were established in cups of artificial diet at densities 1, 2, 4, and 10. At each density, cups were divided at random into three groups of approximately 25 (range = 16 to 30) and categorized as follows: Group I, original density maintained throughout the experiment; Group II, larvae isolated into individual cups of new diet after 7 days at the original density; and Group III, larvae isolated into individual cups of new diet after 14 days at the original density.

A new supply of food for larvae in all treatments was provided by supplying new diet at 0, 7, and 14 days. The experiment was conducted twice using the F_4 and F_5 generations (Experiments I and II, respectively) of an Altus strain. Periodic observations were made until most larvae ($\geq$ 75%) had pupated. For each observation on the three groups at each density, recordings were made on the percent insects alive and the percent distribution of larvae, prepupae, and pupae.

Results and Discussion

Figure 6 presents bar graphs showing the survival and distribution of developmental stages in each group averaged over density with time in Experiment I. Figure 7 presents information obtained in Experiment II. It appears that insects maintained at the original density throughout life entered a successive developmental stage (prepupal or pupal) earlier than insects spending only an initial period of time at the original density. Long (1953) found that crowding increased the rate of development in Plusia gamma L., the larval duration often being 80% of that in solitary larvae. Part of this difference in time was due to the fact that crowded larvae generally underwent fewer instars. The number of instars in P. gamma is not genetically determined but appears to be least when development is fastest. No records were made on the number of instars in the present study.

Moseback-Pukowski (1937) reported that a local temperature rise occurred within closely-packed colonies of Vanessa io L. and V. urticae L. and accounted for the shorter duration of larval development occurring under crowded conditions. Wardzinski (1938) reported similar findings in experiments with Pieris brassicae L.

On most observation dates in both experiments, greatest survival was in Group III composed of insects living crowded the first 14 days of life before isolation. Possibly the greater survival in Group III than in Groups I or II can be explained by defending the premise advanced by Allee (1931). He reported that grouped animals often show increased efficiency which is reflected by longer survival, or better growth, if neither too few or too many animals are present. There is an optimal

population density at some individual point within the possible range of numbers. Perhaps this optimal population density in the crowded larvae was realized at the time of, or just previous to, isolation on the 14th day. Long (1953) reported that larvae initially crowded and then later isolated tend to feed as solitaries at a rate essentially as when crowded; and their total activity remains greater than that of normal solitaries.

Figures 8 and 9 present survival and distribution of developmental stages in the three groups after 22 and 48 days, respectively, in Experiment I. Figures 10 and 11 present survival and distribution of developmental stages in the three groups after 22 and 36 days in Experiment II. Mortality increased with density among insects maintained at the original densities throughout development. This was noticeable after 22 days of association but was most critical in the higher densities (4 and 10) on the last observation date. These results confirm closely to those obtained in the previous section (Selection of Larval Density in a Mass Rearing Program). Similarities can be noted by comparing Figures 1-5 with Figures 8-11.

It appears that the following generalizations may be drawn:

1. Intraspecific larval competition accounted for decreased survival in cultures maintained together for periods as short as 14 days, but competition was most severe in older insects.
2. Larval duration was shortened in insects maintained under crowded conditions throughout development.
3. The optimal population density was between 1 and 10 larvae per cup and was realized at some point between the 7th and 14th day of association.

Temperature in Diet Cups Containing Larvae at Various Densities

The possibility of a local temperature rise in crowded colonies accounting for shorter larval periods as reported by Moseback-Pukowski (1937) and Wardzinski (1938) was examined.

Materials and Methods

Newly-emerged larvae from a mixed strain were placed in cups of artificial diet at densities 1, 2, 3, 4, 5, and 10. On the 11th day paper lids were fitted tightly to five cups at each density and sealed with glue to prevent possible exchange of gases with the outside. The cups were imbedded in dry sand in a pyrex tray and held for about an hour to allow equillibration with the temperature (approximately 78.5° F) of the sand. A hole large enough to allow entry with a temperature probe was made in the center of each lid. A probe was inserted into one cup from each density. The probe's end was held on the surface of the diet, and soft putty was molded around the entrance in the lid to prevent loss of gases. Recordings were made after the thermometer's indicator dial showed that equillibration had been attained for each probe. A YSI 6-probe Thermistemp® Tele-Thermometer (Yellow Springs Instrument Co., Inc., P. O. Box 279, Yellow Springs, Ohio 45387) with instrument accuracy of ± .25° F and readability and reproducibility of ± .1° F was used for temperature recordings. Recordings for the six cups per replication could be made in less than ½ minute. The same procedure was repeated with each replication.

Regression analysis was performed on the data. Since replication

was provided in the performance of the experiment, i.e., more than one temperature reading (Y) was made for each value of density (X), it was possible to subdivide the residual sum of squares into two parts: one part being an estimate of experimental error and the other a measure of the lack of fit of the linear model. Thus, from the analysis of variance two null hypotheses were tested: (1) $b_1 = 0$, i.e., slope equal to zero and variation in X did not contribute to variation in Y and (2) the linear model adequately describes the data--that is, no real lack of fit exists. Similar procedures in analyses and testing hypotheses were employed on other regression data in the remaining parts of this chapter.

Results and Discussion

Figure 12 presents temperature readings at each density portrayed in a scatter diagram with the straight-line regression inserted. There was less than 1° F difference in any of the mean values at the different densities. Analysis of variance in the regression of temperature in cups on larval density of 11-day-old yellow-striped armyworms is shown in Table VIII. From the small values of F obtained, variation in density did not contribute to variation in termperature. Thus, the possibility that a local temperature rise accounting for shorter larval duration in crowded insects of this age is doubtful. However, such inferences can not be made about older larvae which would provide much more mass relative to the confined space.

Effect of Density on Larval Weight

Materials and Methods

Newly-emerged armyworms were placed in diet cups at densities 1, 2, 3, 4, 5, and 10. Fresh diet was furnished periodically. Three age groups of larvae (7, 14, and 25 days old) were selected for weighing. Altus F_7 larvae were used to establish weight for the 7- and 14-day age groups; the 25-day age group contained the progenies of a P_2 California-P_8 Altus mating.

On dates of weighing the following procedures were performed at each density to provide a completely random design: larvae from cups containing the original density were placed into one common pool; three or four groups of 30 larvae were selected at random from the pool; each group represented a replicated experimental unit. Total weight for the 30 insects from each unit was recorded in grams. Enough 7- and 25-day age groups were available to give four replications of 30 larvae. Only three replications were available for the 14-day-old larvae.

Analysis of variance was performed on data from each age group to test the null hypothesis of no difference in weight at the six densities. Duncan's new multiple range test was used to study mean differences at the .05 level of probability.

Results and Discussion

Analyses of variance for the three age groups are given in Tables IX, X, and XI. For each age group the null hypothesis of no difference in the combined weight of 30 larvae at various densities was rejected.

Figures 13, 14, and 15 portray the results graphically. At each

age group, larvae reared at one per cup were significantly heavier than larvae reared at other densities. Difference between the high and low density was most pronounced in 25-day old larvae.

Seven- and 14-day old larvae followed essentially the same trend in weight at the various densities. Larvae at density 1 were heavier than larvae at density 10. But larvae at densities 4 and 5 were heavier than larvae at density 3.

The following observations were made during the study that possibly help explain the favoring of heavier larvae if reared solitarily:

1. Solitary individuals were less active than crowded individuals and spent most of the time in contact with the feeding substrate.
2. Crowded larvae were more aggressive, especially in latter periods of confinement, and spent more time away from the feeding substrate.
3. The component of competition, interference, was evident in cups housing older, crowded larvae; physical contact between members resulting from the spatial restriction usually developed into antagonism. The reciprocal component of competition, exploitation, was also obvious. A fresh supply of food was furnished periodically, but constant depletion between consecutive replenishments allotted less resource per unit member and restricted the opportunity to feed. Modification of the feeding substrate was greater in cups at the higher densities; excrement accumulated and probably enhanced microbial contamination.

Less expenditure of energy and more time for concentration on

feeding in a less exploitable environment allowed solitary members to meet requirements for growth in a period of time not possible in the crowded microcosm.

Effect of Density on Pupal Weight

Materials and Methods

Pupae were provided by larvae from a mixed strain which had been confined in cups of artificial diet at densities 1 through 3 during development. Pupae were weighed individually in grams when about 3 days old. Regression analysis was performed on pupal weight data of each sex.

Results and Discussion

Tables XII and XIII present analyses of variance in the regression of pupal weight on larval density of male and female yellow-striped armyworms, respectively. Highly significant F values indicate that density influenced pupal weight in both sexes. Straight-line regressions were fitted to the pupal weight data (Figures 16 and 17); however, the test for no real lack of fit suggests that the linear model does not adequately describe the female data ($F = 5.4737$, significant; $P = .05$). The hypothesis of no real lack of fit was not rejected with the male; thus, the linear model is assumed to describe the data.

These results agree with the findings of Drooz (1966) with female pupae of the elm spanworm, of Iwao (1962) with Leucania separata, and of Zaher and Moussa (1961) with Prodenia litura Fabricius.

Effect of Density on Developmental Time of Larvae and Pupae

Materials and Methods

Newly-emerged yellow-striped armyworms were partitioned into cups of artificial diet at densities 1 through 5 and observed daily. Pupae were sexed and held individually until eclosion. Recordings were made on the number of days each insect spent in the larval and pupal stages.

Regression analysis was performed on data for each sex to test the null hypothesis that variation in density did not contribute to variation in number of days in the larval stage or pupal stage (i.e., slope equal to zero). In addition, the null hypothesis of no lack of fit was tested.

Results and Discussion

Analyses of variance are shown in Tables XIV, XV, XVI, and XVII. The null hypothesis of slope equal to zero was rejected with data from male pupae indicating that density did contribute to variation in number of days in the pupal stage. In the other three cases, all F values were small. This indicates that density had no significance in the number of days in the larval stage of each sex or number of days in the pupal stage of females. In all cases, the hypothesis of no lack of fit was not rejected.

Scatter diagrams showing density plotted against days in larval stage for females and males are presented in Figures 18 and 19 and density against days in pupal stage for females and males in Figures 20 and 21.

Drooz (1966) reported that density influenced to a degree a longer period of time in the larval stage of the elm spanworm, but was significantly more related to the duration from time of hatching to adulthood. Long (1953) found that crowding accorded more rapid development among larvae of Plusia gamma L. Zaher and Long (1959) reported similar findings in Pieris brassicae L. Iwao (1962) found two patterns in lepidopterous larvae, one exemplified by Leucania separata Walker where crowding accelerated development, and one by L. loreyi Dopunchel where more time was required for larval and pupal development when reared under crowded conditions.

From results reported in Critical Periods in Intraspecific Competition at Varied Larval Density, a premise was advanced. It stated that armyworms maintained crowded throughout the larval stage tended to enter a successive stage in development earlier than armyworms living at the same density for only an initial period of life before isolation as solitaries. Results from the present section do not nullify the aforementioned premise. It merely indicates that larval duration appears independent of density when larvae are maintained at the original density during all of the larval stage. Crowding accelerates larval development in insects crowded continually over development in insects crowded only during an initial interval. But larval development is independent of density when comparing groups maintained at various densities for an equivalent amount of time.

Summary

Larval density was examined to determine its influence on the biology of yellow-striped armyworms. Solitary larvae provided greater

survival values than individuals crowded during the larval stage. Greatest survival was obtained when rearing cups were provided small air holes.

Larvae confined to crowded conditions for a given period of time and later isolated as solitaries provided responses differently in survival and development than larvae maintained continually under crowded conditions. Fourteen days of crowding before isolation produced a higher survival value than 7 days of crowding or continual crowding. The optimal population density was between 1 and 10 and was realized between 7 and 14 days of association.

Variation in larval density did not contribute to variation in temperature inside diet cups containing 11-day old larvae.

Larval density produced a significant difference in weight of 7-, 14-, and 25-day-old larvae. Differences were greatest in the older-age group.

Variation in larval density contributed to variation in pupal weight of both sexes. Higher densities produced smaller pupae.

Larval duration was independent of larval density in a linear sense when the larvae were maintained at the original density throughout development. Higher larval densities shortened the pupal stage in males but never influenced development of female pupae.

CHAPTER V

LIFE TABLE FOR THE YELLOW-STRIPED ARMYWORM REPRESENTING LARVAL AGE WITH RESPECT TO THE DISTRIBUTION OF PUPATION

This chapter presents the life table as a practical device in a laboratory insect rearing program. It is constructed around facts basic to the age distribution of entry into another developmental stage. The conventional life table records facts basic to the age distribution of mortality.

Materials and Methods

Data from F_1 larvae of a California strain of yellow-striped armyworms reported under Biology and Actuarial Data in Chapter III were used for life table construction.

The arithmetical procedure outlined by Deevey (1947) was employed. Data from 33 males and 78 females were converted so each sex represented an initial cohort of 100. For each sex at each age interval, the following quantity was computed:

$$X^1 = \left[\frac{\bar{X} - Ax}{\bar{X}}\right]\left[100\right]$$

where X^1 is age expressed as percent deviation from the mean no. days in larval stage; $\bar{X}$, the mean no. days in larval stage; and Ax, age at the beginning of the interval. The Nx values were plotted against

respective X^1 values to obtain a developmental curve for each sex.

Results and Discussion

The life table representing larval age with respect to the distribution of pupation is shown in Table XVIII. The table was not constructed to make inferences about natural populations of armyworms. Rather, it was modeled around a population implanted in an artificial ecosystem. It does posses practical characteristics, however, which might be very useful in a laboratory rearing program where scheduling in advance for the amount of diet, manpower, etc. is critical. The table could be used to predict future occurrences in populations with developmental rates comparable to the California strain. For a hypothetical example, imagine a cohort of larvae cultured on articicial diet at a known time. Using the table as a guide, refer to the 34-35 day age interval. During this period 9.8% male larvae entering the interval would be expected to pupate. An additional 4.62 days would be predicted before male larvae remaining at the end of the interval would pupate.

A table of this nature probably would be most accurate when predicting events in populations housed under constant conditions such as in environmental chambers where only intrinsic characteristics of the insects could not be quantified.

Figure 22 shows developmental curves for larvae of both sexes. Each curve takes the form of a negatively skew rectangular. Curves like these describe populations where all members are born at the same time, undergo a minimum of change for a considerable period of life, and then enter a successive developmental stage (pupal) rapidly at approximately the same rate.

CHAPTER VI

PARASITES AND PATHOGENS OF THE YELLOW-STRIPED ARMYWORM AND HELIOTHIS

This chapter considers parasitism and disease as factors in influencing the abundance of natural populations of the yellow-striped armyworm, Prodenia ornithogalli; bollworm, Heliothis zea; and tobacco budworm, Heliothis virescens, in Oklahoma.

Natural Parasitism of the Yellow-Striped Armyworm

Materials and Methods

The objective of this research was to determine the importance of various parasites attacking the yellow-striped armyworm. A general survey was conducted to establish the parasite complex associated with the species. Collecting was concentrated in regions where P. ornithogalli occurred sympatrically with Heliothis. P. ornithogalli seldom was detected in cotton; it was most common in alfalfa, hence, collecting was emphasized in the latter crop.

A general survey was begun in 1965 and expanded in 1966 to determine the incidence of parasitism associated with various host plants. Larval samples were brought to the laboratory and held individually in cups of artificial diet. The number yielding parasites was recorded, and pupae were retained for parasite emergence. Many larvae with

symptoms of parasitism died from disease before attaining adequate size for parasite emergence. But parasitism was recorded only from larvae which provided parisites.

Results and Discussion

Table XIX lists parasites reared from yellow-striped armyworms. The month of collection, host plant, location, and remark accompany each parasite. Thirteen species representing the families Tachinidae, Braconidae, Ichneumonidae, Eulophidae, and Perilampidae were collected. All but Perilampus robertsoni Cwfd. are primary parasites. It is a hyperparasite, and a single specimen emerged from a Chelonus texanus Cress. pupa. Only two of the 13 parasites were common enough to be considered important in the suppression of natural populations. C. texanus was a common parasite in most collections from alfalfa. More than 30% of several samples provided C. texanus. It was reared only from armyworm larvae collected in alfalfa. Lespesia archippivora (Riley) was the other important parasite. It was recovered from armyworms collected in alfalfa and native plants. Nearly 70% of yellow-striped armyworms collected from tumbleweed in September were parasitized by this insect.

Table XX presents the seasonal incidence of parasitism in yellow-striped armyworms collected from all host plants in 1966. A total of 307 larvae were collected and 106 (34.52%) pupated. Parasitism was 36.15% in larvae. Only 3.77% of the pupae were parasitized. Parasitism was greatest in larvae collected in July. As previously mentioned, disease was an important factor in premature larval death and possibly obscurred the true incidence of parasitism. Thus, data should be

considered only relative in explaining mortality due to parasitism.

Seasonal and Habitat Distribution of the *Heliothis* Complex in Cotton, 1966

Materials and Methods

Collections of *Heliothis* larvae were made regularly in 1966 from the time they first appeared in cotton until the first killing freeze. Most collections were from Grady County, Oklahoma, with some in latter September from Jackson County. All or portions of each larval sample were placed solitarily in cups of artificial diet.

Larvae were identified to species by examining the dorsal setigerous tubercles of abdominal segments 1, 2, and 8. In *H. virescens* these tubercles are ornamented with microspines in third and latter stadia. As pointed out by Brazzel et al. (1953) and Neunzig (1964), the degree of spinulation is essentially the same in first- and second-instar larvae. Thus, a larva dying before attaining size adequate for identification or when in doubt as to species was recorded as *H.* sp.

Individual records were kept on parasite emergence, larval death, and pupation. Pupae were sexed and retained for parasitic records. Several diseased larvae and pupae were diagnosed by members of the University of California's Invertebrate Pathology Laboratory.

Larval collections were made so that the plant structure as well as the source of collection with regard to insecticidal control and irrigative practice were specified. Larvae were collected from the following sources, defined in regard to insecticidal control:

1. Controlled: cotton receiving regular 3- to 8- day applications

of one or more standard insecticides at rates recommended for bollworm-budworm control during the sequence of sampling.

2. Irregularly Controlled: cotton receiving applications of insecticide only when infestations of Heliothis were extremely high.
3. Noncontrolled: cotton free of insecticide during the sequence of sampling.

Samples were categorized to source in regard to irrigative practice (irrigated or nonirrigated cotton) and plant structure (cotton blooms or cotton bolls and squares).

Results and Discussion

Later sections in the chapter present findings on diseases and parasites. This section is restricted to seasonal and habitat distribution.

Table XXI shows the seasonal distribution of the Heliothis larval complex in cotton in 1966. H. virescens was detected for the first time on August 12 and was found in nearly every sample after that date. It was most abundant the last week in August (12.90%) and the first week in September (13.53%). Of 1,981 Heliothis larvae collected, 103 (5.19%) were H. virescens.

Table XXII shows the incidence of each Heliothis species collected from the different sources in cotton. H. virescens was more abundant in irrigated than nonirrigated cotton (8.34% vs. 3.54%); however, emphasis on larger samples from nonirrigated cotton during low levels of abundance (before mid-August and after mid-September) may have accounted for this.

The pupation rate of Heliothis larvae collected from the different sources is shown in Table XXIII. Data on both species suggest that pupation was greater in larvae from irrigated cotton than in larvae from nonirrigated cotton. Disproportional sample sizes disqualify an appropriate comparison, but it appears that pupation was favored in cotton with insecticide control.

Sex ratio of H. zea pupae from larvae collected from various sources is presented in Table XXIV. Sexes were distributed approximately 1:1.

Natural Parasitism of the Heliothis Complex

Materials and Methods

In 1965 a collection of Heliothis larvae was begun to determine the parasite complex associated with various host plants and to evaluate the importance of parasitism as a factor in regulating natural populations. When possible, collections were made in conjunction with collections of the yellow-striped armyworm. The armyworm was detected only occasionally in cotton; hence, sampling was emphasized in alfalfa where it was common.

A general survey for parasites attacking Heliothis was made in 1965. The seasonal incidence of parasitism was studied in alfalfa and cotton in 1966. Procedures and source of collections in cotton were reported in the foresection. Similar procedures were employed with collections from alfalfa.

Results and Discussion

Table XXV lists the parasites reared from Heliothis in 1965 and 1966. The month of collection, host plant, location, and remark accompany each parasite species. Fifteen species of parasites representing the families Tachinidae, Braconidae, and Ichneumonidae were reared from Heliothis spp. Microplitis croceipes (Cress.) was the most common parasite and the only parasite confirmed from H. virescens. It constituted more than 50% of all hymenopterous parasites reared to adulthood and was the only major parasite of H. zea in cotton. Quaintance and Brues (1905) described the habits of this insect under the binomial M. nigripennes Ashm. Winburn and Painter (1932), Bibby (1943), and Butler (1958a) reported M. croceipes as a common parasite of Heliothis. Mesochorus[1] sp. was apparently hyperparasitic on M. croceipes. Other insects listed in Table XXV are primary parasites.

Chelonus texanus Cress. was the second most abundant parasite. It was confirmed only in H. zea; however, it was reared from a few larvae identified only to Heliothis sp., some of which may have been H. virescens. It comprised about 30% of hymenopterous parasites reared to the adult stage; its incidence was highest in alfalfa. Its laboratory rearing is discussed in a later section of this chapter.

Other parasites commonly reared from Heliothis were the tachinids Eucelatoria armigera (Coq.), and Lespesia archippivora (Riley), and Archytas marmoratus (Tnsd.). E. armigera was the most abundant of the the three and was the only important tachinid in collections from

---

[1]Personal communications; Dr. W. R. M. Mason, Entomology Research Institute, Ottawa, Ontario, Canada.

cotton. L. archippivora was recovered only occasionally from Heliothis in cotton. Butler (1958b) reported that E. armigera parasitizes Heliothis spp. in Arizona. A. marmoratus was common in collections from alfalfa in late September. This insect becomes parasitic in Heliothis larvae but completes development within and emerges from pupae. Parencia (1964) reported this parasite as a limiting factor in the overwintering of the bollworm in Texas.

Table XXVI presents seasonal incidence of parasitism and pupation rate in the Heliothis complex in cotton in 1966. Parasitism in the different collection sources is shown in Table XXVIII. Disease caused considerable premature larval death. Hence, parasitism should be considered only as relative in explaining mortality.

Parasitism was greatest in the sample populations from cotton in September. It was highest in collections from alfalfa in August (Table XXVII). H. virescens was not confirmed in collections from alfalfa so parasitism is listed only as representing Heliothis.

Table XXVIII shows that parasitism was least in cotton with insecticidal control (H. spp. = 2.08%). Fewer insects in noncontrolled cotton (H.spp. = 7.88%) produced parasites than insects in irregularly controlled cotton (H. spp. = 8.54%). This may be due to sampling error. More Heliothis larvae were available for sampling in irregularly controlled cotton when control had not been practiced recently. Consequently, emphasis was on collecting larvae under virtually no insecticidal pressure. Total parasitism in Heliothis (larvae and pupae combined) from cotton in 1966, independent of control, irrigative practice, and plant structure, was as follows: H. zea = 7.45%; H. virescens = 15.94%; H. sp. = 3.33%; and all collections combined, 7.84%. This

compares with 15.90% total parasitism in Heliothis collected from alfalfa. Pupation rate in larvae from cotton was greater than in larvae from alfalfa (Table XXIII, H. zea = 62.20%, H. virescens = 55.07%; cf. Table XXVII, Heliothis = 17.10%).

Pathogens from Field-Collected Yellow-Striped Armyworms and the Heliothis Complex

Disease was an important mortality factor in both yellow-striped armyworms and Heliothis collected during the survey for parasites. Fifty percent or more of the larvae in some collections died in the laboratory from disease which the insects contracted earlier in their natural habitat. This was especially true in late summer and during periods of prolonged rainfall. The incidence of disease was higher in larvae in alfalfa than in larvae from other host plants.

It was impossible to quantify data in regard to suppression of natural populations by disease. The artificial diet was fortified with antibiotics to prevent breakdown of the agar-based medium. The antibiotics may have interferred with the true parasitic pathogens developing normally in nature. Thus, pathogens encountered in the study are presented only for determination purposes with remarks on microbial etiology.[2]

Often the saprophytic fungus, Rhizopus nigricans, was isolated from insects dying on artificial diet. It was present in insects with no apparent pathogens; thus, death probably was not caused by disease.

---

[2]Determinations and remarks on etiology based on observations by microbiologists at the University of California's Invertebrate Pathology Laboratory, Berkeley.

Several armyworm and Heliothis larvae suffered a bacterial infection by a strain of Streptococcus faecalis Andrewes and Horder. This bacterium is considered a potential pathogen. It has no invasive power of its own but readily causes a fatal septicemia whenever it enters the haemocoel. The invasion probably was accomplished through wounds or other causes.

Virosis (granulosis), caused by a granulosis virus, was detected in H. zea.

Mycosis with a secondary bacteriosis was detected in P. ornithogalli. Attempts to isolate the primary fungus were unsuccessful as the fungus had been killed by the invasion of a secondary bacterium. The growth pattern and general appearance indicated a Beauveria infection. However, this was not confirmed. Crumb (1929) listed Beauveria as a pathogen of P. ornithogalli.

Rearing of the Braconid Parasite, Chelonus texanus

Chelonus texanus Cress., a parasite commonly reared from P. ornithogalli and H. zea in the studies on parasitism, was investigated in the laboratory. Ullyett (1949) described the insect as a true larval parasite. The female parasite oviposits in the egg of its host. The latter must be in a suitable stage of embryonic development so that the parasite egg can be deposited within the body of the larval embryo. The eggs hatch only after eclosion of the host egg, therefore, classifying C. texanus as a true larval parasite.

Ullyett described host/parasite relationship as follows: Only one parasite larva can develop to maturity in each host because

superparasitism occurs when more than one parasite egg is deposited in a host egg. The host egg is suitable as a host only near the end of the incubation period; whereas, it can be used successfully by an egg parasite only for a restricted time at the beginning of the period.

Materials and Methods

C. texanus adults were collected by sweeping alfalfa. They were abundant in late September (15-30/100 sweeps). From adults collected in alfalfa, a culture was started and maintained three generations with the yellow-striped armyworm as a laboratory host. The female armyworm's provision of eggs gregariously assembled in clustered masses allowed many larval hosts. Synchronousness in emergence of yellow-striped armyworms from one egg mass allowed a uniform age group of parasitized larvae for life history studies.

Approximately 10 to 15 C. texanus adults were housed in a 1-gallon ice cream carton with a cellophane top. Sugar water was provided by a small shell vial fitted with a cotton wick. A mass of armyworm eggs (> 24 hrs. old) glued to a 3 x 5 index card was offered to adult parasites of various ages. Observations were made on parasite activity, and recordings were made on the biology of parasitized larvae.

Results and Discussion

Life history and biology of the parasite are shown in Table XXIX. From 83.47 to 90.23% armyworms emerging from eggs exposed to adult parasites were parasitized. Adult parasite age was critical. Poor results were obtained when newly-emerged adults were offered eggs even though attempted oviposition was observed in newly-emerged virgin

females. Adult females confined with males for more than 4 but less than 9 days after emergence provided best results. As many as seven adult parasites were observed frequenting one egg mass at the same time. Females often visited infertile masses. But it was not determined whether or not oviposition in the sterile eggs was attempted.

Parasitized armyworm larvae burrowed below the diet surface where the parasitic larvae emerged and pupated. The larval stage ranged from 18-23 days. The pupal stage required 8-13 days. Pupae were damaged easily when handled. Best results were obtained by allowing adults to emerge from pupae left unattended in diet cups. The adult stage was variable (2-28 days). One females visited an egg mass, apparently attempting oviposition, when 15 days old. But maximum age of viable egg laying was not determined.

C. texanus is a very prolific insect, and its docile behavior allows easy handling, making it an ideal laboratory animal.

Summary

Parasitism and disease were considered as environmental factors influencing natural populations of the yellow-striped armyworm and Heliothis spp.

Thirteen parasites were reared from Prodenia ornithogalli; only one, Chelonus texanus, was common in many collections. C. texanus also was a fairly common parasite of Heliothis zea. Microplitis croceipes was the most common of the 15 parasites reared from Heliothis and was the only parasite reared from H. virescens. A total of 307 yellow-striped armyworm larvae were collected and observed for parasitism in 1966. Parasitism in the larval stage was 36.15%; 3.77% pupae were

parasitized. There were 1,086 Heliothis larvae held for parasitism in 1966. Total parasitism, independent of control, irrigative practice, and plant structure, was as follows: H. zea = 7.45%; H. virescens = 15.94%; Heliothis not identified to species = 3.33%; and all collections combined, 7.84%. Parasitism was less in cotton receiving regular control than in cotton receiving either irregular or no control.

In 1966 H. virescens was detected first on August 12 and reached its peak of abundance in late August and early September.

Disease was an important mortality factor in yellow-striped armyworms and Heliothis. However, its actual contribution in the suppression of natural populations was not determined.

C. texanus was an ideal laboratory animal. Data from three laboratory generations showed that 90.23% of the larvae emerging from yellow-striped armyworm eggs exposed to adult parasites were parasitized.

CHAPTER VII

RELATIONSHIPS AND EVALUATION OF THE NATIVE PARASITES ATTACKING SYMPATRIC *PRODENIA ORNITHOGALLI* AND *HELIOTHIS* SPP. IN OKLAHOMA

The previous chapter presented parasite species recovered from the yellow-striped armyworm and *Heliothis* spp. in 1965 and 1966. The relative importance of parasitism as a mortality factor was examined for the noctuids. Parasitism was considered quantitatively in 1966 to allow assessment of its contribution in regulating natural populations collected from various host plants. Thus, the study affords the opportunity to examine the common relationships of native parasites attacking yellow-striped armyworms, bollworms, and tobacco budworms inhabiting a common area and evaluation of parasitism as a limiting factor.

The plastic behavior of an insect makes it a difficult task to predict future occurrences in a population from generation to generation; and, even more difficult, from year to year. Data from several generations exposed to a varied environment must be accumulated before information may predict a future population trend. Canadians have pioneered much of the work in predicting population changes in insects (Morris, 1963). They have achieved surprising success in predictions with several forest insects by analysis of "key-factors" contributing to

mortality. However, this success has culminated from analysis of long-term population data gathered over a period of at least 5 years.

Information on parasites of the three insects in this study was gathered during the relatively short period of 2 years. A large sample size from a selected group of cultivated plants was attempted for each noctuid. The parasite complex for the yellow-striped armyworm and Heliothis may be representative of that expected in routine collecting from year to year; it approximates the findings of workers in other states (Crumb, 1929; Bibby, 1943). However, 2 year's data are inadequate for predicting the role of parasitism in natural populations for any given year. And as discussed in the previous chapter, disease in the sample populations may have underestimated actual parasitism occurring in natural populations. Hence, no attempt will be made to model the role of parasitism in influencing the abundance of the sympatric noctuids. A comparison will be made of the parasites attacking Heliothis and P. ornithogalli, and the theoretical role of parasitism in Heliothis in 1966 will be discussed.

Table XXX compares the parasites reared from H. zea, H. virescens, and P. ornithogalli during the study. Of the 22 parasites, six attacked both Heliothis and P. ornithogalli. Only two were reared frequently from the sympatric noctuids. The braconid Chelonus texanus and the tachinid Lespesia archippivora were major parasites of P. ornithogalli. Both were relatively common but not major parasites of Heliothis.

A comparison of parasites attacking P. ornithogalli and Heliothis may seem unjustified when considering habitats of the two insects. They often are found sympatrically but usually have different niches in the same community. Heliothis selects a diverse group of host plants,

but it is primarily a feeder on fruiting and flowering structures. P. ornithogalli, nearly as broad as Heliothis in host selection, usually feeds on foliage. This difference in manner of feeding and similarity as hosts for common parasites serve as the supporting arguments for the discussion advanced in this chapter. The possibility of utilizing P. ornithogalli as a candidate in serving as reservior in a biological and an integrated control program of Heliothis is discussed.

Biological control of Heliothis might be attempted through release of yellow-striped armyworm larvae harboring C. texanus adults. A technique was developed to produce the large number of yellow-striped armyworm larvae which would be required in a release of this nature. And C. texanus was reported as an amenable laboratory animal in the previous chapter. As many as 90.23% yellow-striped armyworms emerging from eggs exposed to adult C. texanus were parasitized. The release could be scheduled to inundate parasitized armyworms in advance time so as to synchronize adult parasite emergence at staggering intervals when Heliothis eggs were being deposited. The parasites kill their larval hosts at a fairly young age; and armyworms select foilage for food, perhaps allowing cotton to tolerate a high armyworm population. The small percentage of armyworms that escaped parasitism might not be a serious threat to cotton. Cotton probably could tolerate a moderate infestation, and eggs of the released armyworms which escaped parasitism would be under constant parasitism.

Releasing parasitized armyworm larvae appears to have two advantages over releasing adult parasites. First, it would be more economical. Armyworm larvae are parasitized and ready for release upon emergence from eggs. Consequently, they could be released immediately

and would require no diet prior to their release. Egg to adult stage in C. texanus requires a minimum of 26 days. The parasitized larvae would demand diet, and constant monitoring would be necessary previous to adult parasite emergence.

Yellow-striped armyworm larvae normally spend the entire larval stage on one host plant. This behavior allows a second advantage in releasing parasitized armyworms. Parasitized larvae could be distributed evenly throughout cotton to allow adult emergence the same initial distribution pattern. Adult parasites are carried by wind and are moderately strong flyers. Hence, it probably would be difficult to attain an effective initial distribution pattern when releasing adults.

In some regions of the Cotton Belt, cotton is cultivated in an intermixed planting with a secondary crop. Commonly, the system consists of one or two rows of cotton alternating with an equivalent number of rows of the other crop. Cotton is the primary crop and has the greatest potential for returning profits. Cotton and the second crop have different requirements for growth (e.g., moisture), and phenology processes (e.g., flowering) are at different times for each plant. Hence, competition between the two crops is less severe than competition between members of either species. This allows a limited amount of land to produce two crops more efficiently than one crop at the same density. Forage sorghum and guar sometimes are used as secondary crops.

An integrated control program of Heliothis on cotton as the primary crop may fit into such a cropping system. Crumb(1929) lists forage sorghum as a host for P. ornithogalli, and guar has been observed

as a host on the Rolling Plains of Texas.[1] In the present study parasitism was much greater in P. ornithogalli than Heliothis. Thus, it is reasonable that P. ornithogalli residing on the secondary crop would host a large number of native parasites also attacking Heliothis (e.g., C. texanus, E. armigera). When parasites failed to contain Heliothis populations below damaging levels, a ground rig could be used to apply insecticide to the rows of cotton only. This would allow the unsprayed sorghum to serve as refuge for P. ornithogalli and its associated parasites.

Each approach is to be interpreted as a theoretical possibility. But each may warrant investigation as a possible control method.

Table XXI shows that H. virescens contributed only as a small part of the total Heliothis complex in cotton in 1966. The distribution of each Heliothis species is represented only as a percent of the total collection. Thus, the percentages themselves have very little meaning unless the density of the population is known. Adkisson et al. (1964) advanced that the estimation of the number of Heliothis larvae per acre was more informative in evaluating infestations in cotton.

Considering Heliothis spp. as a complex, irrespective of collection source, Table XXVIII shows that 7.84% of the sample populations served as hosts for various parasites in 1966. Adkisson et al. (1964) reported that an average of 2,000 Heliothis larvae per acre are required to cause significant yield losses to cotton. If, in 1966, 7.84% were parasitized at the 2,000 per acre level, nearly 160 larvae would have harbored parasites. If the parasitized larvae were incapable of doing

---

[1]Observations made by D. G. Bottrell in Stonewall Co., Texas, 1967.

damage, parasitism would have contained the Heliothis population to below a damaging level. But if as many as 2,200 larvae per acre were present, parasitism would not have been beneficial in the sense of containing the population level below the damaging threshold. In summary, data from the study in 1966 suggest that natural parasites of Heliothis are valuable to a cotton grower in the sense of containing the population below damaging levels only when the Heliothis population is at a threshold level. However, they probably play a very purposeful role in checking the natural balance of the pests at a level much higher than threshold.

CHAPTER VIII

CONCLUSIONS

Basic research on the biology of the yellow-striped armyworm, Prodenia ornithogalli Guenée, established many prerequisites for studies on the dynamics of laboratory populations. A rearing procedure was developed to produce a large number of insects. Larvae of both sexes passed through six-, seven-, or eight-larval instars before pupating. A technique employing a daylight pigment was useful in detecting successive larval molts. Different strains of armyworms provided progenies with correspondingly different responses in developmental rate, survival, and pupal weight. The sex ratio of 28 samples of pupae combined was approximately 1:1. However, individual samples produced ratios varying from 1:1.1 to 1:5 (male:female). Number of days in the pupal stage and the pupal weight were unrelated to the number of days in the larval stage. Pupal weight was not related to the number of days in the pupal stage.

Armyworms behaved much differently reared solitarily than when reared in groups. This phenomenon was important in developing suitable rearing procedures. Density influenced survival, larval weight, and pupal weight. The number of days in the pupal stage was influenced by larval density in males only. Less time was required in the pupal stage of crowded male larvae. A premise was advanced that armyworms crowded throughout the larval stage entered a successive stage in

development faster than armyworms living at a crowded density for only an initial period of life before isolation as solitaries. But larval development was independent of density in groups maintained at varied density for equivalent periods of time.

A life table for the yellow-striped armyworm was constructed to represent larval age with respect to the distribution of pupation. Life tables previous to this one have expressed age with respect to the distribution of mortality.

Twenty-two species of parasites were collected from P. ornithogalli, Heliothis zea, and H. virescens. Two parasites, Chelonus texanus and Lespesia archippivora, frequently attacked both P. ornithogalli and H. zea. This finding stimulated the construction of two hypothetical approaches for increasing parasitism in Heliothis by exercising P. ornithogalli as a host reservoir for native parasites. A biological control program and an integrated control program were advanced.

Parasitism in the yellow-striped armyworm was greater than in either the bollworm or tobacco budworm. Parasitism was an important mortality factor in Heliothis. But projected as a factor in regulating natural populations, a theoretical example suggested that parasites are beneficial in terms of preventing yield losses only when Heliothis populations are at a minimum economic threshold.

Microbial pathogens caused considerable mortality to the three noctuids, but their exact importance was not determined.

SELECTED BIBLIOGRAPHY

Adams, R. H. 1966. Variation in the response to endrin of progeny from pairs of bollworms, Heliothis zea (Boddie), and validity of average larval weight for computing dosage-mortality curves. Unpub. M. S. Thesis. Oklahoma State University.

Adkisson, P. L., E. S. Vanderzant, D. L. Bull, and W. E. Allison. 1960. A wheat germ medium for rearing the pink bollworm. J. Econ. Entomol. 53: 759-762.

Adkisson, P. L., R. L. Hanna, and C. F. Bailey. 1964. Estimates of the numbers of Heliothis larvae per acre in cotton and their relation to the fruiting cycle and yield of the host. J. Econ. Entomol. 57: 657-663.

Allee, W. C. 1931. Animal Aggregations: A Study in General Sociology. University of Chicago Press, Chicago. 431 p.

Berger, E. W. 1920. The semitropical armyworm. Quart. Bull. Fla. St. Plant Bd. IV. No. 2. pp. 17-33.

Berger, R. S. 1963. Laboratory techniques for rearing Heliothis species on artificial medium. U. S. Dep. Agr. ARS-33-84. 4 p.

Bibby, F. F. 1943. Some parasites of Heliothis armigera (Hbn.) in Texas. J. Econ. Entomol. 35: 943-944.

Brazzel, J. R., L. D. Newsom, J. S. Roussel, C. Lincoln, F. J. Williams, and G. Barnes. 1953. Bollworm and tobacco budworm as cotton pests in Louisiana and Arkansas. La. Agr. Exp. Sta. Tech. Bull. No. 482. 47 p.

Brazzel, J. R., and W. Newton. 1963. Seasonal incidence of tobacco budworms on cotton in Texas, 1962. Texas Agr. Exp. Sta. Progr. Rep. 2272. 5 p.

Bryan, D. E. 1962. Unpublished data. Dep. Entomol. Oklahoma State University, Stillwater, Okla.

Butler, G. D., Jr. 1958a. Braconid parasites reared from lepidopterous larvae in Arizona, 1957. Pan-Pac. Entomol. Vol. XXXIV. pp. 221-223.

Butler, G. D., Jr. 1958b. Tachinid flies reared from lepidopterous larvae in Arizona, 1957. J. Econ. Entomol. 51: 561-562.

Butt, B. A. and E. Cantu. 1962. Sex determination of lepidopterous pupae. U. S. Dep. Agr. ARS-33-75. 7 p.

Crumb, S. E. 1929. Tobacco cutworms. U. S. Dep. Agr. Tech. Bull. 88. 180 p.

Deevy, E. S., Jr. 1947. Life tables for natural populations of animals. Quart. Rev. Biol. 22: 283-314.

Drooz, A. T. 1966. Some effects of rearing density on the biology of the elm spanworm. Can. Entomol. 98: 83-87.

Dublin, L. I. and A. J. Lotka. 1925. On the true rate of natural increase as exemplified by the population of the United States, 1920. J. Am. Stat. (A) 20: 305-339.

Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics. 11: 1-42.

Gowdey, C. C. 1923. Report of the government entomologist. Ann. Rep. Jamaica Dep. Agr. pp. 23-24.

Henry, P. and P. L. Adkisson, 1965. Seasonal abundance of bollworms and tobacco budworms on a typical cotton plantation. Tex. Agr. Exp. Sta. Misc. Pub. 767. 6 p.

Iwao, S. 1962. Studies on the phase variation and related phenomena in some lepidopterous insects. Kyoto Univ. Entomol. Ser. 12. 79 p.

Jones, L. K. 1920. Injurious insects and other pests. Kans. Agr. Exp. Sta. Dir. Rep. 1918-1919. pp. 41-47.

Long, D. B. 1953. Effects of population density on larvae of Lepidoptera. Trans. Roy. Entomol. Soc. Lond. 104: 543-583.

Lowry, W. L. and S. L. Calhoun. 1952. Control of yellow-striped armyworm on cotton with organic insecticides. J. Econ. Entomol. 45: 741.

Merriam, C. H. 1898. Life zones and crop zones of the United States. U. S. Dep. Agr. Div. of Biol. Survey. Bull. 10. 79 p.

Miskimen, G. W. 1960. Comparison of sevin with DDT and rotenone on tomatoes under tropical conditions. J. Econ. Entomol. 53: 1128-1129.

Morrill, A. W. 1917. Cotton pests in the arid and semiarid Southwest. J. Econ. Entomol. 10: 307-317.

Morris, R. F. (ed.) 1963. The dynamics of epidemic spruce budworm populations. Memoirs Entomol. Soc. Can. No. 31. 332 p.

Moseback-Pukowski, E. 1937. Uber die Raupengesellschaften von Vanessa io and Vanessa urticae. Z. Morph. Okol. Tiere. 33: 358.

Neunzig, H. H. 1964. The eggs and early - instar larvae of Heliothis zea and Heliothis virescens (Lepidoptera:Noctuidae). Ann. Entomol. Soc. Amer. 57: 98-102.

Ostle, B. 1963. Statistics in Research, 2nd ed. Iowa St. Univ. Press, Ames. 585 p.

Parencia, C. R., Jr. 1964. Winter Survival of the bollworm in Central Texas. J. Econ. Entomol. 57: 757-758.

Park, T. 1962. Beetles, competition, and populations. Science 128: 1369-1375.

Pearl, R. 1940. Introduction to Medical Biometry and Statistics. 3rd ed. W. B. Saunders Co., Philadelphia, Penn. 537 p.

Porter, J. E. and J. H. Hughes. 1950. Insect eggs transported on the outer surface of airplanes. J. Econ. Entomol. 43: 555-557.

Quaintance, A. L. and C. T. Brues. 1905. The cotton bollworm. U. S. Dep. Agr. Bur. Entomol. Bull. No. 50. 155 p.

Shorey, H. H. and R. L. Hale. 1965. Mass-rearing of the larvae of nine noctuid species on a simple artificial medium. J. Econ. Entomol. 58: 522-524.

Snow, J. W. 1964. Seasonal occurrence of tobacco budworm on cotton in Georgia. J. Econ. Entomol. 57: 787-788.

Sullivan, W. N. and C. G. Thompson. 1959. Survival of insect eggs after stratopheric flights on jet aircraft. J. Econ. Entomol. 52: 299-301.

Sundman, J. A. and R. L. Hanna. 1963. Relative seasonal abundance of two species of Heliothis on cotton in an area of Brazos County, Texas. J. Econ. Entomol. 56: 235-236.

Ullyett, G. C. 1949. Distribution of progeny by Chelonus texanus Cress. (Hymenoptera:Braconidae). Can. Entomol. Vol. LXXXI. pp. 25-44.

Walkden, H. H. and D. B. Whelan. 1942. Owlet moths (Phalaenidae) taken at light traps in Kansas and Nebraska. Circ. U. S. Dep. Agr. No. 643. 25 p.

Wardzinski, K. 1938. Der Einfluss der Einzelhaft sowieder schwachen Vergesell schaftung auf die Entwicklung und das Wachstum der Raupen von Pieris brassicae L. Z. Angew. Ent. 25: 478-486.

Webster, R. L. 1915. Potato insects. Iowa St. Coll. Agr. Exp. Sta. Bull. No. 115. pp. 359-420.

Winburn, T. F. and R. H. Painter. 1932. Insect enemies of the corn earworm (Heliothis obsoleta Fabr.) J. Kans. Entomol. Soc. 5: 1-28.

Zaher, M. A. and D. B. Long. 1959. Some effects of larval population density on the biology of Pieris brassicae L. and Plusia gamma L. Proc. Roy. Entomol. Soc. Lond. (A) 34: 97-109.

Zaher, M. A. and M. A. Moussa. 1961. Effects of population density on Prodenia litura (Lepidoptera:Noctuidae). Ann. Entomol. Soc. Amer. 54: 145-149

APPENDIX

TABLE I

BIOLOGY AND ACTUARIAL DATA FROM THE F_1 GENERATION OF A CALIFORNIA STRAIN OF YELLOW-STRIPED ARMYWORMS

	Duration in Days					
	Male			Female		
	n	Range	Mean*	n	Range	Mean
Larval Stadia No. 1	7	4-7	4.857± .459	23	4-6	4.478±.164
2	7	2-5	3.285± .359	23	2-6	3.217±.177
3	7	3-4	3.571± .202	23	3-5	3.478±.123
4	7	3-4	3.428± .202	23	2-4	2.913±.124
5	7	3-6	4.285± .359	23	3-5	3.956±.147
Type** I 6	1		10.000	5	8-11	9.600±.600
II 6	4	4-5	4.250± .250	16	3-6	3.937±.193
III 6	2		4.000	2	3-4	3.500
II 7	4	8-14	10.250±1.314	16	8-20	10.875±.700
III 7	2	5-6	5.500	2	3-7	5.000
III 8	2	10-12	11.000	2	10-20	15.000
Total Larval Stage	33	28-46	35.242± .746	78	27-51	33.256±.509
Last Molt to Prepupa	7	1-7	4.142± .769	23	3-9	5.478±.349
Prepupal Stage	33	1-5	3.757± .144	78	1-6	3.641±.089
Pupal Stage	12	15-19	17.416± .336	40	13-21	15.825±.274

	Male			Female		
	n	Range	Mean	n	Range	Mean
Pupal Weight (g)	33	.306-.502	.406± .007	77	.306-.593	.451±.006
Pupal Length (cm)	33	1.80-2.15	1.983± .014	78	1.80-2.35	2.038±.011

Mortality***	
Larval Stage (prior to prepupation)	19.4%
Prepupal Stage	18.3
Pupal Stage	33.3 (63.6% males and 50.6% females)
TOTAL	71.0

* Means presented ± the standard error ($\sqrt{\text{variance}/n}$).

** Types I, II, and III indicate respectively larvae completing 6, 7, or 8 instars; frequency of 3 types: male, II>III>I; female, II>I>III.

*** Based on 180 newly-emerged larvae followed daily through eclosion or death of the last pupa.

TABLE II

ANALYSIS OF VARIANCE IN PERCENT PROGENIES FROM COMBINATION MATINGS OF DIFFERENT STRAINS OF YELLOW-STRIPED ARMYWORMS IN THE PUPAL STAGE WHEN 25 DAYS OLD

Source	d.f.	s.s	m.s.	F
Total	14	7,271.3334		
Shelf height	2	885.7334		
Matings	4	4,118.0000	1,029.5000	3.6320 ns
Error	8	2,267.6000	283.4500	

ns Nonsignificant at the .05 level of probability.

TABLE III

ANALYSIS OF VARIANCE IN PERCENT PROGENIES FROM COMBINATION MATINGS OF DIFFERENT STRAINS OF YELLOW-STRIPED ARMYWORMS IN THE PREPUPAL AND PUPAL STAGES COMBINED WHEN 25 DAYS OLD

Source	d.f.	s.s	m.s.	F
Total	14	13,699.7310		
Shelf height	2	659.6558		
Matings	4	12,482.7717	3,120.6929	44.7970 ***
Error	8	557.3035	69.6629	

*** Significant at the .005 level of probability.

TABLE IV

ANALYSIS OF VARIANCE IN PERCENT PROGENIES FROM COMBINATION MATINGS OF DIFFERENT STRAINS OF YELLOW-STRIPED ARMYWORMS REMAINING ALIVE 25 DAYS AFTER LARVAL EMERGENCE

Source	d.f.	s.s.	m.s.	F
Total	14	2,529.7980		
Shelf height	2	203.2060		
Matings	4	1,767.1046	441.7761	6.3168 *
Error	8	559.4874	69.9359	

* Significant at the .05 level of probability.

TABLE V

DATA ON PROGENIES FROM COMBINATION MATINGS OF DIFFERENT STRAINS OF YELLOW-STRIPED ARMYWORMS

Mating (Male-Female)	Mean Percentage of Progenies of the 3 Replications 25 Days after Larval Emergence*			Mean Pupal Weight(g)***
	In pupal stage	In prepupal & pupal stages combined**	Alive (larval, prepupal or pupal stage)	
P_eA X P_eA	33.0	77.0 b	53.6 b	.352
P_2C X P_2C	2.0	11.0 c	77.9 a	.465
P_2C X P_eA	33.0	79.6 ab	86.3 a	.427
P_eA X P_2C	18.6	69.6 b	76.6 a	.448
WS X WS	51.6	94.6 a	72.0 a	.394

*Means sharing the same letter are not significantly different at the .05 level of probability. Duncan's multiple range test not used on data appearing under pupal stage and pupal weight.

**Prepupae and pupae recorded, dead or alive.

***Only normally-developed live pupae.

TABLE VI

CORRELATION OF THE JOINT RELATIONSHIP
OF BIOLOGICAL VARIABLES OBTAINED
FROM LARVAE AND PUPAE OF THE
YELLOW-STRIPED ARMYWORM

Variables		n	r	t*
Days in larval stage	Days in pupal stage	52	-.0980	.6963
Days in larval stage	Pupal weight in grams	110	-.0712	.7418
Days in pupal stage	Pupal weight in grams	52	.0292	.2051

*No t value significant at the .05 level of probability.

TABLE VII

CHI-SQUARE ANALYSIS OF SEX RATIO COMBINING DATA FROM 28 SAMPLES OF LABORATORY-REARED PUPAE REPRESENTING SEVERAL STRAINS OF YELLOW-STRIPED ARMYWORMS

	Total No. Pupae	No. Males	No. Females	Observed Ratio	d.f.	Chi-square
	49	23	26	1 : 1.1	1	.1836
	14	3	11	1 : 3.7	1	4.5714**
	21	9	12	1 : 1.3	1	.4284
	56	30	26	1.1 : 1	1	.2856
	12	7	5	1.4 : 1	1	.3332
	45	21	24	1 : 1.1	1	.2000
	20	13	7	1.9 : 1	1	1.8000
	60	31	29	1.1 : 1	1	.0660
	8	2	6	1 : 3	1	2.0000
	6	1	5	1 : 5	1	2.6666
	95	41	54	1 : 1.3	1	1.7788
	24	15	9	1.7 : 1	1	1.5000
	15	10	5	2 : 1	1	1.6666
	38	21	17	1.2 : 1	1	.4210
	49	32	17	1.9 : 1	1	4.5918**
	44	28	16	1.7 : 1	1	3.2726*
	31	17	14	1.2 : 1	1	.2902
	49	32	17	1.9 : 1	1	4.5918**
	50	29	21	1.4 : 1	1	1.2800
	30	14	16	1 : 1.1	1	.1332
	52	31	21	1.5 : 1	1	1.9230
	14	9	5	1.8 : 1	1	1.1428
	21	8	13	1 : 1.6	1	1.1904
	21	10	11	1 : 1.1	1	.0476
	120	55	65	1 : 1.2	1	.8332
	112	33	79	1 : 2.4	1	18.8928****
	182	107	75	1.4 : 1	1	5.6262***
	19	10	9	1.1 : 1	1	.0526
Total	1,257	642	615	1.04 : 1	1	.5798
Pooled Chi-square					28	61.7700****
Difference (heterogeneity Chi-square)					27	61.1902****

* Significant at the .1 level of probability.

** Significant at the .05 level of probability.

*** Significant at the .025 level of probability.

**** Significant at the .0005 level of probability.

TABLE VIII

ANALYSIS OF VARIANCE IN THE REGRESSION OF TEMPERATURE (Y) INSIDE CUPS ON LARVAL DENSITY (X) OF YELLOW-STRIPED ARMYWORMS

Source	d.f.	s.s	m.s.	F
Total	30	189,379.9375		
Due to b_o	1	189,329.3520		
Due to b_1/b_o	1	.9200	.9200	.5186 ^{ns}
Residual	28	49.6655	1.7737	
Lack of fit	4	.3155	.0788	.0383 ^{ns}
Experimental error	24	49.3500	2.0562	

^{ns} Nonsignificant at the .05 level of probability.

TABLE IX

ANALYSIS OF VARIANCE IN THE WEIGHT OF 7-DAY OLD YELLOW-STRIPED ARMYWORM LARVAE REARED AT VARIOUS DENSITIES INCORPORATING A COMPLETELY RANDOM DESIGN

Source	d.f.	s.s	m.s.	F
Total	23	.0052		
Larval density	5	.0035	.000700	7.4468***
Error	18	.0017	.000094	

*** Significant at the .005 level of probability.

TABLE X

ANALYSIS OF VARIANCE IN THE WEIGHT OF 14-DAY OLD YELLOW-STRIPED ARMYWORM LARVAE REARED AT VARIOUS DENSITIES INCORPORATING A COMPLETELY RANDOM DESIGN

Source	d.f.	s.s.	m.s.	F
Total	17	6.9299		
Larval density	5	4.6188	.9273	4.7984*
Error	12	2.3111	.1925	

*Significant at the .05 level of probability.

TABLE XI

ANALYSIS OF VARIANCE IN THE WEIGHT OF 25-DAY OLD YELLOW-STRIPED ARMYWORM LARVAE REARED AT VARIOUS DENSITIES INCORPORATING A COMPLETELY RANDOM DESIGN

Source	d.f.	s.s.	m.s.	F
Total	23	67.3271		
Larval density	5	63.1692	12.6338	54.7154***
Error	18	4.1579	.2309	

***Significant at the .005 level of probability.

TABLE XII

ANALYSIS OF VARIANCE IN THE REGRESSION OF PUPAL WEIGHT (Y) ON LARVAL DENSITY (X) OF FEMALE YELLOW-STRIPED ARMYWORMS

Source	d.f.	s.s.	m.s.	F
Total	57	9.6669		
Due to b_o	1	9.3087		
Due to b_1/b_o	1	.1714	.1714	50.4118***
Residual	55	.1868	.0034	
Lack of fit	1	.0208	.0208	5.4737*
Experimental error	54	.2076	.0038	

*Significant at the .05 level of probability.

***Significant at the .005 level of probability.

TABLE XIII

ANALYSIS OF VARIANCE IN THE REGRESSION OF PUPAL WEIGHT (Y) ON LARVAL DENSITY (X) OF MALE YELLOW-STRIPED ARMYWORMS

Source	d.f.	s.s.	m.s.	F
Total	54	7.904288		
Due to b_o	1	7.713046		
Due to b_1/b_o	1	.089710	.089710	45.9345***
Residual	52	.101531	.001953	
Lack of fit	1	.000036	.000036	$.0180^{ns}$
Experimental error	51	.101496	.001990	

***Significant at the .005 level of probability.

^{ns}Nonsignificant at the .05 level of probability.

TABLE XIV

ANALYSIS OF VARIANCE IN THE REGRESSION OF DAYS IN LARVAL STAGE (Y) ON LARVAL DENSITY (X) OF FEMALE YELLOW-STRIPED ARMYWORMS

Source	d.f.	s.s.	m.s.	F
Total	29	17,118.0000		
Due to b_o	1	16,993.2413		
Due to b_1/b_o	1	.0242	.0242	$.0052^{ns}$
Residual	27	124.7345	4.6197	
Lack of fit	3	5.8872	1.9624	$.3962^{ns}$
Experimental error	24	118.8473	4.9519	

^{ns}Nonsignificant at the .05 level of probability.

TABLE XV

ANALYSIS OF VARIANCE IN THE REGRESSION OF DAYS IN LARVAL STAGE (Y) ON LARVAL DENSITY (X) OF MALE YELLOW-STRIPED ARMYWORMS

Source	d.f.	s.s.	m.s.	F
Total	24	14,062.0000		
Due to b_o	1	13,920.1666		
Due to b_1/bo	1	14.0895	14.0895	2.4265^{ns}
Residual	22	127.7439	5.8065	
Lack of fit	3	25.3057	8.4352	1.5645^{ns}
Experimental error	19	102.4382	5.3914	

^{ns}Nonsignificant at the .05 level of probability.

TABLE XVI

ANALYSIS OF VARIANCE IN THE REGRESSION OF DAYS IN PUPAL STAGE (Y) ON LARVAL DENSITY (X) OF FEMALE YELLOW-STRIPED ARMYWORMS

Source	d.f.	s.s.	m.s.	F
Total	21	4,267.0000		
Due to b_o	1	4,257.1904		
Due to b_1/b_o	1	1.2831	1.2831	2.8595^{ns}
Residual	19	8.5265	.4487	
Lack of fit	3	1.6515	.5505	1.2814^{ns}
Experimental error	16	6.8750	.4296	

^{ns}Nonsignificant at the .05 level of probability.

TABLE XVII

ANALYSIS OF VARIANCE IN THE REGRESSION OF DAYS IN PUPAL STAGE (Y) ON LARVAL DENSITY (X) OF MALE YELLOW-STRIPED ARMYWORMS

Source	d.f.	s.s.	m.s.	F
Total	15	3,658.0000		
Due to b_o	1	3,650.4000		
Due to b_1/b_o	1	3.3092	3.3092	10.0278**
Residual	13	4.2908	.3300	
Lack of fit	3	.8907	.2969	$.8732^{ns}$
Experimental error	10	3.4001	.3400	

**Significant at the .01 level of probability.

^{ns}Nonsignificant at the .05 level of probability.

TABLE XVIII

LIFE TABLE FOR THE YELLOW-STRIPED ARMYWORM REPRESENTING LARVAL AGE WITH RESPECT TO THE DISTRIBUTION OF PUPATION

Age Interval X*	X^1		P_x		N_x		100 P/N		E_x	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
0-1	-100.0	-100.0	0	0	100	100	0	0	34.74	33.74
1-2	- 97.1	- 96.9	0	0	100	100	0	0	33.78	32.75
2-3	- 94.3	- 93.9	0	0	100	100	0	0	32.82	31.77
3-4	- 91.4	- 90.9	0	0	100	100	0	0	31.86	30.78
4-5	- 88.6	- 87.9	0	0	100	100	0	0	30.91	29.80
5-6	- 85.8	- 84.9	0	0	100	100	0	0	29.95	28.82
6-7	- 82.9	- 81.9	0	0	100	100	0	0	28.99	27.83
7-8	- 80.1	- 78.9	0	0	100	100	0	0	28.03	26.85
8-9	- 77.2	- 75.9	0	0	100	100	0	0	27.08	25.87
9-10	- 74.4	- 72.9	0	0	100	100	0	0	26.12	24.88
10-11	- 71.6	- 69.9	0	0	100	100	0	0	25.16	23.90
11-12	- 68.7	- 66.9	0	0	100	100	0	0	24.21	22.92
12-13	- 65.9	- 63.8	0	0	100	100	0	0	23.25	21.93
13-14	- 63.1	- 60.8	0	0	100	100	0	0	22.29	20.95
14-15	- 60.2	- 57.8	0	0	100	100	0	0	21.33	19.97
15-16	- 57.4	- 54.8	0	0	100	100	0	0	20.38	18.98
16-17	- 54.5	- 51.8	0	0	100	100	0	0	19.42	18.00
17-18	- 51.7	- 48.8	0	0	100	100	0	0	18.46	17.02
18-19	- 48.9	- 45.8	0	0	100	100	0	0	17.51	16.03
19-20	- 46.0	- 42.8	0	0	100	100	0	0	16.55	15.05
20-21	- 43.2	- 39.8	0	0	100	100	0	0	15.59	14.07
21-22	- 40.4	- 36.8	0	0	100	100	0	0	14.63	13.08
22-23	- 37.5	- 33.8	0	0	100	100	0	0	13.68	12.10
23-24	- 34.7	- 30.8	0	0	100	100	0	0	12.72	11.12
24-25	- 31.8	- 27.7	0	0	100	100	0	0	11.76	10.13
25-26	- 29.0	- 24.7	0	0	100	100	0	0	10.81	9.15
26-27	- 26.2	- 21.7	0	0	100	100	0	0	9.85	8.17
27-28	- 23.3	- 18.7	0	4	100	100	0	4.0	8.89	7.18
28-29	- 20.5	- 15.7	3	6	100	96	3.0	6.3	7.93	6.46
29-30	- 17.7	- 12.7	3	5	97	90	3.1	5.6	7.19	5.84
30-31	- 14.8	- 9.7	6	9	94	85	6.4	10.6	6.43	5.14
31-32	- 12.0	- 6.7	3	5	88	76	3.4	6.6	5.85	4.65
32-33	- 9.1	- 3.7	15	21	85	71	17.6	29.6	5.07	3.92
33-34	- 6.3	- 0.7	9	12	70	50	12.9	24.0	4.99	4.17
34-35	- 3.5	+ 2.2	6	10	61	38	9.8	26.3	4.62	4.19
35-36	- 0.6	+ 5.2	19	14	55	28	34.5	50.0	4.06	4.35
36-37	+ 2.1	+ 8.3	6	5	36	14	16.7	35.7	4.74	6.70
37-38	+ 4.9	+ 11.3	6	1	30	9	20.0	11.1	4.53	8.86
38-39	+ 7.8	+ 14.3	0	1	24	8	0	12.5	4.46	8.80
39-40	+ 10.6	+ 17.3	0	1	24	7	0	14.3	3.49	8.87
40-41	+ 13.5	+ 20.3	12	1	24	6	50.0	16.7	2.51	9.13
41-42	+ 16.3	+ 23.3	3	0	12	5	25.0	0	3.09	9.68
42-43	+ 19.1	+ 26.3	3	0	9	5	33.3	0	2.80	8.61
43-44	+ 22.0	+ 29.3	3	0	6	5	50.0	0	2.69	7.53
44-45	+ 24.8	+ 32.3	0	0	3	5	0	0	3.33	6.45
45-46	+ 27.6	+ 35.3	0	1	3	5	0	20.0	2.22	5.38
46-47	+ 30.5	+ 38.3	3	1	3	4	100.0	25.0		5.38

TABLE XVIII - Continued

Age Interval X*	X^1		P_x		N_x		100 P/N		E_x	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
47-48		+ 41.3		0		3		0		5.70
48-49		+ 44.4		0		3		0		4.56
49-50		+ 47.4		0		3		0		3.42
50-51		+ 50.4		0		3		0		2.28
51-52		+ 53.4		3		3		100.0		

*Data compiled from 33 males and 78 females with a mean no. of days in the larval stage of 35.24 and 33.24 days, respectively.

The column headings used in the life table are:

X_1 = Age interval in days.

X = Age as percent deviation from mean no. days in larval stage.

P_x = No. pupating during X; based on an original cohort of 100 larvae each sex.

N_x = No. larvae entering X; based on an original cohort of 100 larvae each sex.

100 P/N = P_x as a percent of N_x.

E_x = No. days expected before pupating.

TABLE XIX

PARASITES REARED FROM THE YELLOW-STRIPED ARMYWORM IN OKLAHOMA, 1965-1966

Parasite	Month and Year of Collection	Host Plant	County	Remark
Tachinidae				
Archytas apicifer (Wlk.)	Aug.,Oct.,1966	carelessweed, alfalfa	Payne, Tillman	Adult emerged from host pupa
Lespesia archippivora (Riley)	Jul.-Oct.,1966	tumbleweed, alfalfa, carelessweed	Payne,Kiowa, Grady,Tillman, Woodward	Most common tachinid
Winthemia sp.	Sept.,1966	alfalfa	Payne	Single record
Lespesia aletiae (Riley)	Oct.,1966	carelessweed	Tillman	Single record
Euphorocera tachinomoides Tnsd.	Sept.,Oct.,1966	tumbleweed	Kiowa	Not common
E. omissa (Rnh.)	Aug.,Sept.,1966	tumbleweed, alfalfa	Kiowa, Grady	Adult emerged from host pupa
W. rufopicta (Big.)	Sept.,1966	alfalfa	Woodward,Grady	Not common
Braconidae				
Chelonus texanus Cress.	Jul.-Oct.,1965-1966	alfalfa	Payne,Grady, Jackson	Most common hymenopteran
Zele sp.	Aug.-Sept.,1966	alfalfa	Grady	Not common
Ichneumonidae				
Campoletis peridistinctus (Vier.)	Jul.,1966	alfalfa	Grady	Single record
Netelia sp.	Sept.,1966	alfalfa	Grady	Single record
Eulophidae				
Euplectrus platyhypenae How.	Sept.,Oct.,1966	carelessweed, alfalfa, tumbleweed	Kiowa,Grady, Tillman	External gregarious parasite
Perilampidae				
Perilampus robertsoni Cwfd.	Sept.,1966	alfalfa	Grady	Single record, hyperparasite of *C. texanus*

TABLE XX

SEASONAL INCIDENCE OF PARASITISM IN THE YELLOW-STRIPED ARMYWORM COLLECTED FROM SEVERAL HOST PLANTS IN OKLAHOMA, 1966

County	Date	Larvae		Pupae**	
		No.*	% Parasitized	No.*	% Parasitized
Grady	July 11-31	6	66.66	2	.00
Grady, Payne	Aug. 1-15	48	14.58	27	7.4
	16-31	12	25.00	3	.00
	Total	60	16.66	30	6.66
Grady, Kiowa, Rogers, Jackson	Sept. 1-15	48	27.08	14	.00
	16-30	171	46.19	51	.00
	Total	219	42.00	65	.00
Tillman, Kiowa, Jackson	Oct. 1-15	22	22.72	9	22.22
	Grand Total	307	36.15	106	3.77

*No. field-collected insects observed for parasite emergence.

**Of the 307 larvae held for parasite emergence, 106 (34.52%) pupated (52 males, 48 females; 6 not sexed).

TABLE XXI

SEASONAL DISTRIBUTION OF THE *HELIOTHIS* LARVAL COMPLEX IN COTTON, 1966

Date*	No. Larvae Collected	No. *H. zea*	No. *H. virescens*	% *H. virescens*
July				
16-23	3	3	0	.00
24-31	8	8	0	.00
Total	11	11	0	.00
Aug.				
1-7	178	178	0	.00
8-14	309	308	1	.32
15-21	62	58	4	6.45
22-31	124	108	16	12.90
Total	673	652	21	3.12
Sept.				
1-7	303	262	41	13.53
8-14	377	351	26	6.89
15-21	505	493	12	2.37
22-30	82	80	2	2.43
Total	1,267	1,186	81	6.39
Oct.				
1-12	30	29	1	3.33
Grand Total	1,981	1,878	103	5.19

*Most collections made in Grady Co., Okla.; portions of collections in September from Jackson Co.

TABLE XXII

DISTRIBUTION OF THE *HELIOTHIS* LARVAL COMPLEX COLLECTED FROM DIFFERENT SOURCES IN COTTON, 1966

Source	No. Larvae Collected	No. *H. zea*	No. *H. virescens*	% *H. virescens*
Controlled Cotton	84	79	5	5.95
Noncontrolled Cotton	1,154	1,090	64	5.54
Cotton Blooms	1,264	1,210	54	4.27
Cotton Bolls and Squares	473	445	28	5.91
Irrigated Cotton	683	626	57	8.34
Nonirrigated Cotton	1,298	1,252	46	3.54

TABLE XXIII

PUPATION RATE IN THE *HELIOTHIS* LARVAL COMPLEX COLLECTED FROM DIFFERENT SOURCES IN COTTON, 1966

Source	*H. zea*		*H. virescens*	
	No*	% Pupation	No.*	% Pupation
Controlled Cotton	39	74.35	3	66.66
Noncontrolled Cotton	716	62.15	42	50.00
Cotton Blooms	911	65.20	51	60.78
Cotton Bolls and Squares	16	68.75	1	.00
Irrigated Cotton	340	71.47	30	66.66
Nonirrigated Cotton	737	57.93	35	51.42
Total, Independent of Source**	1,077	62.20	69	55.07

*No. field-collected larvae placed on artificial diet.

**Total no. less than sum of individual nos. because each collection involved each source; e.g., larvae collected in blooms could further be categorized as from controlled, irrigated cotton.

TABLE XXIV

SEX RATIO OF PUPAE OF HELIOTHIS ZEA REARED FROM LARVAE COLLECTED FROM DIFFERENT SOURCES IN COTTON, 1966

Source	No.	No. Male Pupae	No. Female Pupae	% Female
Controlled Cotton	26	9	17	65.38
Noncontrolled Cotton	427	227	200	46.83
Cotton Blooms	568	295	273	48.06
Cotton Bolls and Squares	11	5	6	54.54
Total, Independent of Source*	644	329	315	48.91

*Total no. less than sum of individual nos. because each collection involved each source; e.g., larvae collected in blooms could further be categorized as from controlled cotton.

TABLE XXV

PARASITES REARED FROM *HELIOTHIS* IN OKLAHOMA, 1965-1966

Parasite	Month and Year of Collection	Host Plant	County	Remark
Tachinidae				
[a]*Eucelatoria armigera* (Coq.)	June, Aug., Sept., 1965-66	Alfalfa, cotton	Payne, Grady, Jackson	Most common tachinid
[a]*Lespesia archippivora* (Riley)	Aug., Sept., 1965-66	Alfalfa, cotton	Payne, Grady, Jackson, Greer	Second most common tachinid
[d]*Voria aurifrons* (Tnsd.)	Aug., 1966	Peanut	Payne	Single record
[b]*Plagiomima ?spinosula* (Big.)	June, 1965	Corn	Jackson	Not common
[a]*Euphorocera tachinomoides* Tnsd.	Sept., 1965-66	Alfalfa, sorghum	Grady, Jackson	Not common
[e]*Archytas marmoratus* (Tnsd.)	Sept., 1966	Alfalfa	Payne	Common in collections from alfalfa in late Sept.
[a]*Winthemia rufopicta* (Big.)	Sept., 1966	Alfalfa	Payne	Common in collections from alfalfa in late Sept.
[eb]*Euphorocera omissa* (Rnh.)	Sept., 1966	Alfalfa	Payne	Single record
Braconidae				
[a]*Chelonus texanus* Cress.	Aug., Sept., 1966	Cotton, alfalfa	Payne, Grady	Second most common braconid

TABLE XXV - Continued

Parasite	Month and Year of Collection	Host Plant	County	Remark
[c]*Microplitis croceipes* (Cress.)	Aug., Sept., 1965-66	Alfalfa, cotton	Payne, Grady, Jackson, Greer	Most common parasite; only important parasite of *H. zea* in cotton; only parasite confirmed in *H. virescens*
Ichneumonidae				
[b]*Mesochorus* sp.	Sept., 1966	Alfalfa	Payne	Apparently a hyperparasite of *M. croceipes*
[d]*Temelucha* sp.	Sept., 1966	Alfalfa	Payne	Single record
[d]*Pristomerus spinator* (Fab.)	Sept., 1966	Alfalfa	Grady	Single record
[b]*Netelia* sp.	Sept., 1966	Alfalfa	Payne	Not common
[b]*Mastrus* sp.	Sept., 1966	Cotton	Grady	Single and unusual record

[a]Reared from *H. zea* and *Heliothis* not identified to species (*H.* sp.).

[b]Reared only from *H.* sp.

[c]Reared from *H. zea* and *H. virescens*.

[d]Reared only from *H. zea*.

[e]Parasite completed development within and emerged from host pupa.

[?]Before a name indicates doubt.

TABLE XXVI

SEASONAL INCIDENCE OF PARASITISM IN THE *HELIOTHIS* COMPLEX IN COTTON, 1966

Date*	*H. zea*		*H. virescens*		*H.* spp.***	
	No.	% Parasitized**	No.	% Parasitized**	No.	% Parasitized**
July						
16-31	11	.00			12	.00
Total	11	.00			12	.00
Aug.						
1-15	203	2.95			228	2.63
16-31	110	14.54	16	12.5	129	13.95
Total	313	7.02	16	12.5	357	6.72
Sept.						
1-15	347	8.93	41	19.51	389	10.28
16-30	387	4.90	11	9.09	398	5.02
Total	734	6.81	52	17.30	787	7.62
Oct.						
1-15	28	32.14	1	.00	29	31.03
Total	28	32.14	1	.00	29	31.03

*Most collections made in Grady Co., Okla.; portions of collections in September from Jackson Co.

**Includes parasites from both larvae and pupae.

***Includes *H.* sp. not reported separately in table.

TABLE XXVII

SEASONAL INCIDENCE OF PARASITISM AND PUPATION RATE IN *HELIOTHIS* FROM ALFALFA, 1966

Date*	No.***	% Parasitized**	No.***	% Pupation
Aug.				
1-15	74	18.91	68	39.70
16-31	144	27.08	139	15.10
Sept.				
1-15	128	11.71	128	11.71
16-30	86	2.32	86	10.46
Oct.				
25	8	.00	—	—
Total	440	15.90	421	17.10

*Most collections made in Grady Co., Okla.; portions of collections in September and October from Jackson Co.

**Includes parasites from both larvae and pupae.

***No. field-collected larvae (not identified to species) placed on artificial diet.

TABLE XXVIII

INCIDENCE OF PARASITISM IN THE HELIOTHIS COMPLEX COLLECTED FROM DIFFERENT SOURCES IN COTTON, 1966

Source with Respect to Control	Nonirrigated No.*	Nonirrigated % Parasitized	Irrigated No.	Irrigated % Parasitized	Blooms No.	Blooms % Parasitized	Bolls & Squares No.	Bolls & Squares % Parasitized	Total
Controlled									
H. zea	15	.00	24	4.16	25	4.00	10	.00	2.56%
H. virescens	1	.00	2	.00	3	.00			.00
H. sp.			6	.00	5	.00			.00
H. spp.	16	.00	32	3.12	33	3.03	10	.00	2.08
Noncontrolled									
H. zea	489	8.17	236	6.35	624	5.60	6	.00	7.58%
H. virescens	17	17.64	25	16.00	30	20.00	1	.00	16.66
H. sp.	2	.00	17	.00	17	.00			.00
H. spp.	508	8.46	278	6.83	671	6.11	7	.00	7.88
Irregularly Controlled									
H. zea	242	9.50	80	2.50	271	7.38			7.76%
H. virescens	17	23.52	7	.00	18	16.66			16.66
H. sp.	5	20.00			4	25.00			20.00
H. spp.	264	10.60	87	2.29	293	8.19			8.54
TOTAL									
H. zea		8.44		5.29		6.08		.00	
H. virescens		20.00		11.76		17.64		.00	
H. sp.		14.28		.00		3.83			
H. spp.		9.01		5.54		6.61		.00	

Total Parasitism, Independent of Control, Irrigative Practice and Plant Structure

	No.	% Parasitized
H. zea	1,086	7.45
H. virescens	69	15.94
(cont.) H. sp.	30	3.33
H. spp.	1,185	7.84

*No. field-collected larvae placed on artificial diet and observed for parasite emergence.

TABLE XXIX

LIFE HISTORY AND BIOLOGY OF THE BRACONID PARASITE, CHELONUS TEXANUS, USING THE YELLOW-STRIPED ARMYWORM AS A LABORATORY HOST

Parasite Generation in Laboratory	% Parasitism in Armyworms Emerging from Eggs Exposed to Adult Parasites*		Chelonus texanus										Age Adult Female Most Successfully Parasitic
			Larval Stage		Success Pupation		Pupal Stage		Adult Emergence		Adult Stage (sexes not differeriented)		
	No.	%	No.	Range (days)	No. Larvae	%	No.	Range (days)	No. Pupae	%	No. Adults	Range (days)	$\bar{X}$	No. Days
I	121	83.47	101	18-23	101	82.17	83	8-12	83	95.18	56***	2-28	11.82	4-8
II**	not recorded		not recorded		not recorded		not recorded		31	29.03				> 4
III	256	90.23	not recorded		231	74.89	182	8-13	173	99.42	not recorded			6-9

*No. armyworm larvae parasitized ÷ total no. armyworm larvae collected from egg masses exposed for parasitism.

**Poor results in Generation II partially attributed to contamination of artificial diet used to rear larval hosts.

***Data from Generations I and II combined.

TABLE XXX

PARASITES REARED FROM *HELIOTHIS ZEA* (BODDIE), *H. VIRESCENS* (FABRICIUS), AND *PRODENIA ORNITHOGALLI* GUENÉE IN OKLAHOMA, 1965-1966

Heliothis	*Prodenia ornithogalli*
[a] Tachinidae	Tachinidae
[bd] *Eucelatoria armigera* (Coq.)	[h] *Archytas apicifer* (Wlk.)
[*d] *Lespesia archippivora* (Riley)	[*b1] *Lespesia archippivora* (Riley)
[g] *Voria aurifrons* (Tnsd.)	*Winthemia* sp.
[e] *Plagiomima* ?*spinosula* (Big.)	*Lespesia aletiae* (Riley)
[*d] *Euphorocera tachinomoides* Tnsd.	[*] *Euphorocera tachinomoides* Tnsd.
[h] *Archytas marmoratus* (Tnsd.)	[h*] *Euphorocera omissa* (Rnh.)
[*d] *Winthemia rufopicta* (Big.)	[*] *Winthemia rufopicta* (Big.)
[h*e] *Euphorocera omissa* (Rnh.)	Braconidae
Braconidae	[*c1] *Chelonus texanus* Cress.
[*d] *Chelonus texanus* Cress.	*Zele* sp.
[cf] *Microplitis croceipes* (Cress.)	Ichneumonidae
Ichneumonidae	*Campoletis peridistinctus* (Vier.)
[e] *Mesochorus* sp. (hyperparasite of *M. croceipes*)	[*] *Netelia* sp.
[g] *Temelucha* sp.	Eulophidae
[g] *Pristomerus spinator* (Fab.)	*Euplectrus platyhypenae* How.
[*e] *Netelia* sp.	Perilampidae
[e] *Mastrus* sp.	*Perilampus robertsoni* Cwfd. (hyperparasite of *C. texanus*)

[a] All tachinids identified by Dr. D. M. Wood; eulophid and perilampid by Dr. O. Peck; *C. texanus* by Dr. C. W. McComb; other braconids by Dr. W. R. M. Mason; inchneumonids by Dr. Mason and Mr. G. S. Walley.

[b] Most common tachinid parasite of *Heliothis*.

[b1] Most common tachinid parasite of *P. ornithogalli*.

[c] Most common hymenopterous parasite of *Heliothis*.

[c1] Most common hymenopterous parasite of *P. ornithogalli*.

[d] Reared from *H. zea* and *Heliothis* not identified to species (*H.* sp.).

[e] Reared only from *H.* sp.

[f] Reared from both *H. zea* and *H. virescens*.

[g] Reared only from *H. zea*.

[h] Parasite completed development within and emerged from host pupa.

? Before a name indicates doubt.

* Parasites reared from both *Heliothis* and *P. ornithogalli*.

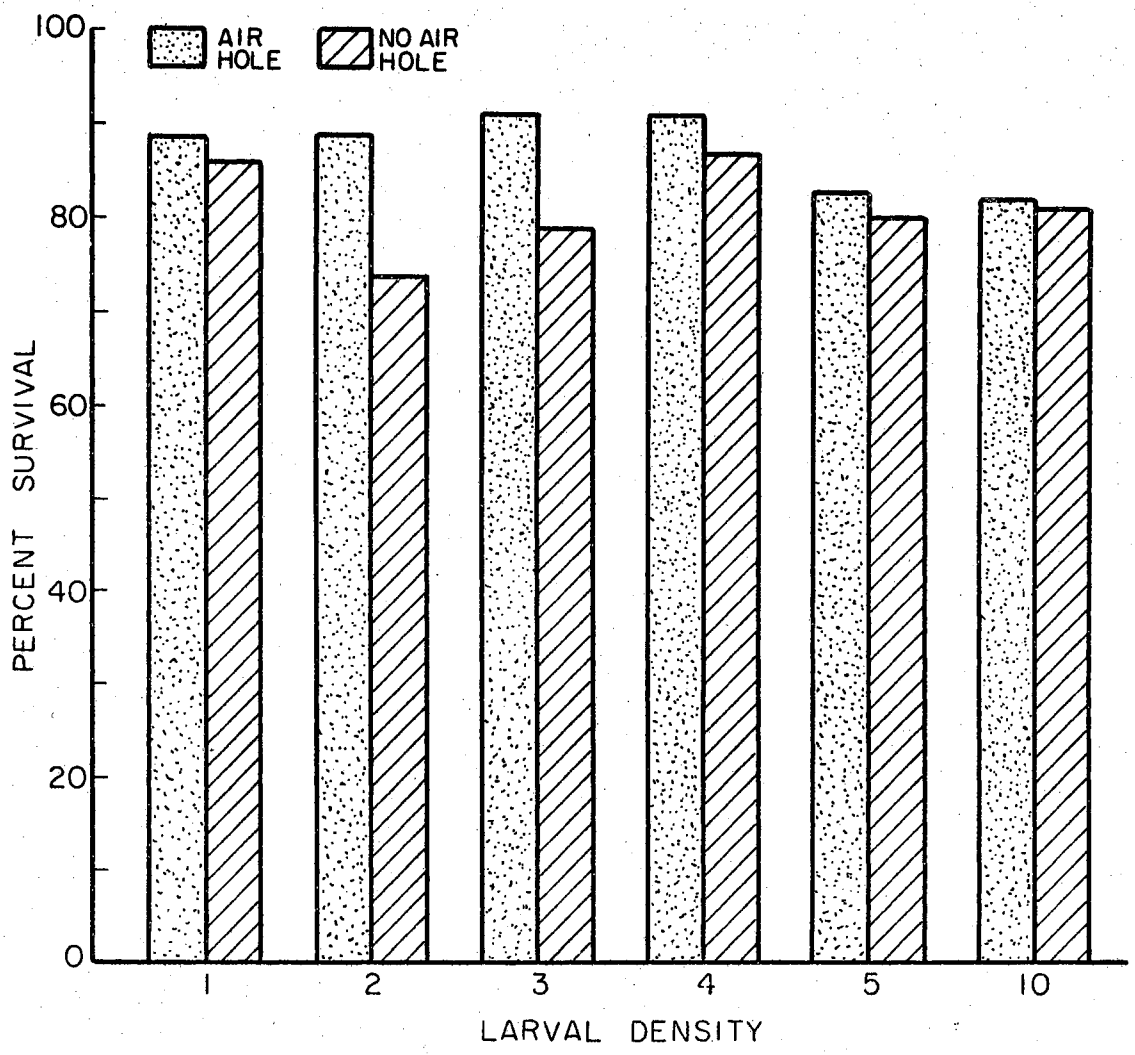

Figure 1. Survival of the Yellow-Striped Armyworm After One Week at Various Larval Densities. Each Bar Represents the Mean Response of Four Replications of 25 Cups.

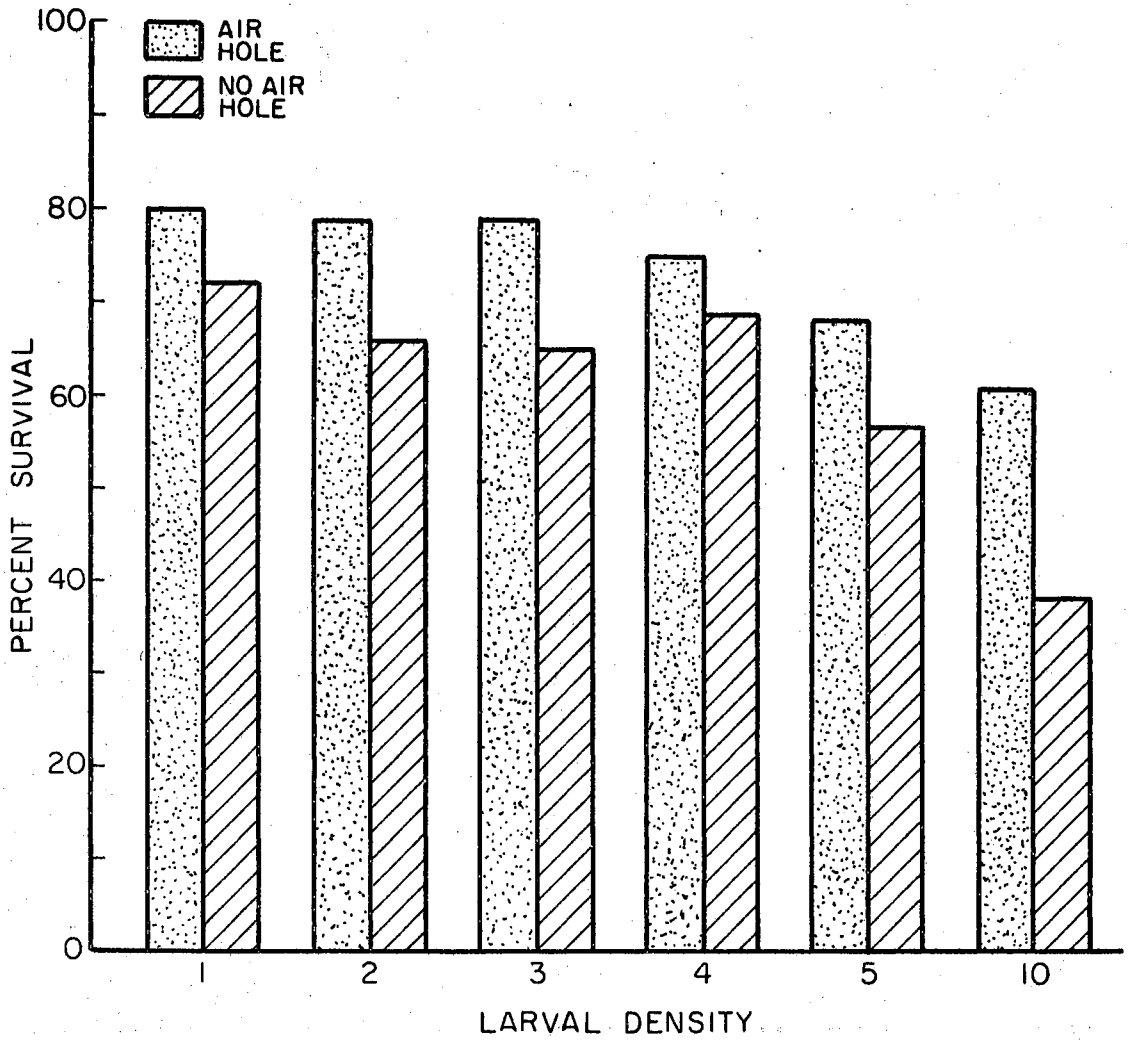

Figure 2. Survival of the Yellow-Striped Armyworm After Three Weeks at Various Larval Densities. Each Bar Represents the Mean Response of Four Replications of 25 Cups.

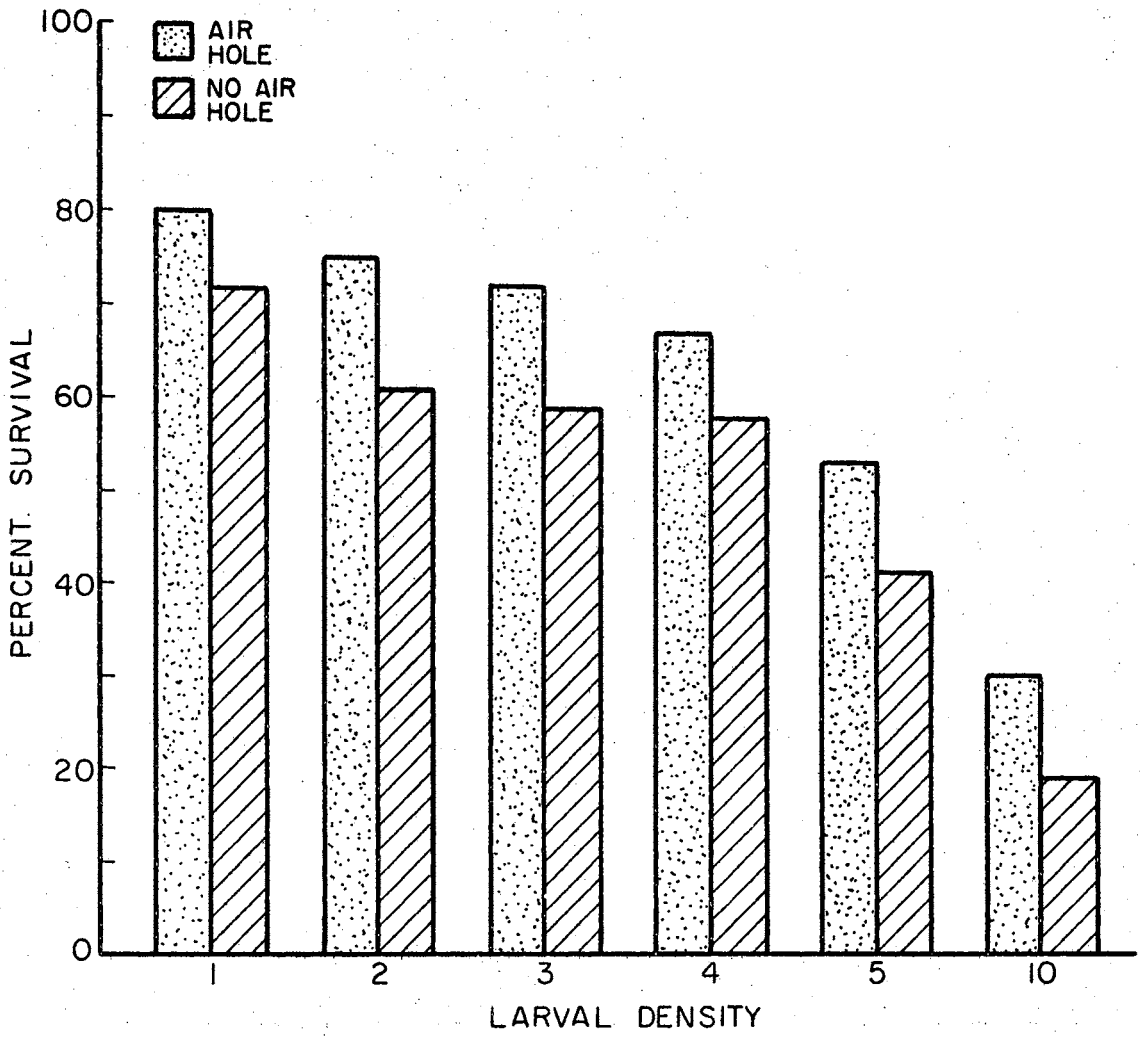

Figure 3. Survival of the Yellow-Striped Armyworm After Four Weeks at Various Larval Densities. Each Bar Represents the Mean Response of Four Replications of 25 Cups.

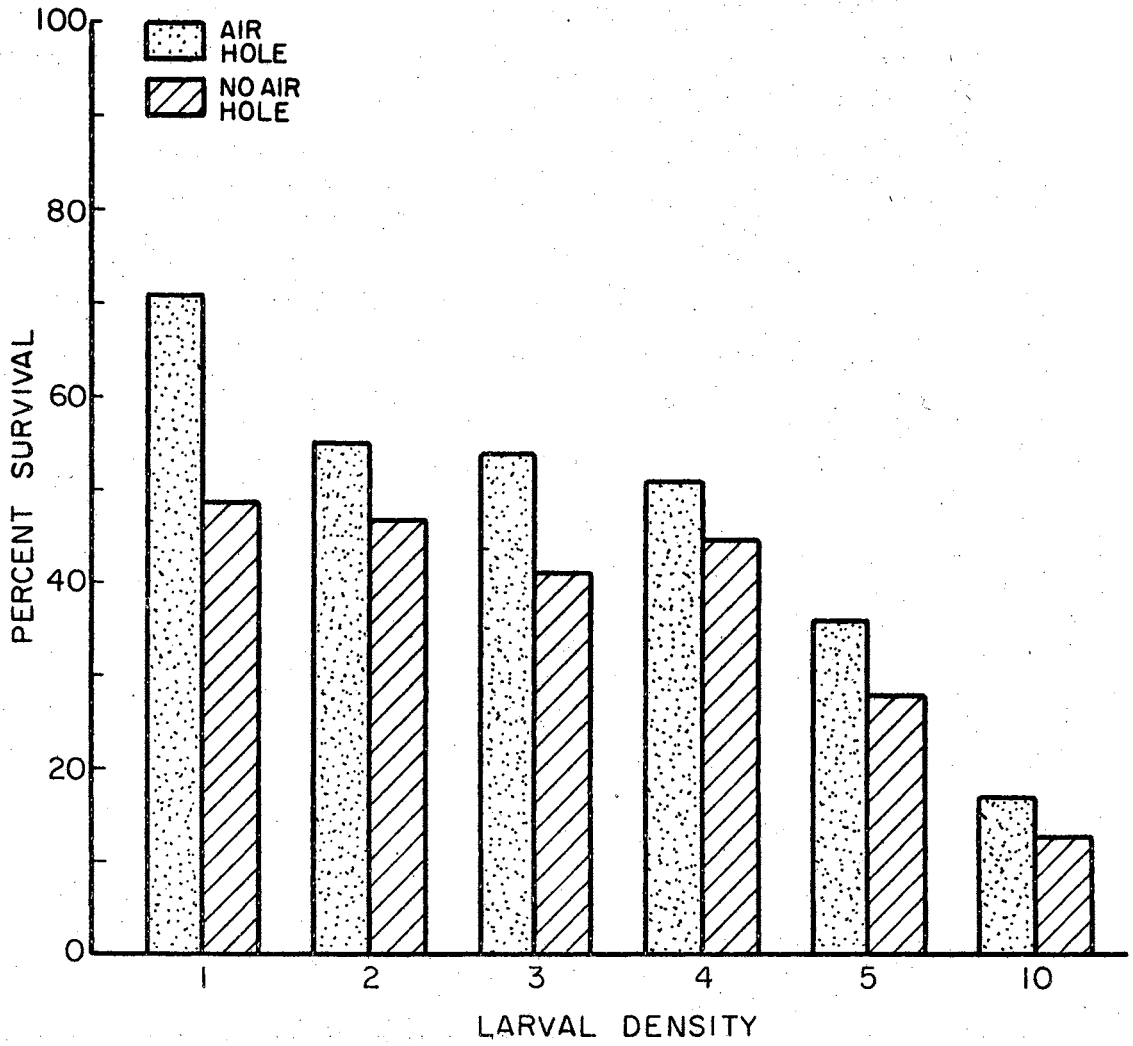

Figure 4. Survival of the Yellow-Striped Armyworm After Five Weeks at Various Larval Densities. Each Bar Represents the Mean Response of Four Replications of 25 Cups.

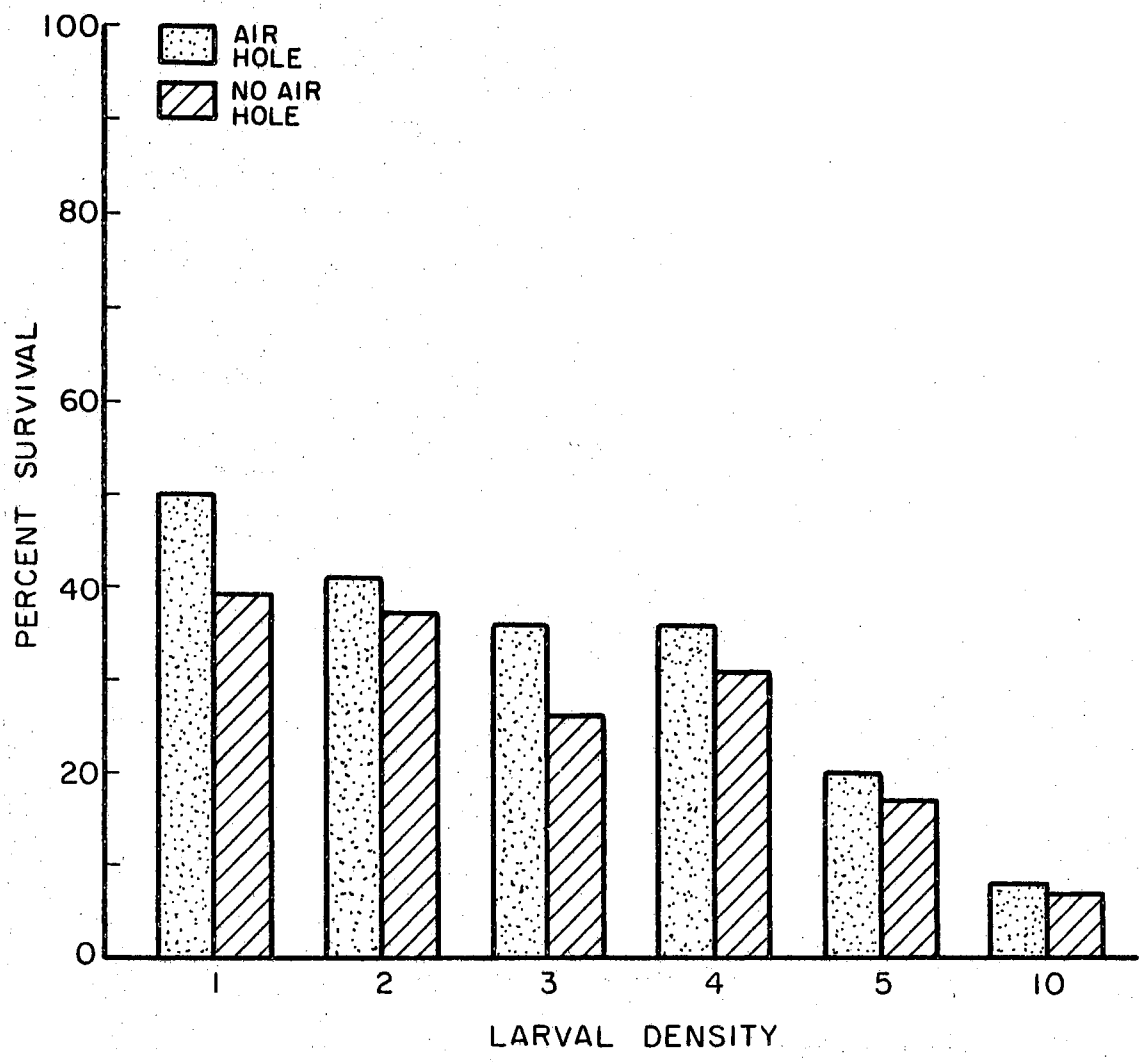

Figure 5. Survival of the Yellow-Striped Armyworm After Six Weeks at Various Larval Densities. Each Bar Represents the Mean Response of Four Replications of 25 Cups.

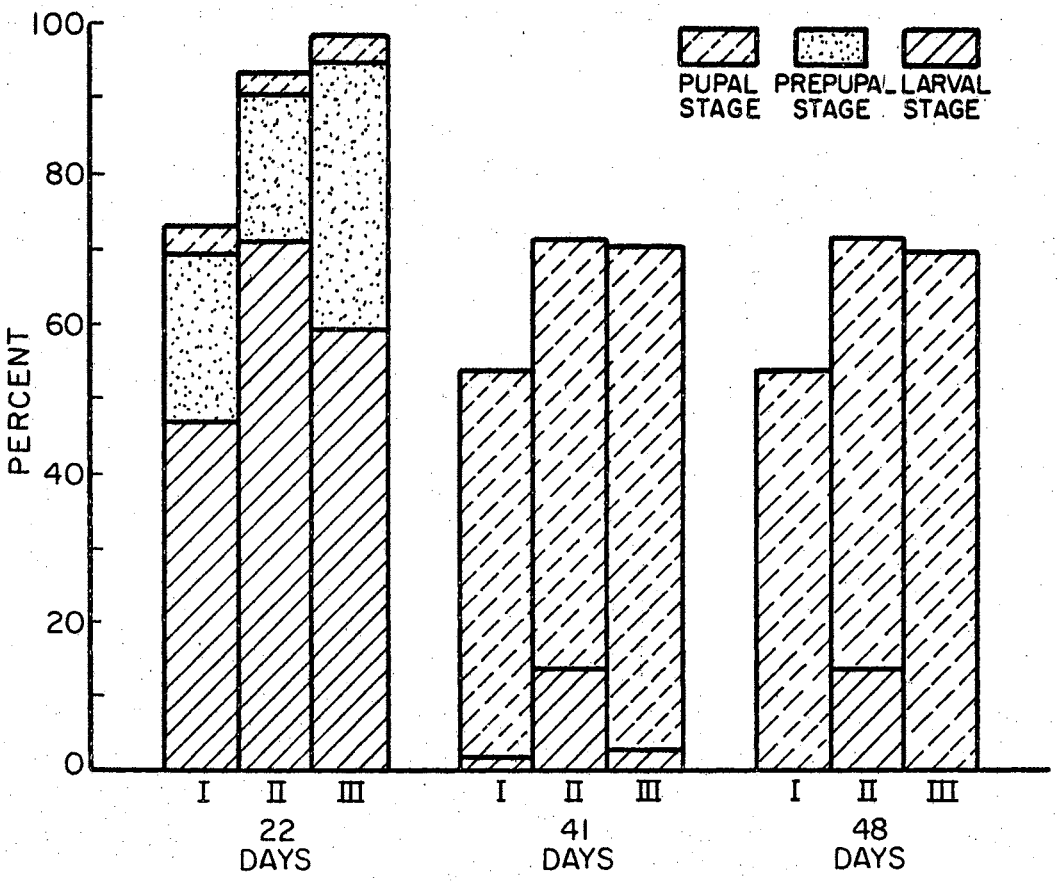

Figure 6. Survival and Distribution of Developmental Stages in the Yellow-Striped Armyworm Averaged Over Density with Time in Experiment I. (I = Maintained at Original Larval Density Throughout Experiment; II = Larvae Isolated Individually After Seven Days at Origianl Density; III = Larvae Isolated Individually After 14 Days at Original Density.)

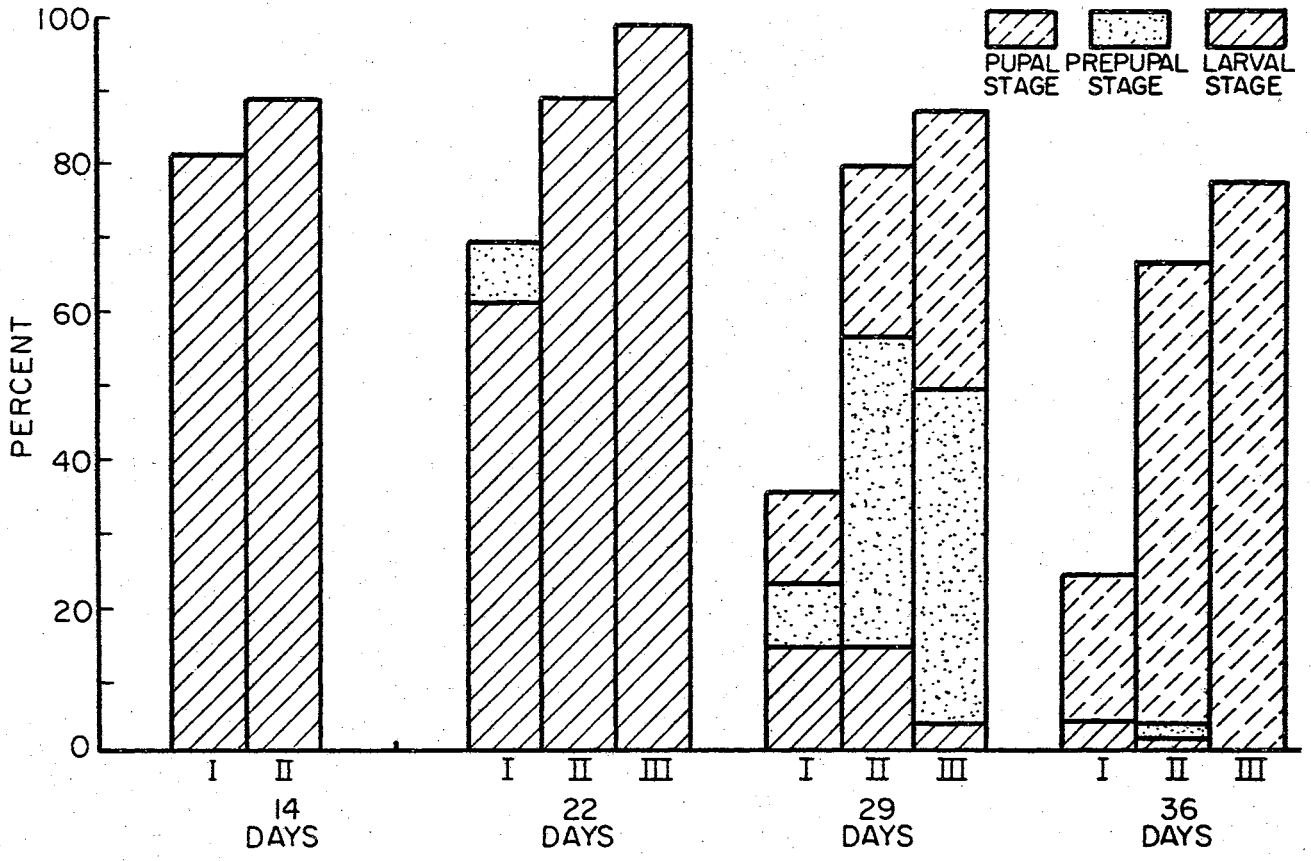

Figure 7. Survival and Distribution of Developmental Stages in the Yellow-Striped Armyworm Averaged Over Density with Time in Experiment II. (I = Maintained at Original Larval Density Throughout Experiment; II = Larvae Isolated Individually After Seven Days at Original Density; III = Larvae Isolated Individually After 14 Days at Original Density.)

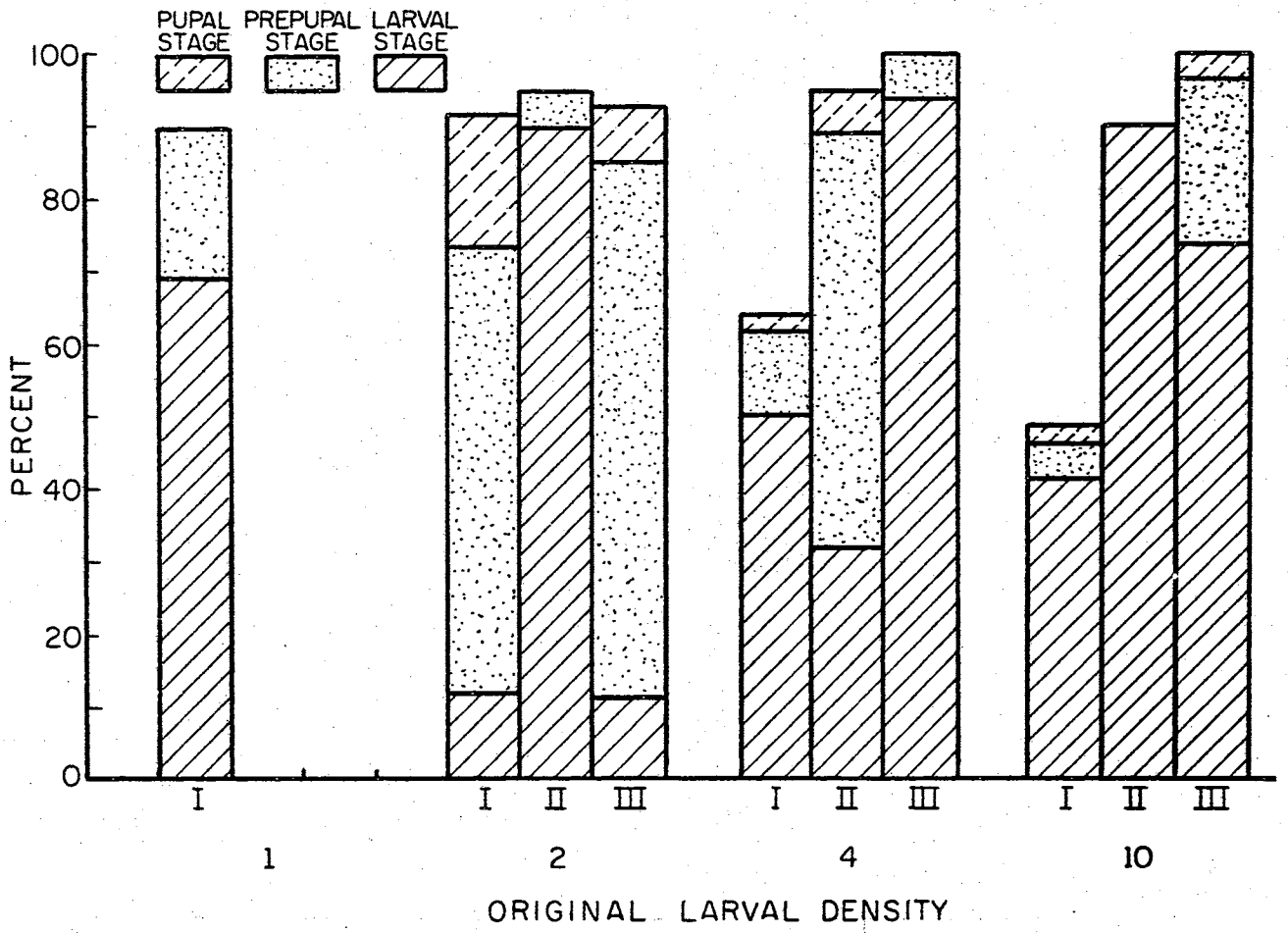

Figure 8. Survival and Distribution of Developmental Stages in the Yellow-Striped Armyworm at Various Larval Densities After 22 Days in Experiment I. (I = Maintained at Original Larval Density Throughout Experiment; II = Larvae Isolated Individually After Seven Days at Original Density; III = Larvae Isolated Individually After 14 Days at Original Density.)

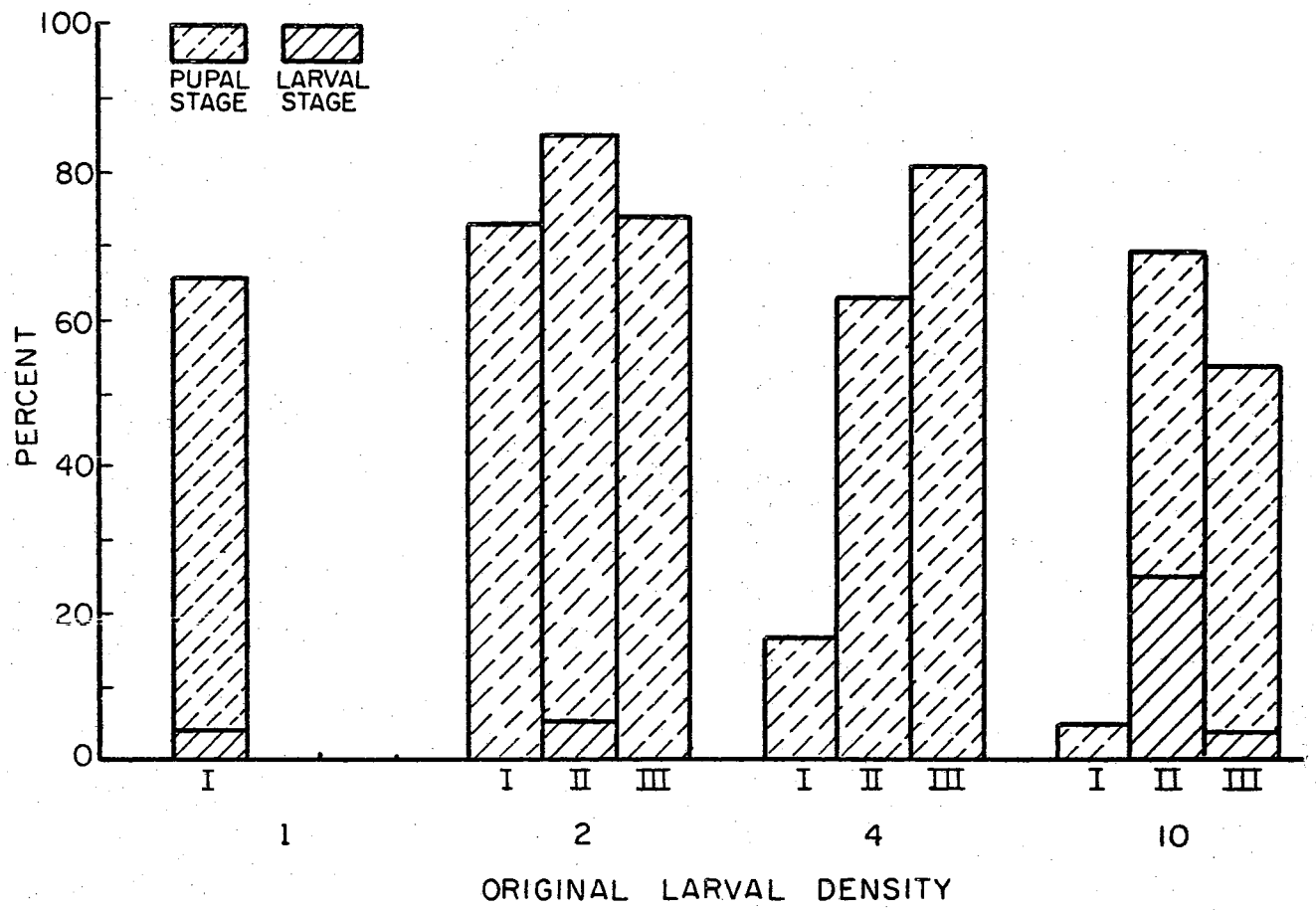

Figure 9. Survival and Distribution of Developmental Stages in the Yellow-Striped Armyworm at Various Larval Densities on the Last Observation Date (48 Days) in Experiment I. (I = Maintained at Original Larval Density Throughout Experiment; II = Larvae Isolated Individually After Seven Days at Original Density; III = Larvae Isolated Individually After 14 Days at Original Density.)

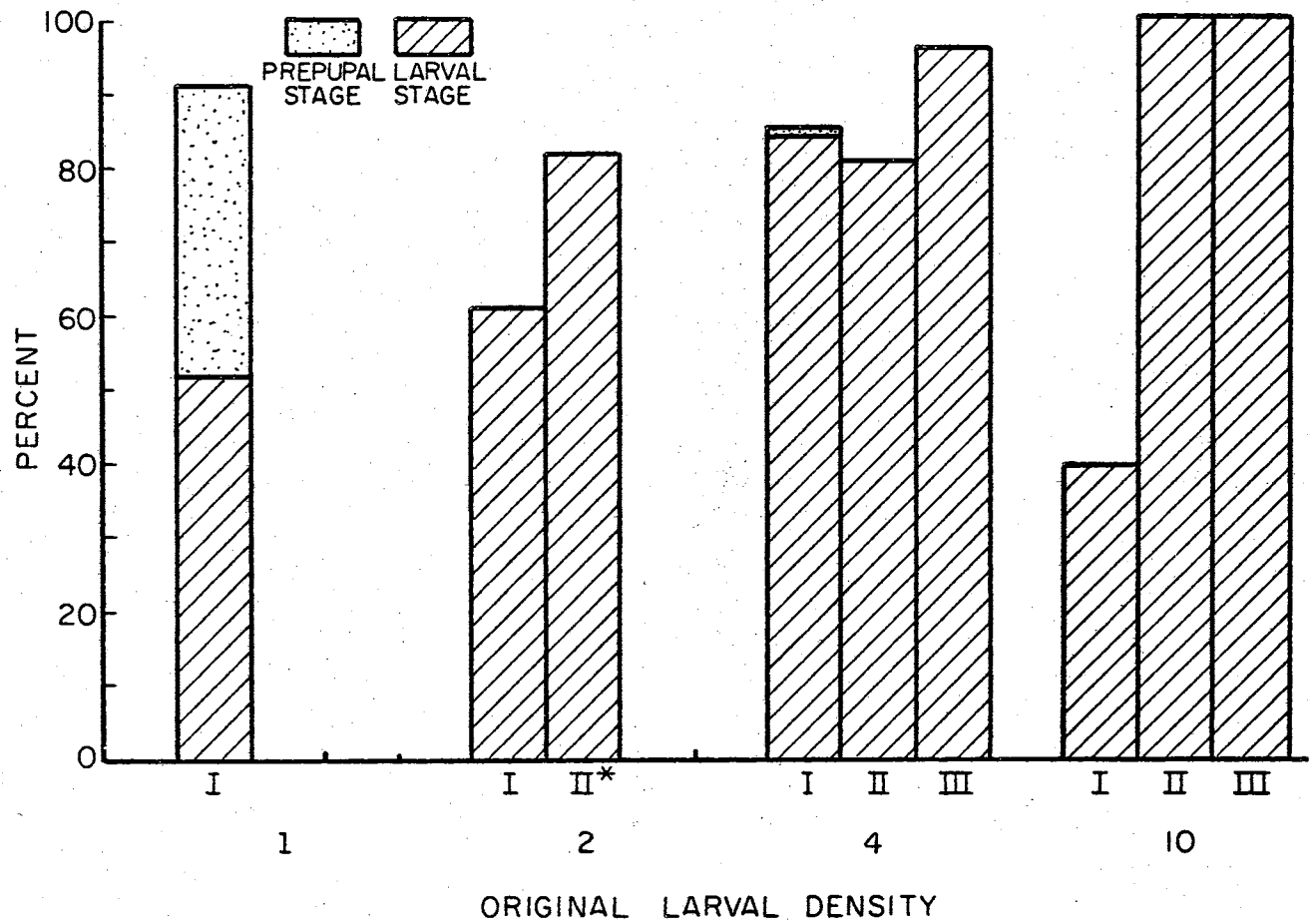

Figure 10. Survival and Distribution of Developmental Stages in the Yellow-Striped Armyworm at Various Larval Densities After 22 Days in Experiment II. (I = Maintained at Original Larval Density Throughout Experiment; II = Larvae Isolated Individually After Seven Days at Original Density; III = Larvae Isolated Individually After 14 Days at Original Density.) *Not enough insects available to establish III.

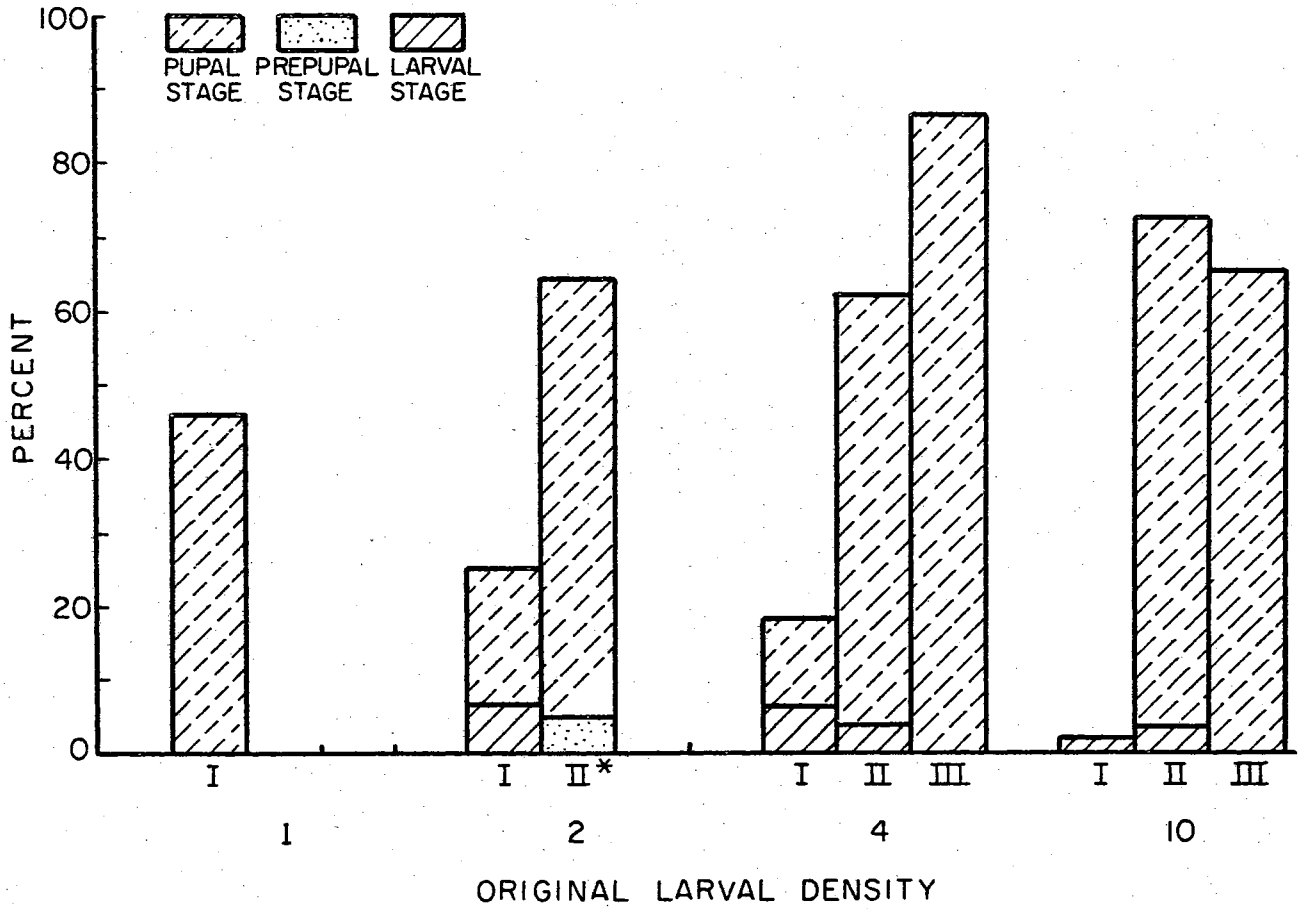

Figure 11. Survival and Distribution of Developmental Stages in the Yellow-Striped Armyworm at Various Larval Densities on the Last Observation Date (36 Days) in Experiment II. (I = Maintained at Original Larval Density Throughout Experiment; II = Larvae Isolated Individually After Seven Days at Original Density; III = Larvae Isolated Individually After 14 Days at Original Density.)
*Not enough insects available to establish III.

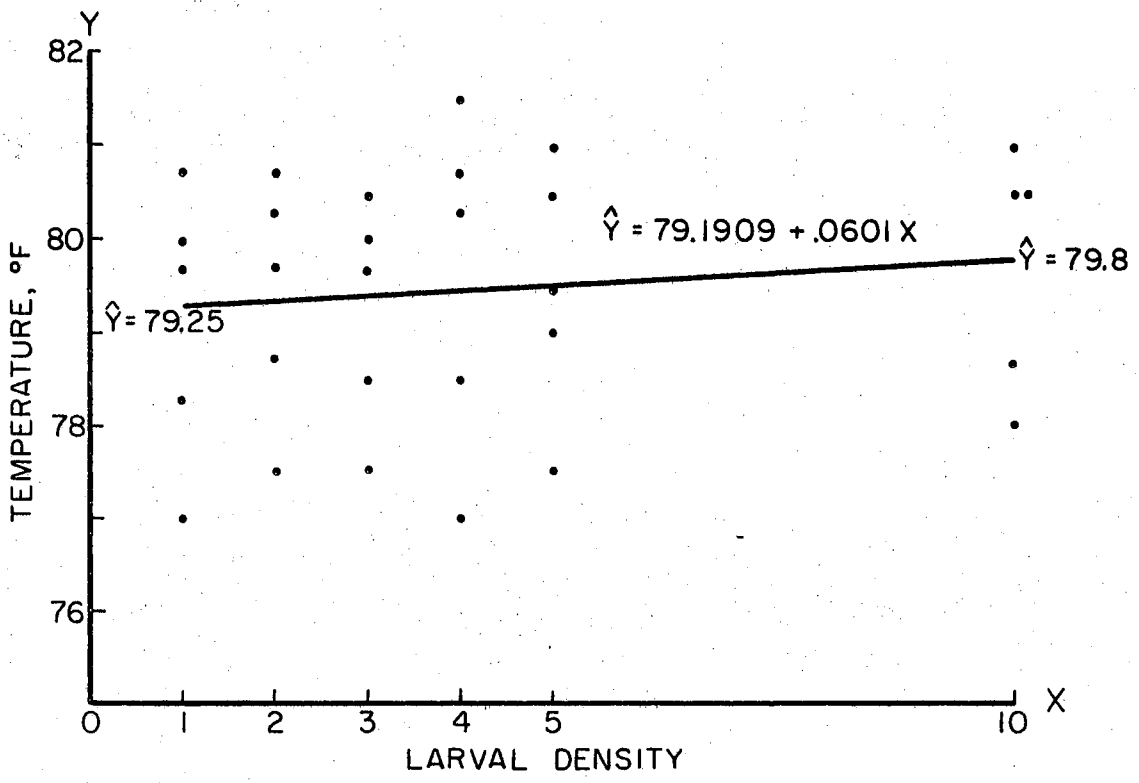

Figure 12. Temperature (Y) in Diet Cups Containing 11-Day Old Yellow-Striped Armyworms at Various Densities (X).

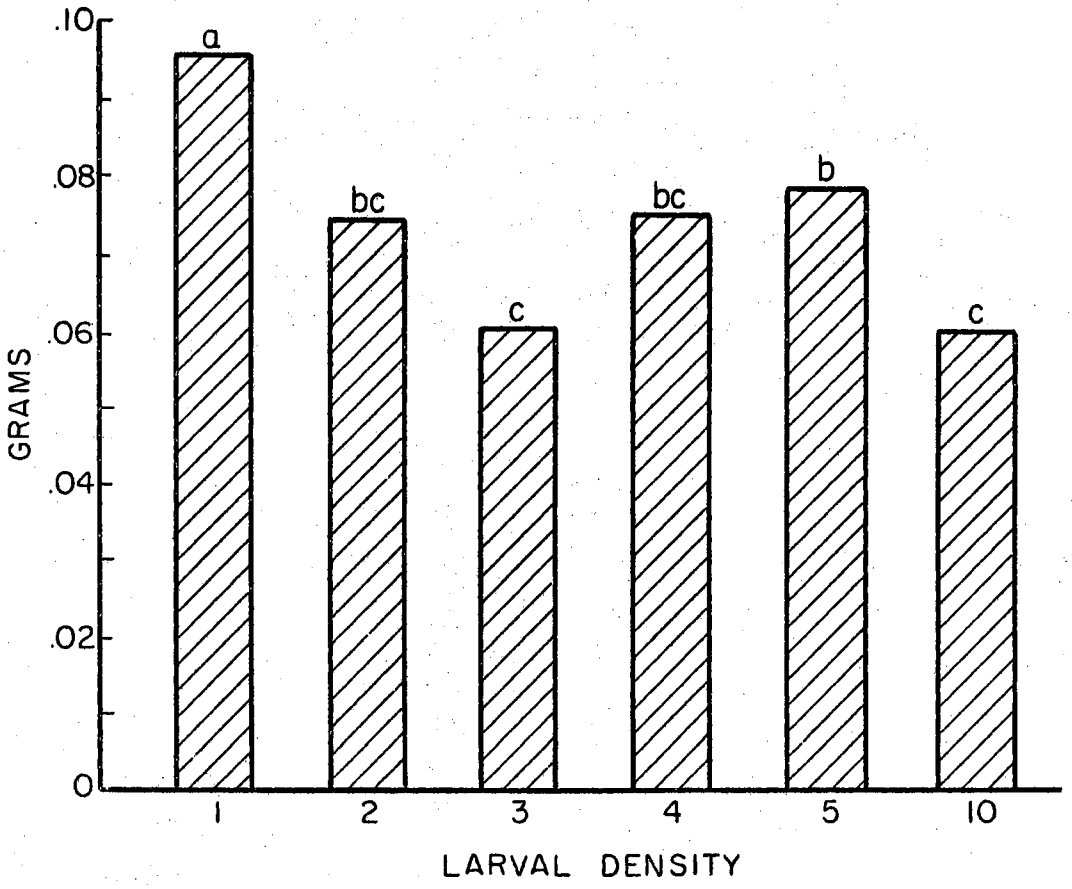

Figure 13. Weight of 7-Day Old Yellow-Striped Armyworm Larvae Reared at Various Densities. Bars Represent Mean Weight of 4 Replications of 30 Larvae Combined. Bars Sharing the Same Letter are not Significantly Different at the .05 Level of Probability.

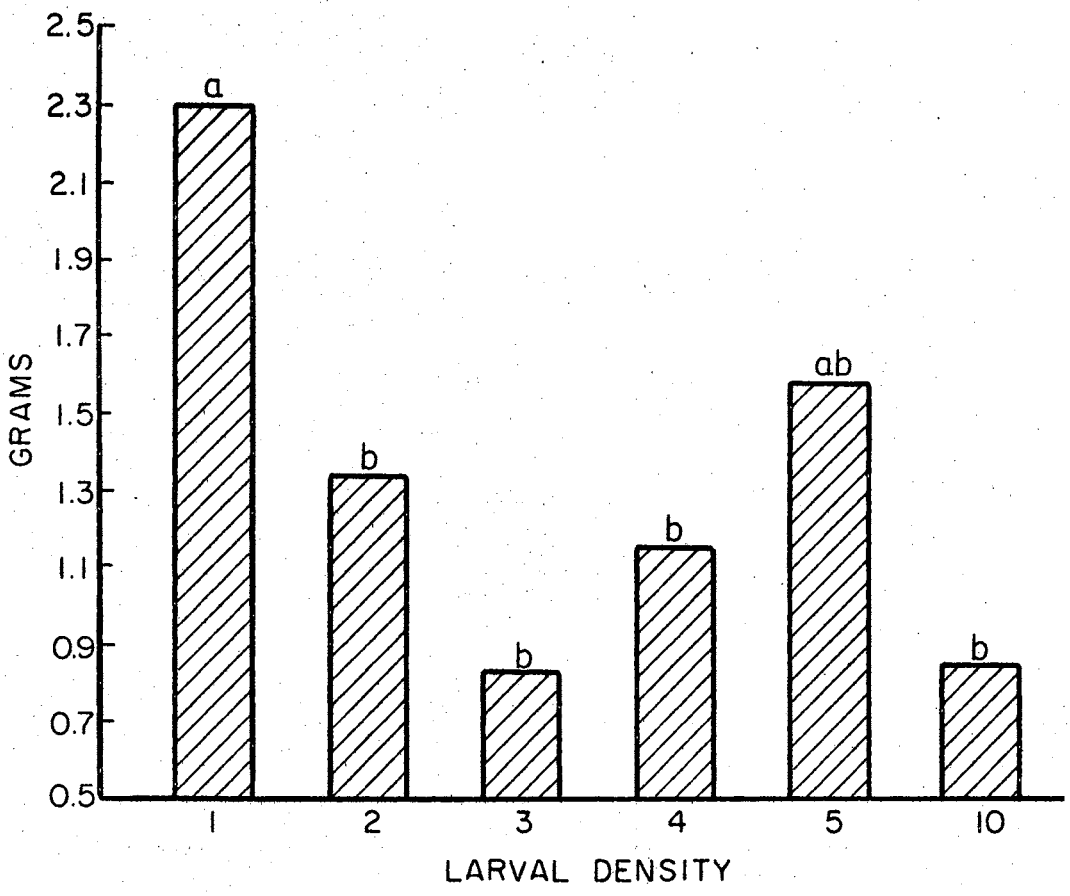

Figure 14. Weight of 14-Day Old Yellow-Striped Armyworm Larvae Reared at Various Densities. Bars Represent Mean Weight of 3 Replications of 30 Larvae Combined. Bars Sharing the Same Letter are not Significantly Different at the .05 Level of Probability.

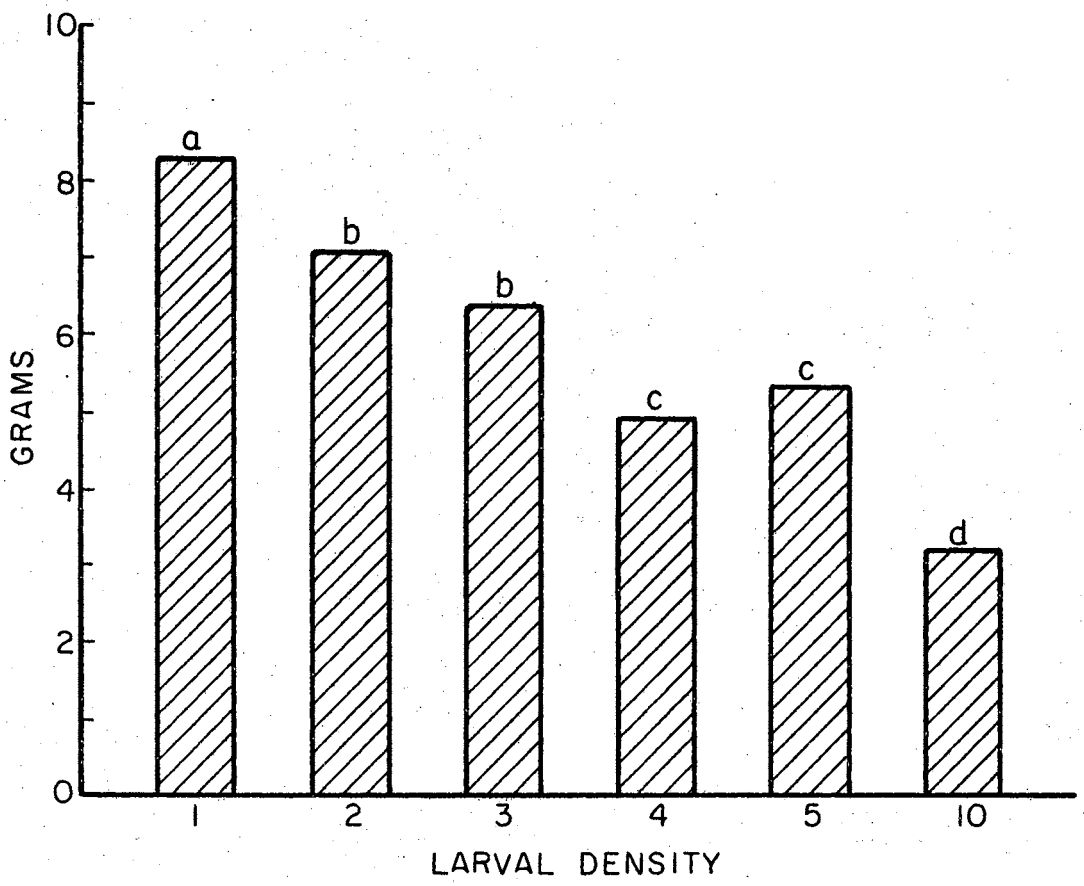

Figure 15. Weight of 25-Day Old Yellow-Striped Armyworm Larvae Reared at Various Densities. Bars Represent Mean Weight of 4 Replications of 30 Larvae Combined. Bars Sharing the Same Letter are not Significantly Different at the .05 Level of Probability.

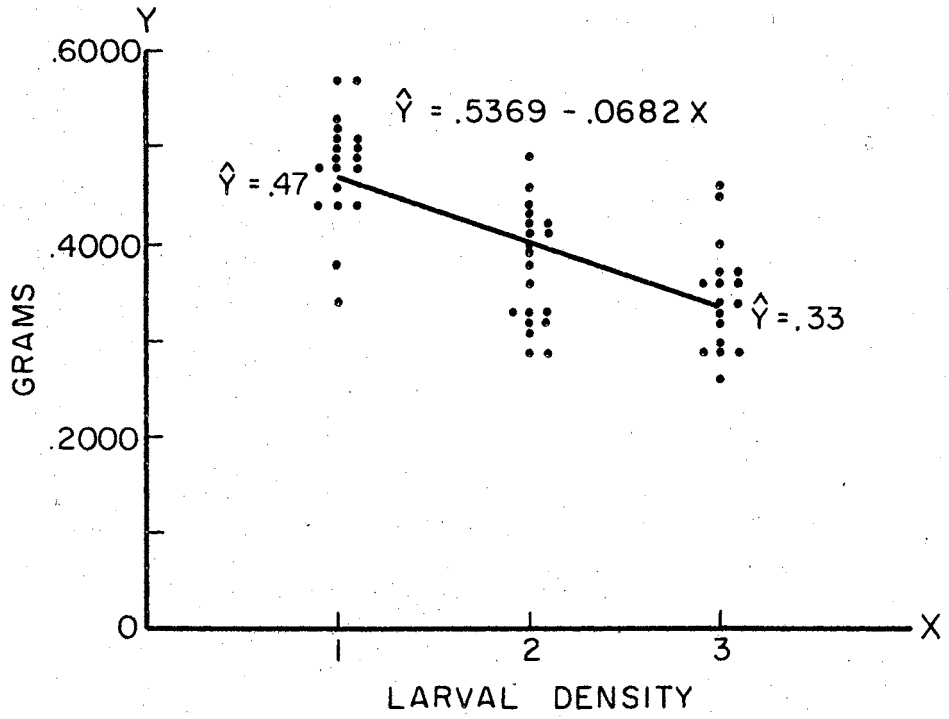

Figure 16. Effect of Larval Density (X) on Pupal Weight (Y) of Female Yellow-Striped Armyworms.

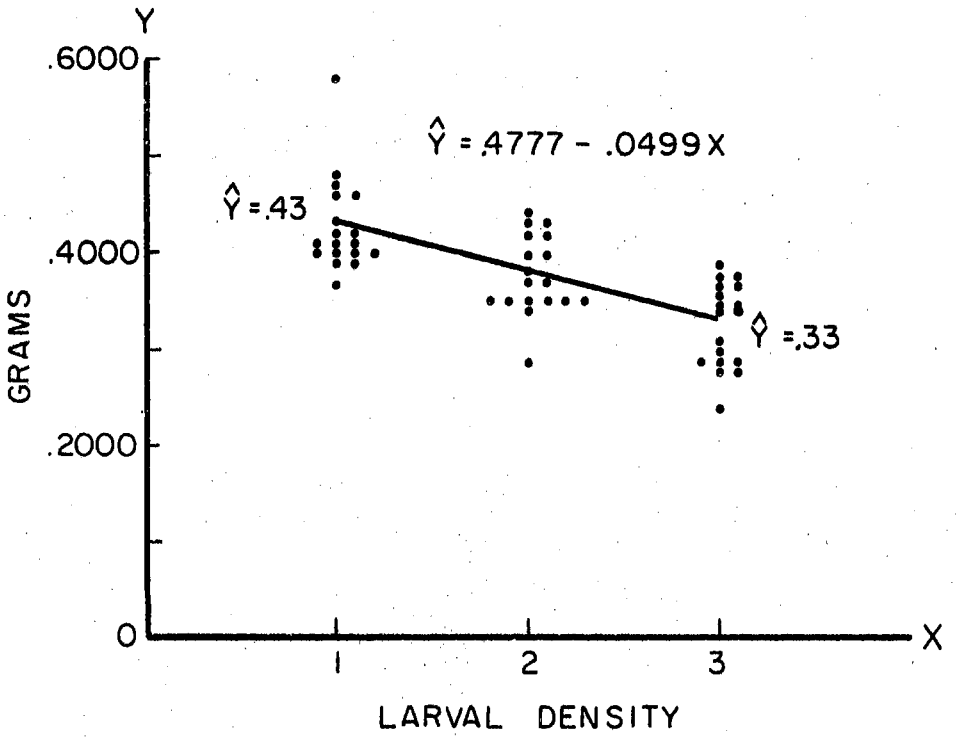

Figure 17. Effect of Larval Density (X) on Pupal Weight (Y) of Male Yellow-Striped Armyworms.

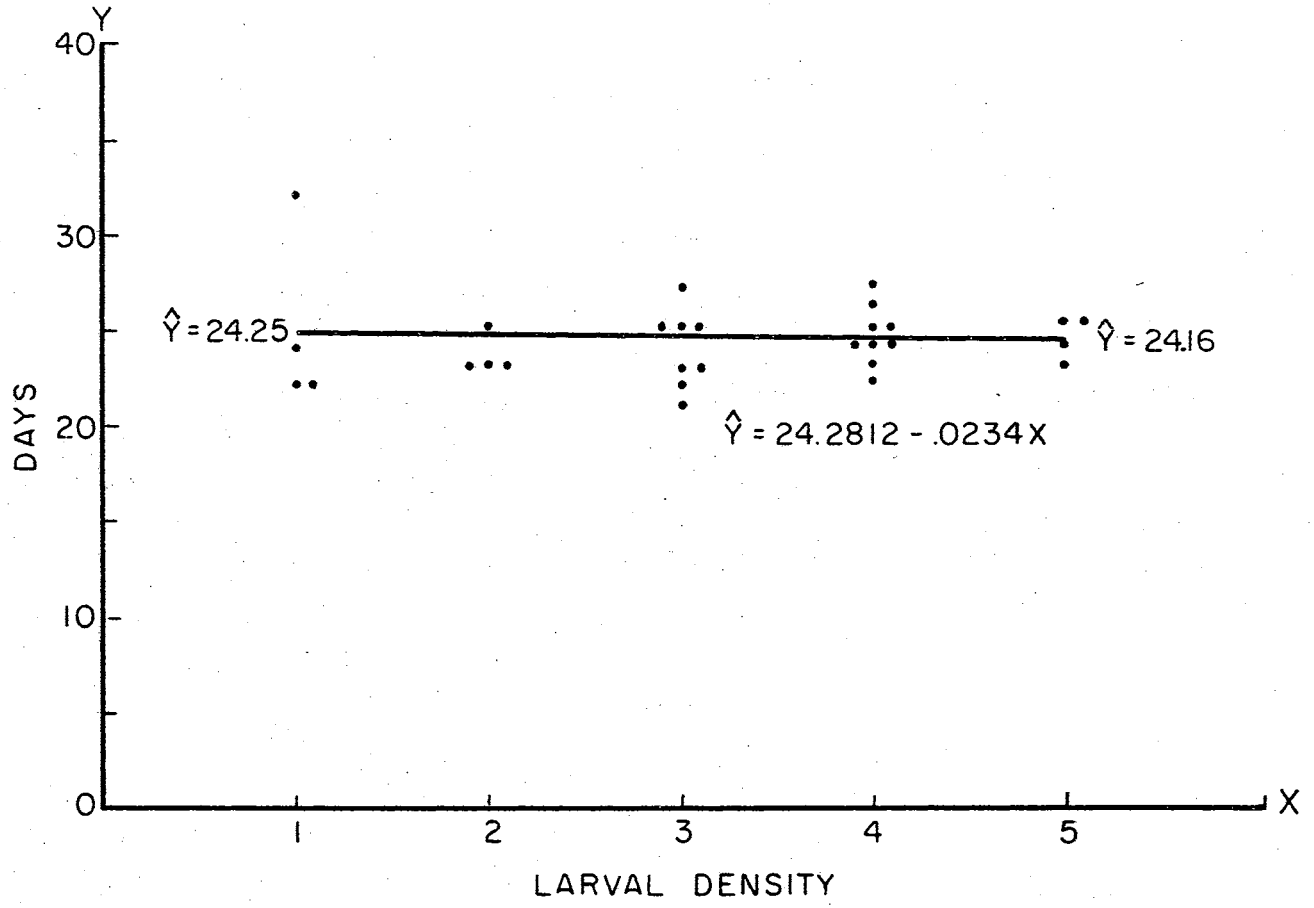

Figure 18. Effect of Larval Density (X) on Days in Larval Stage (Y) of Female Yellow-Striped Armyworms.

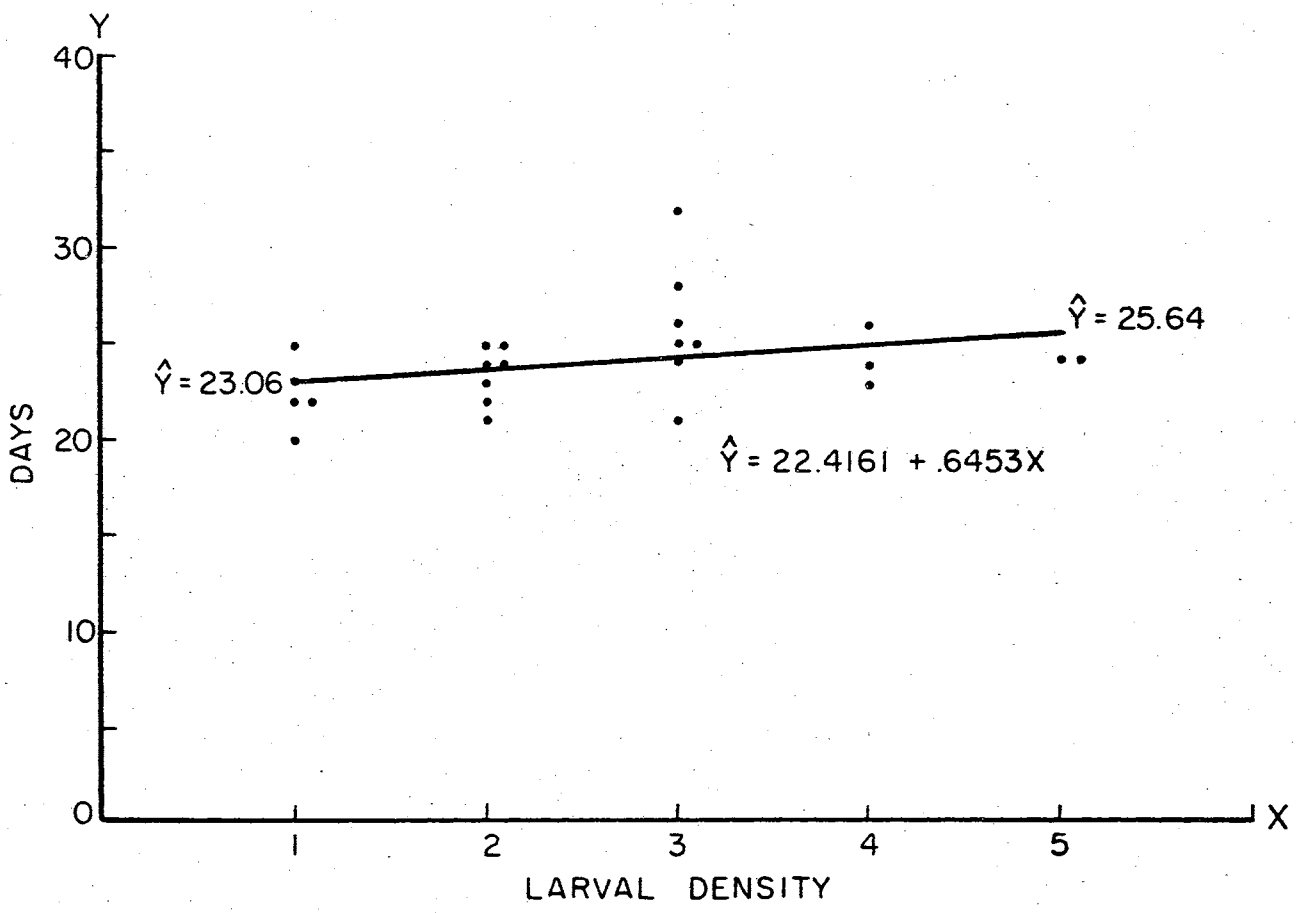

Figure 19. Effect of Larval Density (X) on Days in Larval Stage (Y) of Male Yellow-Striped Armyworms.

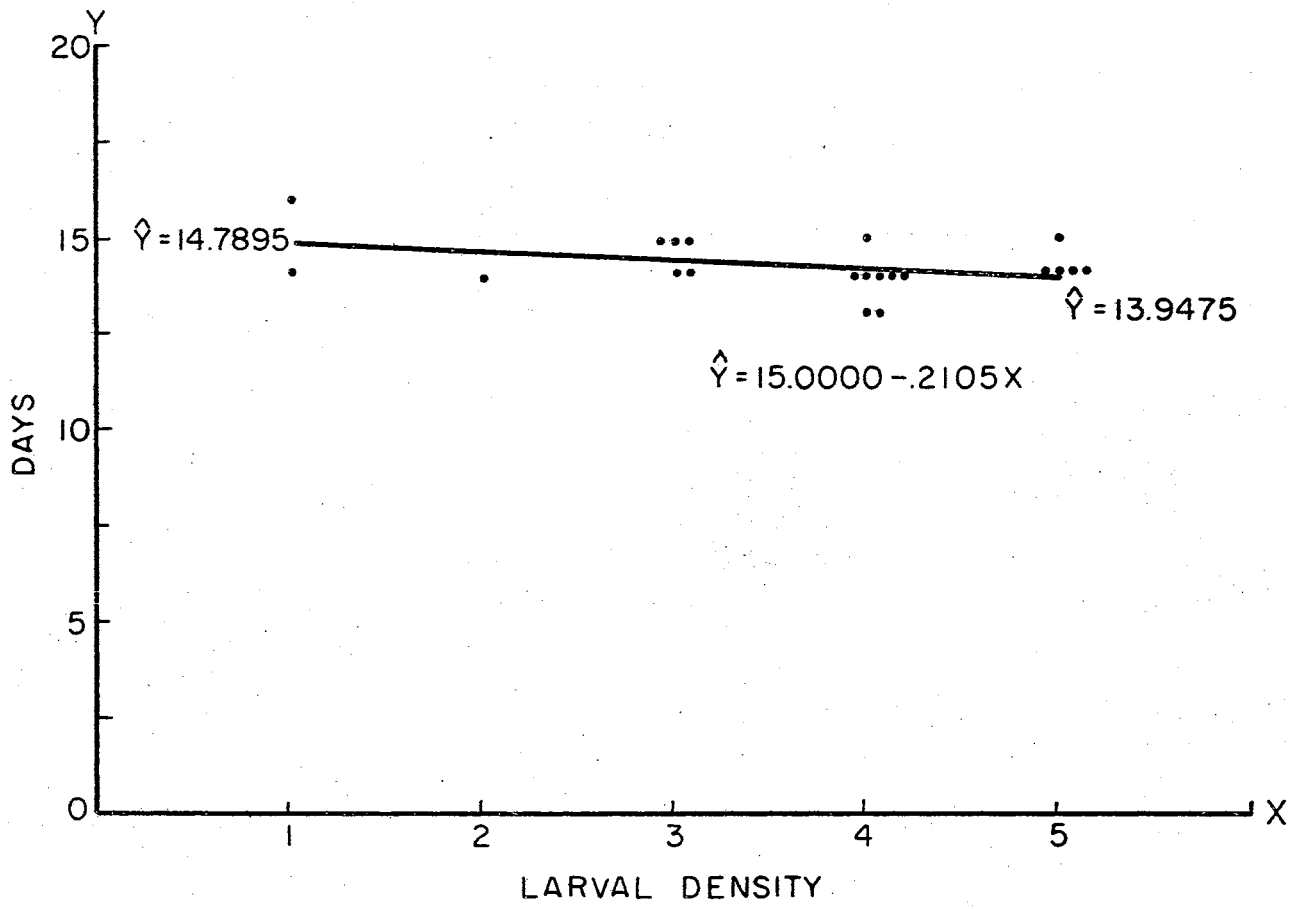

Figure 20. Effect of Larval Density (X) on Days in Pupal Stage (Y) of Female Yellow-Striped Armyworms.

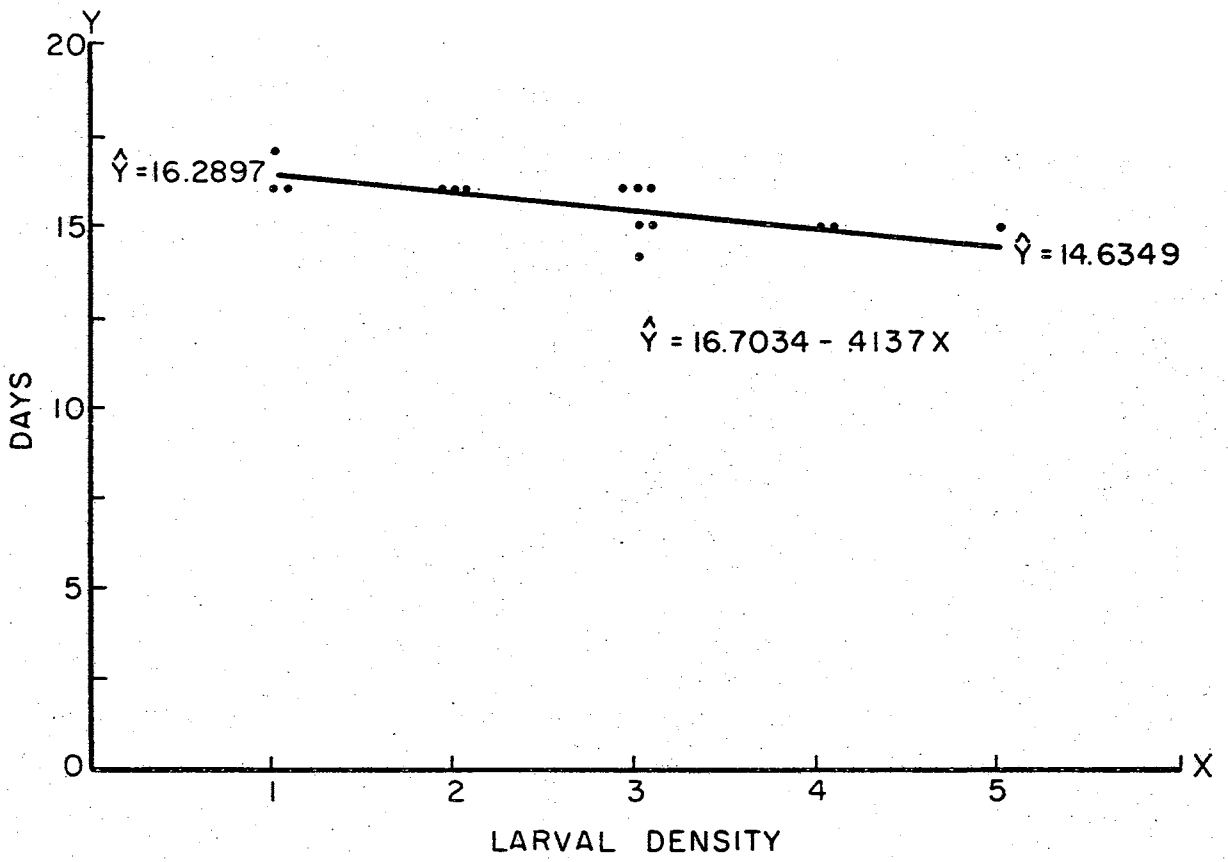

Figure 21. Effect of Larval Density (X) on Days in Pupal Stage (Y) of Male Yellow-Striped Armyworms.

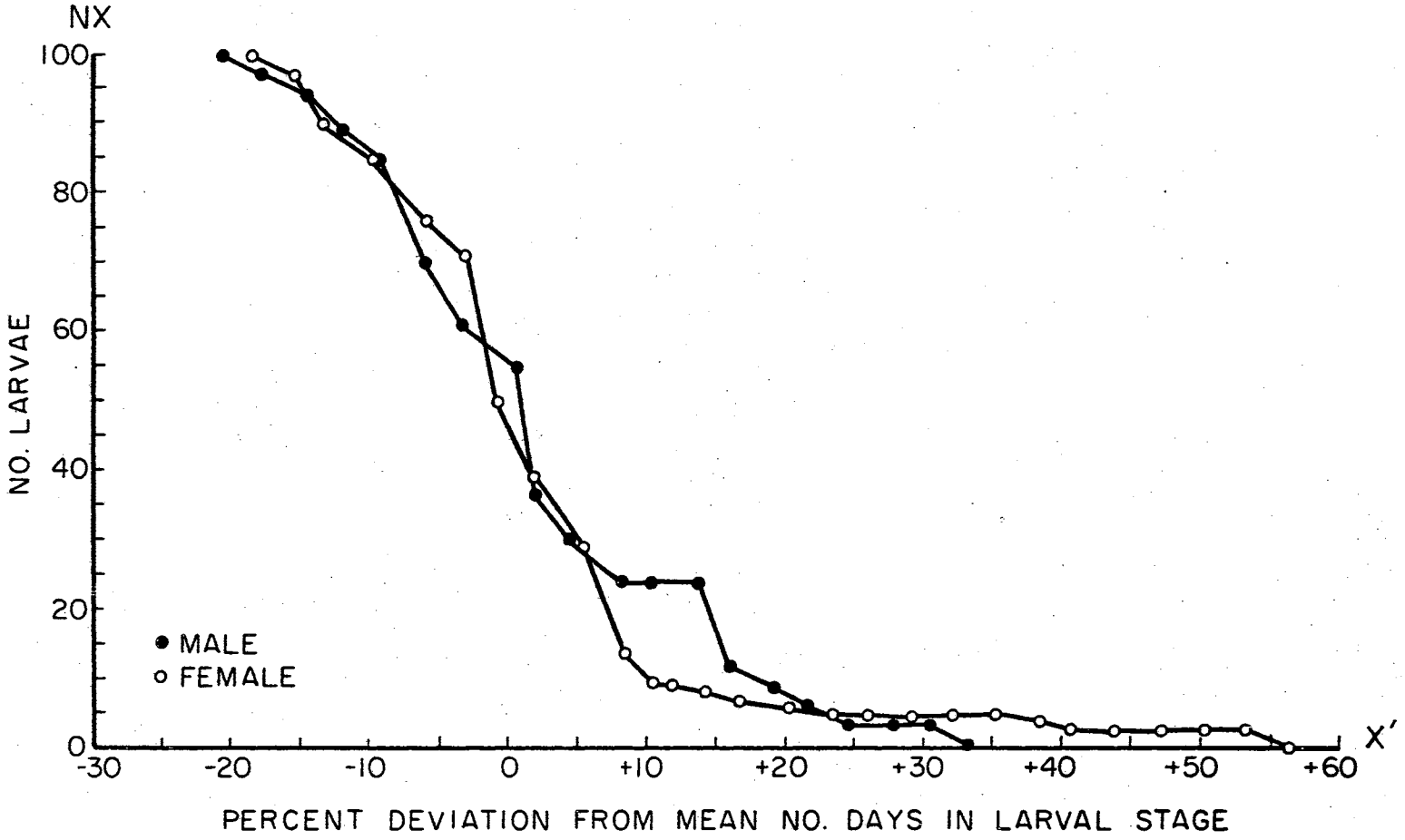

Figure 22. Developmental Curves for Male and Female Yellow-Striped Armyworms.

VITA

Dale George Bottrell

Candidate for the Degree of

Doctor of Philosophy

Thesis: REARING AND DYNAMICS OF LABORATORY POPULATIONS OF THE YELLOW-STRIPED ARMYWORM, PRODENIA ORNITHOGALLI GUENÉE, AND THE RELATIONSHIPS OF ITS NATIVE PARASITES WITH SYMPATRIC HELIOTHIS SPP.

Major Field: Entomology

Biographical:

Personal Data: Born in Ponca City, Oklahoma, July 28, 1940, the son of George H. and Leona D. Bottrell.

Education: Graduated from Ponca City Senior High, 1958. Attended Northern Oklahoma College, Tonkawa, Oklahoma, September, 1958, to January, 1960; Received Bachelor of Science Degree, Oklahoma State University, Stillwater, Oklahoma, January, 1963; attended Graduate School, Clemson University, Clemson, South Carolina, on a National Defense Educational Act Fellowship, September, 1963, to May, 1964; completed requirements for the Doctor of Philosophy Degree, May, 1968.

Professional Experience: Undergraduate Research Assistant, Department of Entomology, Oklahoma State University, September-December, 1962; Cotton Scout, Red Barn Chemicals, Inc., Van Horn, Texas, Summers 1962, 1963,and 1964; Teaching Assistant, School of Agriculture, Clemson University, September, 1963, to May, 1964; Graduate Research and Teaching Assistant, Oklahoma State University, September, 1964, to July, 1967; Assistant Professor of Entomology, Texas Agricultural Experiment Station, South Plains Research and Extension Center, Lubbock, Texas, August 1, 1967, to present.

Organizations: Entomological Society of Canada, Entomological Society of America, Oklahoma Academy of Science, Phi Sigma, Sigma Xi.