PREDICTING THE EMERGENCE OF POPULATION OF DIAPAUSING BOLLWORM AND NONDIAPAUSING SORGHUM MIDGE

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PREFACE

These studies were done as a contribution to the search for tools for increasing the efficiency in the integrated management of two important insect pests in agroecosystems such as cotton, corn, and sorghum.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Bollworm

The genus *Heliothis* contains some of the most important pests in the world from the point of view of potential crop loss.

In the United States, the bollworm, *Heliothis zea* (Boddie) (Lepidoptera:Noctuidae), is a serious threat to many important agriculture crops (Kogan et al. 1978).

Heliothis zea (Boddie) seems to be restricted to the western hemisphere, and in many instances it is a limiting factor in growing cotton, *Gossypium hirsutum* L.; soybeans, *Glycine max* (L.) Merrill; corn, *Zea mais* L.; tomatoes, *Solanum lycopersicum* L.; sorghum, *Sorghum bicolor* (L.) Moench; peanuts, *Arachis hypogea* L.; and many other crops. It also feeds on many noncultivated plants (Metcalf and Flint 1939). The larvae feed on the leaves and fruits of a wide range of hosts. Corn is the most preferred host (Hardwick 1965). Whorl stage corn is often infested, but damage is seldom of economic importance. The adult lays eggs on the fresh silks, and when the larvae hatch, they move toward the kernels. Many eggs are laid on the silks, but canibalistic behavior results in only one or sometimes two larvae reaching the last instars.

In cotton, eggs are laid mainly on the terminals of the plant. Initial feeding begins there, continuing with the flowers and small bolls. Quaintance and Brues (1905), and Kincade et al. (1967), found that each bollworm damages an average of 8 squares, 2/3 to 1 boll, and 1 flower.

Heliothis zea (Boddie) is also considered the major insect pest of soybeans in most southern states (Kogan et al. 1978). During severe outbreaks, larvae continue to strip the leaves after destroying the pods. Turnipseed and Kogan (1976) found that the soybean-corn-cotton-small grains rotations create a suitable environment for the development of potential *Heliothis* outbreaks in soybeans.

The bollworm is also an important pest in peanuts. Peanut foliage is susceptible to insect damage during the entire growing season; however, damage to the bloom and pegs has not been reported even with high infestation levels of *Heliothis* (Pitre et al. 1979).

In a review of sorghum entomology by Young and Teetes (1977), *Heliothis* is categorized as a foliage feeder as well as a headworm on sorghum. Larvae of *Heliothis* in sorghum panicles were considered only occasional pests. Although *Heliothis zea* (Boddie) exhibits a canibalistic behavior, panicles with more than one larvae have been observed (Burkhardt and Breithanpt 1955).

Sorghum Midge

Grain sorghum, Sorghum bicolor (L.) Moench, is an important crop, extensively cultivated in Africa, India, China, and North America. It is also grown in Central and South America.

About 90% of the total world grain sorghum crop is grown in China, India, Manchuria, and Africa. Nearly 75% of the total crop is used for human consumption, and 16% as livestock feed.

This plant was introduced into the United States from different areas of Africa and Asia, and it is now considered an important crop in the South and the Southwest. In Mexico, it was introduced from the United States in 1940 and is now widely cultivated in the northeastern part of the country.

The crop is generally distributed from the tropics to 45 degrees latitude, and it has been classified into these different groups (Leonard and Martin 1963):

> The Kafirs, with juicy stalks, were brought to this continent from South Africa which is their main habitat.
>
> The Milos, brought from east-central Africa, tiller considerably and are more tolerant to heat and drought than the Kafirs.
>
> Other types: Feteritas from Sudan; Durras from North Africa, the Near East and the Middle East; Shallu from India; Kaoliang from China; and Hegari from Sudan.

Most of the grain sorghum hybrids and varieties in the United States and Mexico were developed from crosses involving Milo and Kafir types.

Sorghum grain is similar to corn in food value, but it contains slightly more protein and less fat. When compared with wheat, sorghum grain has a composition similar to that of hard wheat, except that it has less fiber and more fat (Leonard and Martin 1963).

The most common use of sorghum grain in America is as livestock and poultry feed; but in China, India, and Africa it is an important part of the human diet.

Grain sorghum is an economical and practical alternative crop for non-irrigated lands in low rainfall areas. It can withstand some moisture stress without greatly reducing the yield.

Sorghum is attacked by several species of insects during its growing season; however, only one or two of these insects become key pests. The sorghum midge, Contarinia sorghicola Coquillet (Diptera:Cecidomyiidae), is the key insect pest for most grain sorghum producing areas in the world.

It was referred to for the first time by Tryon (1894) in Queensland, Australia, and he described it under the genus Diplosis.

In the United States, Ball (1908), studied a situation he coined "blast" where sorghum panicles did not produce grain in some of their flowers. He found that the cause was the larval stage of Diplosis sorghicola feeding on the ovary of the individual flowers, which prevented the formation of seed. At that time, he proposed the name of sorghum midge for this insect. It is believed to have come from Africa (Harris 1969).

Early season build-up of the sorghum midge occurs slowly on early plantings of sorghum and grasses, especially Johnsongrass (Young and Teetes 1977).

Several management systems have been developed for the control of sorghum midge. Practices include planting hybrids that bloom uniformly, early planting dates, and control of Johnsongrass flowering and that of other wild sorghums near the sorghum field because they often harbor developing midge larvae. The use of resistant hybrids, natural enemies, and chemical control are the most common practices in an IPM program for control of the sorghum midge.

Theoretically, controlling sorghum midge by early planting dates is the simplest and easiest way (Teetes 1975). This is not always possible due to climatological conditions. For example, you must have a good moisture gradient in the soil to ensure good germination. On the other hand, the presence of excessive rainfall will not allow the farmers to plant at a given time. When planting is delayed and sorghum must be planted because it is still the best alternative, these fields will be threatened by sorghum midge infestation and the use of insecticides is irreplaceable. At this point, knowledge of economic thresholds is very important in deciding whether or not to treat with insecticides.

The use of chemicals is always disruptive in the agroecosystems (Baxendale 1983). Sorghum producers cannot afford several applications of an insecticide, so it is necessary to perform a careful inspection in the field to decide on treatment as well as the type of insecticide that should be used.

With the recent development of computers, the use of mathematical models has made it possible for scientists to simulate some biological processes. Agroecosystems are perhaps the most suitable means to develop and validate these models because the number of variables has been reduced. That is, in the agroecosystem only one variety of a crop usually occurs and it is subject to the same agricultural practices.

To construct a model, the interaction of scientists of more than one discipline, a statistician and an engineer, is desirable.

Insect pest models help farmers to have a better understanding of agroecosystems. They provide them with tools that will increase their chances for success.

Objectives

1. The *Heliothis zea* spring emergence study was conducted to obtain reliable information on the time of adult emergence in two different types of habitat as well as pupal interaction to different soil depths. At the same time, to

determine if it is possible to predict the events of 1984 using the descriptive equation of 1983.

2. To construct a temperature-dependent model for the development of nondiapausing sorghum midge from egg to adult emergence.

CHAPTER II

LITERATURE REVIEW

Models for Insects

The application of computers in biological sciences has allowed researchers to develop complicated models. Models can be descriptive and/or predictive. The first describe by mathematics or by simulation technique, the process associated with a historical population (Fye 1974). A descriptive model becomes a predictive model (Fye 1974) if all possible events have occurred while the information for the model was set up.

The main objective of the predictive model is to foretell what would happen if certain simultaneous events appear.

Modeling a biological process is difficult due to the diversity and complexity of the system.

A good model can tell us when we can expect an event or events in the population dynamics of the species. The great advantage of the model is the absence of retrogression once the basic model is developed.

A disadvantage is that predictions could be made without suitable data for providing predictive capability. In most instances, historical data is needed to improve the accuracy of this tool.

Insect models are used by extension workers and insect management specialists in the design of insect trapping devices as well as for the timing of insect population sampling. Lemon et al. (1977) reported that eight scientists and engineers at four locations were using systems methodology with insect population models.

Usually, to begin the process of description, a measure of growth is related to some driving force. Wanjura et al. (1973) found that, in predicting cotton emergence, this force is temperature. In many cases, models of insects start from the development of the insect under controlled temperatures, assuming that temperature is the main driving force of development.

Sharpe and DeMichele (1977) found that the development of poikilotherm individuals is regulated by a single control enzyme whose reaction rate determines the development rate of the organism, and that the control enzyme can exist in two temperature-dependent inactivation states as an active state. Under this concept, the validity of the linear approximation (day-degree concept) in the mid-temperature range takes place, and sometimes it establishes a low temperature threshold for development and the reduction of the rate development at higher temperature. Schoolfield et al. (1981) modified Sharpe and DeMichele's equation to make it suitable for nonlinear parameter estimation.

Based on the previous approach and using Trichogramma praetiosum Riley, Goodenough et al. (1983) found that the degree day model was much easier to develop and appears acceptable for prediction.

In similar ways, Mellors et al. (1984), Anderson et al. (1982), and Powell et al. (1981), using different species of insects, were able to draw some conclusions in favor of construction of models having temperature as a main factor.

If we establish the fact that insect development is a stochastic process, individuals grown under the same environmental conditions show a great variability in developmental time. Sharpe et al. (1977) proposed that if the rate controlling enzyme in a given population has a random total concentration, a distribution skewed to the longer times results naturally from the transformation of development rate to emergence of development times.

Bollworm Bionomics

The importance of Heliothis zea (Boddie) in agriculture, especially in the southern portions of the United States, has been known for a long time and it is supported by the amount of literature which indicates large volume of research devoted to this insect.

Heliothis zea shows adaptability; therefore, we can find it in different geographical areas as well as on different commercial crops such as cotton, corn, tomatoes, soybeans, grain sorghum and vegetables. Its common name varies according to the crop attacked, but generally it is more widely known as the corn earworm and cotton bollworm.

In the eastern hemisphere exists a comparable species, *Heliothis armigera* (Hubner), whose behavior is closely related to *H. zea*.

In some regions, at least in North America, infestations may develop by one of two different ways -- from overwintering populations, or migration of populations from the southern regions.

The overwintering population is the result of some adverse environmental factors that drive the insect to seek ways of survival (Andrewartha 1952). Physiological changes occur creating a stage called diapause. Diapause can be defined as the state of an insect during which development has been spontaneously arrested and metabolism proceeds at a greatly reduced rate. This is an important adaptation in many insects. It enables them to exist in regions which would otherwise be unfavorable for permanent habitation.

Diapause can be obligate, experienced by uni-voltine insects, where every individual of every generation undergoes diapause regardless of any possible variation in the environment. Diapause can also be facultative, which arises as a response to variation in the environment and is usually present in multi-voltine life cycles where one or more generations has few individuals entering diapause (Andrewartha 1952).

The incidence of diapause increases with the approach of autumn. This increase occurs at the time when temperature is falling, food is scarce, and humidity is less favorable. Generally, diapausing individuals tend to be heavier and have a lower percentage of tissue water than those of an earlier generation resulting in the theory of deficiency of water in the tissue (Andrewartha 1952). The absence of a particular growth promoting hormone, proposed by Wigglesworth (1948), offers another explanation to this phenomena. Meola and Adkisson (1977) suggested that ecdysone production is regulated by temperature in the diapausing pupae.

Lees (1956) indicated that diapause is sporadically independent from temperature, and generally speaking, diapause is suppressed by high temperature and induced by low temperature. Ditman et al. (1940), working with the _H. zea_, found that diapause during the pupal period is caused by low temperatures during the larval period. Another function that is linked with diapause is oxygen consumption, which often drops more than one tenth of the normal value (Lees 1956).

The reduction of water in the insect influences other conditions such as undercooling (Ditman et al. 1943). The undercooling situation enables the insect to survive when it is exposed to subzero temperatures; but Phillips and Newson (1966) found that chilling is not as important for _H. zea_ as it is for other insects.

In a study of diapause in _H. zea_ done by Phillips and Newson (1966), it was found that photoperiod sensitivity is in the last larval instar. It was also found that larval eye spots are present in the postgenal region when pupae are in diapause. When this condition is reversed, those pigment spots migrate and disappear by the fourth day. This is a useful feature for identifying individuals that are in diapause. Benschoter (1968) found that the length of photoperiod had a direct effect on development of both larvae and pupae.

As we stated before, diapause is closely related to temperature. In areas with warm temperatures such as Brownsville and Weslaco, Texas, there are continuous generations; this is based on light trap captures during all months of the year (Snow and Copeland 1971). Nevertheless, Graham and Fife (1972), in an overwintering study done in the Lower Rio Grande Valley, showed that larvae of H. zea collected in mid to late October did not emerge, indicating that they were in diapause.

Wellso and Adkisson (1966) reported the importance of photoperiod to the larval stage for inducing diapause; that is, the larval stage needs to be exposed to a shorter day length than the previous parent and egg stage. This suggests that insects use some unknown system to distinguish between fall and spring. Their study showed that the maximum induction of diapause occurs when there are 12 and 13 hours of light. Fye and Carranza (1973), in overwintering experiments with H. zea in Arizona found results similar to those obtained by Wellso and Adkisson (1966) in Texas, except that the initiation of diapause was somewhat shifted earlier.

The apparent northern limit for overwintering of *H. zea* coincides with a climate where the last spring freeze occurs April 30 (Snow and Copeland 1971). Hardwick (1965), in an analysis made on *H. zea* pupal hibernation, found that with increasing latitude, pupal hibernation becomes more frequent and has longer duration. At this time he developed an equation for *H. zea* by which emergence can be predicted based on latitude.

Termination of *H. zea* diapause is controlled by temperature, not by photoperiod (Roach and Adkisson 1971), (Stadelbacher and Martin 1981). They found that as temperature decreased, the time required for diapause termination increased. Also, the results obtained by Roach and Adkisson (1971), showed that all diapausing *H. zea* pupae resume adult development in less than 105 days when held at 18.5°C under continuous darkness.

A tendency exists for first larvae going into diapause in autumn, to be the last to emerge in spring, suggesting that warmer temperatures at the time when diapause is induced may affect the triggering mechanism for breaking diapause.

Holtzer et al. (1976) conducted a series of diapause experiments using strains of *H. zea* from North Carolina and one from Florida. They reported a geographic variation of diapausing adults. Experimental conditions suggested that genetic plays a role in these effects. Tauber and Tauber (1976) established in a review that in most species with an "overwintering diapause", diapause ends by midwinter rather than spring.

Diapause was divided into three different phases: (1) the initial phase which is the transition period into diapause, (2) the second phase which represents true diapause, and (3) the third phase which is the transition out of diapause. This last or third phase was called "reactivation stage" by Willson et al. (1979). Once again, temperatures above the fixed threshold received by the insect appeared to be the limiting factor.

Studies concerning emergence from diapause have been done by many researchers. Stadelbacher and Martin (1980) concluded that soil temperatures during late winter and spring are responsible for the timing of adult emergence. Holtzer et al. (1976), in similar studies, stated that females emerged in slightly but significantly shorter time than males. Similar results were found by Roach (1981), Lopez and Hartstack (1983), and Slosser et al. (1975).

Ellis (1939) reported emergence of *H. zea* from diapause studies to be greater in Oklahoma than other areas of the country. His research also showed that the average soil depth was less than three inches and that moth emergence started on May 26 and continued until June 20. Young and Price (1977), in an overwintering study conducted in Southwestern Oklahoma under different environments, found that emergence was very low, and that the first adults emerged on May 15 and the first adult captured in a light trap was on May 10. They also concluded that alfalfa, as an undisturbed environment, was the most likely site for overwintering. Agreement with these results on overwintering sites was also found by Roach (1981).

Many researchers who have worked with winter survival of _H. zea_ report a great negative effect from cultural practices (Fyfe and Graham 1966, Roach and Campbell 1983, Roach and Hopkins 1979). Large overwintering populations can be destroyed by plowing and disking. Limited tillage of preferred host plants may allow considerable increase in moth survival.

Lopez and Hartstack (1983) reported that consistently more females than males emerged, associating this effect with the possible intensification of predation of males emerging later than females.

Rainfall is another abiotic factor affecting overwintering survival; therefore, excessive moisture in winter or spring can result in a significant reduction of populations. This was confirmed by Young and Price (1968) when testing the effect of irrigation on _H. zea_, and by Slosser et al. (1975). Eger et al. (1983) stated that survival of non-diapausing pupae was lower than that of diapausing pupae.

Logan et al. (1979) made a descriptive model for predicting spring emergence where the spatial distribution of pupae on the soil and the distribution of soil temperature showed a variation related to the edaphic factor.

Sorghum Midge Bionomics

Sorghum midge, *Contarinia sorghicola* (Coquillet), (Diptera:Cecydomyiidae), is a very well known insect among researchers associated with grain sorghum because its destruction of grain can cause a total loss in the field (Duncan 1981, Sifuentes 1977, Duncan 1980, Young and Teetes 1977).

In the United States, Ball (1908), after having observed that grain sorghum failed to produce seed, found that this damage was caused by the feeding habits of a cecidomyiid described under the name *Diplosis* sorghicola, for which he proposed the common name "sorghum midge".

This insect, a native from Africa, is distributed almost in all grain sorghum producing areas of the world. It is believed that transporation of poorly cleaned grain, which can take diapausing forms (Young and Teetes 1977), is responsible for its distribution.

The adult is tiny, fragile-looking, orange-colored and gnat-like. Its life as an adult is very short. It lives from 24 to 48 hours.

Oviposition periods are generally only one day and occur on blooming sorghum, but oviposition may occur before anthesis. Oviposition in a sorghum spikelet does not reoccur (Wiseman and McMillian 1973). About 90% of egg deposition occurs in the flowering spikelet, 10% in the post flowering spikelet and less than 0.5% in pre-flowering spikelet (Hallman et al. 1984).

The inability to rear this insect on natural and artificial diets in laboratories has delayed its biological studies. The morphological characteristics of the larva were described by Petralia et al. (1979). They believed that the mandibles were important for piercing or rasping plant tissue. The insect also secreted some digestive enzyme that liquified tissue and the larva would insert its mouth parts to feed in the resulting fluid.

Studies of the life cycle have been done by many researchers (Taley et al. 1971, Atherton 1941, Randolph and Montoya 1964, Passlow 1965). They showed a range from 12 to 25 days. Randolph and Montoya (1964) found that over 80% of sorghum midge completed its development in 18 to 21 days. Summer (1975), in an adult emergence study, found that the eclosion peak was 1 to 2 hours after sunrise and that males emerged earlier than females. Male emergence was at 12.8°C to 15.6°C and female emergence was at 18.4°C to 20.1°C. Summer (1975) also reported that females dispersed to susceptible hosts and laid eggs until they died, but males continued to swarm around the panicles from which they emerged.

The abiotic factors, temperature and moisture, have been studied by Fisher and Teetes (1982) and the results agree with those obtained for most insects, that temperature is the main driving force in population dynamics. Rainfall clearly plays an important role in population dynamics also.

Diapause in the sorghum midge is facultative. It occurs in the larval stage and it is known that it can remain in that stage up to four years (Passlow 1965). Diapausing larvae can be found in trash, sorghum fields, unharvested panicles, improperly stored sorghum seed, and panicles of Johnsongrass.

Barward (1981) reported that hibernation of the sorghum midge maggot can occur in sessile and pedicelate spikelets.

The termination of diapause seems to be related to high temperature and relative humidity (Baxendale and Teetes 1983, Passlow 1954).

Infestation in the field depends upon several factors such as the date when panicles emerge from the boot, weather conditions, and proximity to other sorghum fields (Wolfenbarger 1972). Harding and Hogg (1968) indicated that migration of the adult midge appeared to be of little consequence in the development of midge infestations; that is, adult dispersion is accomplished by the wind and not by adult flight.

Early season build-up of the sorghum midge occurs slowly on early planting dates of grain sorghum.

Several methods of controlling this insect are known but their use depends on the circumstances. Early planting is encouraged as much as possible but, sometimes, due to lack of adequate moisture in dryland areas, this cannot be done. In some countries, the lack of availability of equipment to plant large extensions in relatively short periods, makes this practice impossible. Planting hybrids that flower uniformly over a very short period of time also helps to reduce damage. The destruction of Johnsongrass which is the main alternate host is another advisable practice for reducing sorghum midge population. The use of resistant hybrids that can yield more than susceptible commercial types is another desirable practice for grain sorghum (Jotwani 1978, Teetes 1975).

The economic threshold (ET) is defined as the density at which control measures should be applied to prevent an increasing pest population from reaching the economic injury level. In the case of the sorghum midge, an average of one adult per panicle has been determined to be the ET in Texas (Young and Teetes 1977); one adult per every two heads is reported by Duncan (1980) in Georgia; and one adult per panicle (personal observation) in the northeastern part of Mexico. When these population levels are reached, the use of insecticide is the only practice that can be followed. This is the most expensive and ecologically disruptive practice. Since the production of grain sorghum allows only a low profit margin, insecticide applications should be well timed. When sorghum is planted late, the use of insecticides to control heavy midge population levels has been the only effective means of control available (Teetes 1975, Huddleston et al. 1972).

CHAPTER III

MATERIALS AND METHODS

Bollworm Seasonal Fluctuation

H. zea pheromone "cone 75-50" Traps (Fig. 1), described by Hartstack et al. (1979), were used for collecting data on population dynamics of *H. zea*. These traps were provided by the USDA ARS at College Station, Texas. Four of these traps were placed at the Stillwater OSU Agronomy Station, and three at the Perkins OSU Agronomy Station. The bottom of the trap was ca. 1.20 m from the ground; a reinforced metal bar of 12.7 mm in diameter was used to hold the trap at the desired height.

These traps were installed in February, 1982. During that year, it was noticed that strong winds which are common in this area bent the bars, making it difficult to keep the traps straight up, PVC pipe of 44 mm in diameter helped to solve that problem in 1983 and 1984.

All traps were baited with Zea lure® (Herculite Products Co.) the last day of February, and trap inspections were begun on March 1st. Traps were checked and all arthropods were removed. Bollworms were counted and destroyed. Plastic bags of 112.5 lts. capacity proved to be useful as lethal chambers where ethyl acetate was used for killing the moths.

Each year traps were inspected daily until the last day of June, and weekly during July, August, and September. Every four weeks the pheromone Zea lure was changed for a new one and the old one was destroyed.

Bollworm Spring Emergence

For the experiment in 1983, pupae already in diapause were obtained from the USDA Cotton Insect Research Laboratory at College Station, Texas. For the experiment in 1984, larvae of *Heliothis zea* (Boddie) were collected in the cotton field at Chickasha, Oklahoma, in late August 1983, and were kept in the laboratory on artificial diet (Burton 1969). The progeny of this generation was used to induce artificial diapause. To induce diapause, during the first five days after hatching, a photoperiod of 14 hours light and 10 hours dark and a temperature of 80°F were used. After the fifth day, the photoperiod was changed to 10 hours light and 14 hours dark and the temperature was 66°F. Twelve days after pupation, checks for larval eye spot recognition were made on the pupae (Phillips and Newson 1966). This was found to be a reliable method for recognition of individuals already in diapause.

After diapause was confirmed, all pupae were stored at 56°F under dark conditions. Pupae were not sexed.

Two locations were selected at the Perkins Agronomy Experiment Station, 10 miles south of Stillwater. The first location was bare soil which was kept that way for the duration of the experiment. Soil at this location is classified as Farnum Silt Loam. The selected location was well drained.

The second location was an alfalfa field. The spot selected in 1983 was relocated in 1984 within the same alfalfa field because there were problems of excessive moisture in 1983. The soil at this location is classified as Teller Loam. Both places, bare soil and alfalfa, were in a sandy loam soil type.

The diapausing pupae were placed in the soil during the last week of January. The type of cage used to hold them was constructed using plastic cups of 120 ml. (4 oz.) capacity. The lids had been previously perforated with ca. 2 mm (20 1/16") holes. At the center of the lid, a larger hole was drilled and a plastic pipe of 150 mm (6") in length and 12 mm (.5") in diameter was glued (Fig. 2). A piece of cotton ball was introduced at the buried portion of the pipe to serve as a plug and resting place for the pupae. All the plastic materials used were transparent to reduce the effect of temperature.

Four different depths were selected to observe their effect on the emergence: 12.7 mm, 25.4 mm, 50.8 mm and 76.2 mm. Twenty-five pupae were randomly assigned for each depth for a total of 100 for all depths. Each observation (cage-pupa) was separated from the next one ca. 30.48 cm. In this manner, each experiment covered approximately

3.00 x 3.00 m. To set each pupa at the right depth, a piece of reinforced bar of 12.7 mm in diameter, a stop previously welded at the desired length, was utilized to dig the holes.

The cages were observed daily and as soon as the adult emergence started, it was recorded. Weather data was obtained from the weather station located at the OSU Agronomy Station.

Sorghum Midge Nondiapause Emergence

This experiment was done at the Rio Bravo Agricultural Experiment Station located in the northeastern region of Mexico. The hybrid INIA 3006, a commercial variety of grain sorghum widely grown in that area, was used during the years of the experimentation. In 1982, the planting date was April 15, and five panicles were selected. In 1983, the number of panicles involved in the experiment was raised to ten, and the sorghum planting date was April 20. In 1984, two planting dates were used, April 13 and April 27; and five cages were used in each planting date. Selected panicles were infested when they reached 50% blooming.

All the selected panicles were covered with plastic cages before anthesis to avoid any previous infestation or any damage by other insects. The cages were made with screen Lumite® (Chicopee Co.) saran screen 52 x 52 natural. These cages were cylinder-type, 30 cm long and 14 cm in diameter, and an extension of white cloth was added at the bottom to tighten it to the main rachis of the head. The cage was suspended with two poles between the selected plants in order to avoid adding extra weight to the plant.

When the selected plants reached 50% bloom, 10 females were collected early in the morning, at 08:00 and 08:30 CDST from nearby susceptible blooming sorghum panicles, using an aspirator with removable vials. These vials, with the desired number of adults, were inserted into the selected panicles through the bottom of the cage next to the peduncle. The cage then remained on the plants until insect development was completed and adults began to emerge.

A Tangletrap® (Tangle Foot Co.) was used inside the lid to keep all emerged adults in that place. When emergence began, the lid was removed daily, the adults counted, and the lid replaced with Tangletrap again. This method provided information from egg deposition to adult emergence.

CHAPTER IV

RESULTS AND DISCUSSION

Bollworm Seasonal Fluctuation

Pheromone traps are a useful tool for monitoring *Heliothis zea* (Boddie) population, especially in the spring and early in the summer, before large numbers of females begin to compete with the trap (Hartstack et al. 1979). Trap captures are not a measure of emergence since adults can live several days when the temperature is warm, so the catch on one particular night represents the active *H. zea* male population of different ages.

During the year of 1982, the first male *H. zea* was caught at Perkins on March 17 (Table I), and two weeks later we found the first adult at Stillwater. During the month of April, daily average captures ranged <1 adult, but after April 28, catches increased to an average of >1 at both locations (Figure 5).

In Figure 3, we can observe three peaks during the growing season of summer crops in the area of Perkins; however, at the Stillwater location, a different picture was obtained as we can see in Figure 4, where only two peaks are shown.

During 1983, the first capture of an adult male was reported at Stillwater on April 18, and at Perkins on April 27 (Table II). Four peaks of high population can be observed at Perkins (Figure 6).

The number of adult population at Perkins in 1982 and 1983 was similar, except in August, where counts in 1982 were three times as much as in 1983 (Figures 3 and 6). At Stillwater, in 1983, adult population showed high numbers on May 12, June 16, July 9, and August 23 (Figure 7).

In 1984, at Perkins, the first capture was made on April 12; then captures were suspended for a period of time until April 25. After this date, captures were more regular (Table III). The situation at Stillwater was different. The first capture was on March 27; the last 10 days of June showed the highest captures of adults of the whole year (Table III). This year, Stillwater (Figure 8) showed consistently higher populations than Perkins (Figure 9). This was unusual because, as a general rule, between June and August more susceptible hosts are found at Perkins than at Stillwater.

An analysis of Figures 5, 10 and 11 shows that the generation around late August is likely to produce the overwintering population because food becomes scarce and the photoperiod and the temperature are suitable for starting diapause. More research is suggested in this field of study.

Bollworm Spring Emergence

During 1983, the results showed that the first overwintering adult emerged by May 19, and belonged to those that were at 12.7 mm (0.5") depth. The first adult from diapause pupae buried at 76.2 mm (3.0") emerged on May 26. Both are from the bare soil test (Table IV). This result coincides with the results reported by Ellis (1939) at similar depths. However, he did not report whether the emergence came from bare soil or soil covered with vegetation.

Pupae on bare soil at 12.7 mm started to emerge on May 19 and finished by June 4, having the highest percentage of emergence by May 23. The highest percentages for pupae buried at 25.4 mm, 50.8 mm, and 76.2 mm were observed on May 28, 29, and 31 respectively (Table V). Figure 12 shows how percentages of emergence at 12.7 mm and 76.2 mm deep were distributed throughout the julian days on bare soil.

The results from the alfalfa test in 1983 were greatly affected by the excess of moisture, and the population was considerably reduced. This adverse effect was reported previously by Young and Price (1968) and Slosser et al. (1975).

The emergence on the alfalfa test was initiated by June 14, and the emergence from the deepest pupae started on June 23 (Tables VI and VII). Figure 13 shows the same population distributed as percentages on the basis of julian days. Figure 10 displays the seasonal fluctuation of adult bollworm and the appearance of the first emergence of adults from pupae buried at 12.7 and 76.2 mm in both environments in 1983.

If we consider that alfalfa is the most likely environment for the bollworm to hibernate in this area (Young and Price 1977), it is indicated that the most abundant overwintering population emerged by June 23. This is almost one month later than that reported by Ellis (1939).

In 1984, emergence of overwintering pupae on bare soil started by May 15 for pupae buried at 12.7 mm and by May 26 for the pupae at 76.2 mm deep. Pupae buried at 25.4 and 50.8 mm emerged on May 21 and 22 respectively (Table VIII). For the shallower depth, the highest emergence was reached on May 21 (Figure 14). For the 76.2 mm depth similar percentages of emergence were reached by May 29 (Figure 14). Emergence at 12.7 mm lasted 14 days, and 10 days for the pupae at 76.2 mm depth (Table IX).

The pupae buried in alfalfa in 1984, in the same manner as the experiment in 1983, showed that this environment delays emergence for almost two weeks, when compared to bare soil (Table X). In this environment, the same trend as in 1983 was observed in 1984 for 12.7 and 76.2 mm depths. The first overwintering adult emerged on May 28 and June 8, respectively. Table XI shows percentages of emergence obtained from alfalfa, and Figure 15 shows the fluctuation of emergences for the shallowest and deepest treatments. As in 1983, these results suggest that the environment affects soil temperature, which plays an important role in bollworm spring emergence. This agrees with the information reported by Logan et al. (1979) in their descriptive model.

Figure 11 displays the seasonal fluctuation of adult bollworms and the appearance of the first emergence of hibernating populations from pupae buried at 12.7 and 76.2 mm, in both environments.

Table XII shows how the emergence was distributed in 1983 and 1984 through the different dates, without considering either depth or environment. During 1983, only one day had an overlapping emergence in both environments. The emergence of overwintering pupae from bare soil lasted longer than that from alfalfa. In 1984, however, adult emergence seemed to be equally distributed in both environments.

In the past, a close relationship has been found between the pupal hibernation and the latitude. Metcalf and Flint (1939) concluded that it would be difficult for a bollworm to overwinter beyond the 40° latitude. Hardwick (1965) developed an equation by which the emergence of overwintering bollworms can be predicted based on latitude. Keeping this in mind, for Stillwater, Oklahoma, which is on latitude 36°, the calculated earliest emergence date is May 18. In 1983 and 1984, the first emergence was observed on May 19 and May 15 respectively (Table XIII).

If we compare the overwintering adult emergence and the pheromone catches, no defined trend between these two variables was apparent. However, we can observe that high numbers of males were caught in 1983 before the first spring emergence (Table XII). Trap catches in 1983 and 1984 strongly suggest that migrating populations of this insect must play an important role in increasing the population in this area. Further studies are suggested to help determine the contribution of this migration to the population of this area and, finally, to find out its importance in terms of injury to the crops.

When a stepwise multiple regression analysis was used, the adult bollworm was arranged in a cumulative way and the best two variable models found accounted for 87.8% of the variation ($R^2 = 0.8780$) which resulted highly significant ($P < 0.0001$). The variables were environment and julian day, which was used to represent time of moth emergence. The partial correlation between the number of adults (TOTAD) and julian day was 0.90312. For the environment and the same dependent variable it was 0.63544. Also, according to the results from the same statistical analysis, the variable depth did not explain the variation of the emergence.

The adult totals in Figure 16 depicted its linearity when plotted versus julian day.

The following equation developed with information from 1983, gave us an estimated line of total predicted adults.

$$Y = -494.11025+(-32.32441103)+(3.85606225XJD) \qquad (1)$$

Figure 16 shows both populations, the observed and the predicted according to the previous equation.

When the information of 1984 was analyzed statistically, the same stepwise regression analysis was used, and the best one-variable model was found. The chosen variable was julian day and it explained 98.6% of the variation of the experiment this year ($R^2 = 0.9886$) which was also highly significant ($P<0.0001$), and only a minor increase is obtained when more variables are added.

When a general linear model analysis was used, the significance of the variables used was as follows: Environment $P<0.3033$, Depth $P<0.5802$, Degree day $P<0.6348$. The correlation between total number of adults emerged and julian day resulted in 0.9933.

From julian day 149 to 156 in Figure 17, the interruption of the straight trend observed is due to the overlapping of the two environments.

To predict the total emergence of adults in 1984, the equation (1) developed in 1983 was used. This gave us the possibility of validating the model of 1983 which was the main objective of this experiment. Figure 17 shows that when total adult emergence was plotted versus julian days, the model predicted fairly accurately the emergence in the first two weeks. Thereafter, the estimated values were underestimated according to the observed values. In Table XIV, a comparison of emergence of overwintering pupae buried at 76.2 mm in both environments in 1983 and 1984, is shown. If we consider that alfalfa is the most likely place for overwintering in this area, we can expect the emergence of overwintering bollworm in this environment by mid June. This will produce only one or two generations of *H. zea* and it is very likely that the second generation will be the one that will go into diapause again.

In 1983, a population of bollworms obtained from a laboratory condition was used. In 1984, aside from the main experiment, a comparison of behavior of a native population and a laboratory population was conducted. Table XV shows results from bare soil where we observed that native populations started to emerge on May 22, and moths from laboratory populations on May 23, with 40% emergence reached by May 28 for the native population, and on May 27 for the laboratory population.

In the alfalfa test, both populations started to emerge on June 5 (Table XVI), with 50% emergence reached by June 7 for the laboratory population and by June 8 for the native population.

Table XVII shows the two populations. The laboratory population was sexed, showing that females emerged before males in the bare soil test. In alfalfa, emergence from both sexes started on the same date (June 5), but the number of females was significantly higher than the males (Table XVIII). These results agree with those found by Slosser et al. (1975), Roach (1981), and Lopez and Hartstack (1983).

Sorghum Midge Nondiapause Emergence

During 1982, the results of emergence of nondiapausing sorghum midge, *Contarinia sorghicola* (Coquillet), from egg to adult ranged from 11 to 34 days. Table XIX shows that

80% to 95% of emergence was completed in 18 to 21 days. Randolph and Montoya (1964) reported 80% emergence in the same period of time.

During 1983, emergence of nondiapausing adults varied from 12 to 30 days. For the same period of time previously reported in 1982, 92 to 96% emergence occurred in 1984. The cumulative degree days for the same period were from 284 to 321 (Table XX).

For the statistical analysis of this information, we used the stepwise regression analysis, taking degree days, days of emergence, and cloudiness as variables. It was found that degree days was the variable that best explained the biological event studied. Once this was determined, a polynomial model, having degree days as the variable, was used. The model equation for this is:

$$Y = B_0 + B_1 X_1 + B_1^2 X_2 + \ldots + B_n^k X_n + E$$

From the polynomial regression using degree days, we found that linearity has $R^2 = 0.5971$, quadratic increased $R^2 = 0.9086$, and cubic raised R^2 to 0.9074.

Since a polynomial equation including linear and quadratic provided enough explanation of the variability, this equation was used to find the estimated population of adults.

$$\text{Estad} = -821.6765 + 5.9149 \text{xDD} - 0.0081 \text{xDD}^2 \qquad (2)$$

Figure 18 shows the total adults observed throughout the cumulative degree days, and Figure 19 shows the observed total number and the predicted number of adults according to the developed equation.

In the 1984 experiment of sorghum midge, from the first planting date (1984 A), emergence of nondiapausing adults started on day 13 and ended by day 31. The highest average for adults was obtained on the 19th day of emergence. Seventy to 90% of total adult emergence was reached on day 21 to 22 (Table XXI), showing that it took longer than in 1982 and 1983. Results for the test on the second planting date (1984 B), showed that 80% of the total emergence was reached on day 20 (Table XXII); meanwhile, the first test of this year showed only 63% of emergence at the same time. No differences were observed in the amount of degree days at the same time.

Information of both tests from 1984 was used to validate the polynomial model equation developed in 1983, showing, in Figure 20, that it tended to predict fairly well the population of nondiapausing sorghum midge. For the population that emerged early in the season, the model tends to predict higher values than the observed, but at the end of the emergence, the model tends to predict lower population than was actually observed.

If we compare the observed population in the second planting date (Figure 21), we notice that a good estimation of the population can be made only for the population emerged until 290 degree days, which accounts for 70% of the total population.

CHAPTER V

SUMMARY AND CONCLUSIONS

A successful integrated pest management system for keeping populations of Heliothis zea (Boddie) below economic thresholds, requires several strategies. For handling populations of bollworms, the use of pheromone traps provided an excellent method to keep track of the population, especially at the beginning of the season. Another important factor is to know when the emergence of the overwintering populations takes place as well as where they are located. Information on weather data, especially temperature, offers an important tool to explain the above mentioned events.

When a dynamic population study of bollworms was conducted using pheromone traps, it showed that capture of bollworm adults started no earlier than mid-March and no later than mid-April. High captures were obtained around mid-June to mid-July. Another peak for the three consecutive years is also found around mid-August.

The two year study of emergence of overwintered bollworms, under two different environments and at different depths, provided information which suggests that the earliest spring emergence of bollworm at 12.7 mm depth and in bare soil, started on May 19 in 1983 and on May 15 in 1984. The equation used by Hardwick (1965) based on latitude, estimates spring emergence for Stillwater, Oklahoma (36^{o} latitude) by May 18.

The latest emergence in alfalfa for pupae buried at 76.2 mm was on June 27 in 1983, and on June 15 in 1984.

Ellis (1939) reported in an overwintering bollworm study, that pupae at ca. 76.2 mm depth emerged by May 26. This study produced the first adult from pupae buried at 76.2 mm in bare soil, on May 26 in both years.

When the experiment was statistically analyzed, a high correlation was found between adults and julian days (taken at time of emergence), followed by environment as the second most important variable.

An equation described as a multiple linear model having julian days and environment as independent variables, created with the data from 1983, described reasonably well the spring emergence of overwintered bollworms during 1984.

Seasonal fluctuation of the adult bollworm suggests that migration of bollworms occurred at least thirty days before the emergence of the overwintered bollworm.

Emergence from different environments showed that these are significantly different. The latest to emerge were from alfalfa.

An overall picture of the population dynamics and spring emergence suggests that the higher percentages of the next overwintering generations may be from migrating populations. More research on this aspect is suggested.

A successful management of the sorghum midge, Contarinia sorghicola (Coquillet), requires the use of several tactics of control to maintain adult midge populations below the economic threshold level. A need for nondiapausing emergence studies becomes a reality for scheduling sampling procedures and timing insecticide applications.

A three-year study of emergence of nondiapausing sorghum midge was conducted at Rio Bravo, Mexico. Since the success of the experiment depended upon natural populations of sorghum midge, the planting dates of susceptible sorghum hybrids were at the end of April to ensure availability of adults of sorghum midge when needed.

Results of this experiment showed that in 1982, by the 16th day after the eggs were laid, 50% of the emergence was reached. The same percentage was obtained by the 15th day in 1983, and days 18th and 19th in 1984.

A polynomial model based on degree days and developed with information from 1983, predicted fairly well the population for nondiapausing sorghum midge in one test in 1984 (1984 A), and for the other test (1984 B), provided a good estimation for the first half of the emerged population.

Considering the results obtained in this study, the sorghum producer who plants after the recommended planting dates increasing the probability for an outbreak of sorghum midge, will be able to estimate the dates of emergence of sorghum midge populations and take the necessary control measures.

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APPENDIX A

TABLES

TABLE I

AVERAGE OF ADULT *HELIOTHIS ZEA* AT TWO DIFFERENT LOCATIONS FROM PHEROMONE TRAPS IN 1982

Date	Stillwater	Perkins	Overall Mean	Temps. (Perkins) Max.	Min.
March 17		0.6	0.3	74	45
31	0.3	1.3	0.7	69	41
April 05	0.3	0.6	0.4	74	40
12	0.2	0.0	0.1	70	50
13	0.2	2.7	1.3	91	49
14	1.8	1.0	1.4	82	51
15	1.3	3.0	2.0	86	61
16	0.8	0.3	0.6	86	66
24	0.5	0.3	0.4	64	47
26	0.3	0.0	0.1	70	48
27	0.3	1.0	0.6	70	46
28	0.5	0.3	0.4	70	38
May 02	0.3	2.0	1.0	68	47
03	1.8	2.0	1.9	71	57
04	4.3	7.6	5.7	78	49
05	2.8	3.0	2.9	81	62
06	2.5	3.0	2.7	76	45
07	0.5	0.0	0.3	55	37
08	3.3	4.3	3.7	70	49
09	4.3	6.0	5.0	78	53
10	4.3	12.7	7.9	70	58
12	4.3	13.3	8.1	63	55
13	0.5	2.3	1.3	68	56
14	7.3	8.0	7.6	74	51
15	6.3	14.0	9.6	81	53
16	18.0	16.0	17.1	67	50
17	0.8	2.0	1.3	71	54
18	9.3	23.0	15.1	78	58
19	12.5	5.0	9.3	73	57
20	11.5	5.0	8.7	81	56
21	11.5	4.3	8.4	67	56
22	10.0	15.3	12.3	75	56
23	17.8	8.0	13.6	78	57
24	17.3	8.0	13.3	65	55
25	16.8	8.0	13.0	71	53
26	9.8	18.7	13.6	73	55
27	3.8	8.3	5.7	79	57
28	14.3	7.0	11.1	72	61
29	11.0	19.6	14.7	88	68
30	31.3	20.0	26.4	88	55
31	10.3	8.7	9.6	88	55
June 01	0.5	2.0	1.1	65	45
02	13.3	12.7	13.0	71	55

TABLE I (Continued)

			Overall	Temps. (Perkins)	
Date	Stillwater	Perkins	Mean	Max.	Min.
June 03	9.3	12.7	10.7	61	55
04	9.0	12.0	10.3	64	54
05	26.0	49.7	36.1	78	54
06	14.8	16.7	15.6	78	55
07	17.0	22.3	19.3	80	57
08	14.8	20.3	17.1	86	67
09	4.5	6.7	5.4	88	68
10	11.0	5.6	8.7	85	53
11	60.3	39.0	51.1	78	60
12	83.8	62.7	74.7	70	54
13	36.5	42.7	39.1	75	54
14	33.0	41.3	36.6	78	58
15	42.0	46.0	43.7	88	53
16	38.5	44.0	40.8	79	55
17	104.5	47.0	79.9	79	55
18	122.8	49.0	91.1	79	60
19	84.3	50.7	69.9	84	59
20	34.8	28.7	32.1	78	56
21	33.8	28.3	31.4	83	60
22	26.8	25.6	26.3	79	59
23	26.3	25.3	25.9	85	63
24	25.0	25.3	25.1	85	61
25	40.3	28.6	35.3	76	60
26	18.0	14.3	16.4	81	62
27	17.3	28.6	22.1	85	63
28	17.0	31.6	23.3	80	61
29	14.5	30.3	21.3	84	63
30	24.0	38.6	30.3	90	68

TABLE II

AVERAGE OF ADULT *HELIOTHIS ZEA* AT WO DIFFERENT LOCATIONS FROM PHEROMONE TRAPS IN 1983

Date		Stillwater	Perkins	Overall Mean	Temps. (Perkins) Max.	Min.
April	18	0.3		0.1	74	39
	26	0.3		0.1	78	47
	27	3.8	2.7	3.3	82	57
	28	2.3	4.0	3.0	80	56
	29	4.5	7.7	5.9	73	57
	30	6.8	5.0	6.0	83	59
May	01	7.3	5.0	6.3	83	62
	02	6.5	5.0	5.9	84	42
	03	2.3	1.3	1.9	65	42
	04	0.0	0.3	0.1	71	43
	05	30.0	11.0	21.9	83	54
	06	1.8	3.3	2.4	85	62
	07	7.3	7.3	7.3	87	52
	08	7.8	8.0	7.9	75	50
	09	8.0	8.7	8.3	72	46
	10	11.0	13.0	11.9	75	50
	11	10.8	15.0	12.6	69	56
	12	46.8	31.0	40.0	79	63
	13	20.3	9.7	15.7	88	59
	14	4.8	2.3	3.7	78	55
	15	4.8	2.7	3.9	57	43
	16	5.3	3.7	4.6	60	52
	17	16.8	13.7	15.4	69	53
	18	16.8	13.7	15.4	68	50
	19	19.3	15.3	17.6	69	46
	20	17.8	15.3	16.7	74	55
	21	13.3	10.7	12.1	78	55
	22	13.3	11.0	12.3	68	50
	23	11.8	11.3	11.6	82	56
	24	11.3	28.3	18.6	79	55
	25	30.8	33.0	31.7	83	60
	26	37.5	22.3	31.0	83	60
	27	27.8	37.0	31.7	85	63
	28	11.3	9.3	10.4	90	59
	29	11.3	9.6	10.6	90	58
	30	11.8	10.0	11.0	81	50
	31	12.0	10.0	11.1	57	45
June	01	11.8	10.0	11.0	72	48
	02	12.8	9.7	11.4	73	54
	03	13.3	18.0	15.3	80	64
	04	15.8	8.7	12.7	83	60
	05	14.5	8.7	12.0	84	61
	06	17.3	9.0	13.7	80	52

TABLE II (Continued)

Date	Stillwater	Perkins	Overall	Temps. (Perkins)	
			Mean	Max.	Min.
June 07	4.5	1.6	3.3	72	47
08	4.5	2.0	3.4	79	54
09	11.0	4.0	8.0	83	60
10	10.8	3.7	7.7	85	64
11	25.3	19.3	22.7	86	64
12	26.5	19.3	23.4	79	66
13	27.8	19.3	24.1	83	69
14	71.0	54.7	64.0		
15	20.5	17.7	19.3	81	56
16	21.8	22.0	21.9	86	64
17	43.3	49.0	45.7	86	62
18	26.0	36.3	30.4	89	64
19	26.0	36.3	30.4	92	65
20	26.3	37.3	31.0	93	73
21	20.5	31.6	25.3	92	63
22	17.3	54.0	33.0	92	68
23	11.5	56.0	30.6	91	68
24	13.5	57.7	32.4	91	68
25	7.8	35.3	19.6	89	61
26	7.8	35.7	19.7	84	66
27	8.0	34.7	19.4	85	62
28	8.0	35.7	19.9	85	63
29	24.3	43.3	32.4	86	62
30	24.3	46.7	33.9	88	68

TABLE III

AVERAGE OF ADULT HELIOTHIS ZEA AT TWO DIFFERENT LOCATIONS FROM PHEROMONE TRAPS IN 1984

Date	Stillwater	Perkins	Overall Mean	Temps. (Perkins)	
				Max.	Min.
March 27	0.3		0.1	63	43
April 11	0.3		0.1	63	47
12	1.0	2.0	1.4	74	43
18	0.3	0.0	0.1	67	38
19	0.3	0.0	0.1	70	43
20	0.8	0.0	0.4	72	50
21	0.3	0.0	0.1	68	44
22	0.3	0.0	0.1	60	38
23	0.3	0.0	0.1	54	35
24	0.3	0.0	0.1	70	45
25	0.8	0.7	0.7	86	59
26	0.0	0.3	0.1	83	62
27	0.5	1.3	0.9	85	49
28	0.8	1.0	0.9	73	41
29	1.0	1.0	1.0	68	48
30	1.3	2.3	1.7	66	46
May 01	1.5	0.7	1.1	77	44
02	8.3	4.7	6.7	78	48
03	1.8	0.7	1.3	68	54
04	0.3	1.0	0.6	69	45
05	1.3	1.3	1.3	81	51
06	1.3	1.3	1.3	56	54
07	2.0	2.0	2.0	68	52
10	2.5	9.3	5.4	79	55
11	3.5	7.0	5.0	89	64
12	6.5	13.7	9.6	89	57
13	6.5	13.7	9.6	88	68
14	7.0	14.0	10.0	93	65
15	11.0	15.3	12.9	88	57
16	9.8	17.7	13.1	86	58
17	12.3	16.3	14.0	82	54
18	11.5	15.7	13.3	84	56
19	9.3	5.3	7.6	87	61
20	9.5	5.3	7.7	72	58
21	9.5	5.6	7.9	73	57
22	8.0	3.0	5.9	83	61
23	11.3	3.0	7.7	76	56
24	5.3	4.0	4.7	80	56
25	1.3	1.3	1.3	83	67
26	36.8	28.0	33.0	89	55
27	37.0	28.3	33.3	70	54
28	36.8	28.3	33.1	88	51
29	1.8	4.3	2.9	63	40

TABLE III (Continued)

Date	Stillwater	Perkins	Overall Mean	Temp. (Perkins) Max.	Min.
May 30	21.0	23.3	22.0	73	46
31	22.8	18.7	21.0	76	53
June 01	8.3	6.0	7.3	86	60
02	98.8	30.0	69.3	88	61
03	98.8	30.3	69.4	75	58
04	98.8	30.3	69.4	89	62
05	22.5	12.7	18.3	88	66
06	6.0	2.7	4.6	89	63
07	2.5	2.0	2.3	89	64
08	8.3	3.0	6.0	93	74
09	46.8	20.7	35.6	91	71
10	47.3	21.0	36.0	90	65
11	47.3	21.0	36.0	82	64
12	56.5	41.0	49.9	87	66
13	77.0	40.0	61.1	90	66
14	75.0	68.0	72.0	93	66
15	77.0	87.0	81.3	94	70
16	107.0	63.0	88.1	94	74
17	107.5	63.3	88.6	97	68
18	107.5	63.0	88.4	96	69
19	82.3	53.0	69.7	90	72
20	291.8	85.3	203.3	94	68
21	299.3	85.3	207.6	93	70
22	336.0	95.3	232.9	98	70
23	222.7	34.0	141.9	100	71
24	223.3	34.0	142.1	95	65
25	223.8	34.0	142.4	89	59
26	154.0	37.7	104.1	94	63
27	154.0	37.7	104.1	88	64
28	154.7	38.0	104.7	93	59
29	135.8	66.3	106.0	94	62
30	207.5	47.0	138.7	92	60

TABLE IV

HELIOTHIS ZEA EMERGED FROM DIAPAUSE AT DIFFERENT DEPTHS IN BARE SOIL PERKINS, OK - 1983

Date		Depth (mm) (1)			
		12.7	25.4	50.8	76.2
May	19	2			
	20	0			
	21	0			
	22	0			
	23	6	3		
	24	1	0		
	25	3	2		
	26	0	0		2
	27	1	4	2	0
	28	4	5	4	2
	29	3	4	5	1
	30	3	3	3	1
	31	0	1	1	4
June	01	0	1	1	3
	02	0	0	0	0
	03	0	1	3	0
	04	1		1	3
	05			1	1
	06			0	0
	07			0	0
	08			0	0
	09			0	1
	10			0	0
	11			0	1
	12			1	0
	13			1	0
	14				1

(1) 25 pupae were used for each depth.

TABLE V

PERCENTAGE OF *HELIOTHIS ZEA* EMERGING FROM DIFFERENT DEPTHS IN BARE SOIL PERKINS, OK - 1983

Date		Depth (mm)		
	12.7	25.4	50.8	76.2
May 19	8.0			
20	0.0			
21	0.0			
22	0.0			
23	25.0	12.0		
24	4.0	0.0		
25	12.0	8.0		
26	0.0	0.0		10.0
27	4.0	17.0	9.0	0.0
28	17.0	21.0	17.0	10.0
29	12.0	17.0	22.0	5.0
30	13.0	12.0	13.0	5.0
31	0.0	4.0	5.0	20.0
June 01	0.0	4.0	5.0	15.0
02	0.0	0.0	0.0	0.0
03	0.0	5.0	13.0	0.0
04	5.0		4.0	15.0
05			4.0	5.0
06			0.0	0.0
07			0.0	0.0
08			0.0	0.0
09			0.0	5.0
10			0.0	0.0
11			0.0	5.0
12			4.0	0.0
13			4.0	0.0
14				5.0

TABLE VI

HELIOTHIS ZEA EMERGING FROM DIAPAUSE AT DIFFERENT DEPTHS IN ALFALFA PERKINS, OK - 1983

Date	Depth (mm)(1)			
	12.7	25.4	50.8	76.2
June 14		1		
15		0		
16	2	0		
17	0	1	1	
18	2	2	0	
19	1	1	1	
20		0	0	
21		0	2	
22		0	1	
23		0	1	1
24		0	0	1
25		1	0	0
26			1	0
27				1

(1) 25 pupae were used for each depth.

TABLE VII

PERCENTAGE OF *HELIOTHIS ZEA* EMERGING FROM DIFFERENT DEPTHS IN ALFALFA PERKINS, OK - 1983

Date	Depth (mm)			
	12.7	25.4	50.8	76.2
June 14		16.6		
15		0.0		
16	40.0	0.0		
17	0.0	16.6	14.2	
18	40.0	33.3	0.0	
19	20.0	16.7	14.2	
20		0.0	0.0	
21		0.0	28.5	
22		0.0	14.2	
23		0.0	14.2	33.3
24		0.0	0.0	33.3
25		16.6	0.0	0.0
26			14.2	0.0
27				33.3

TABLE VIII

HELIOTHIS ZEA EMERGING FROM DIAPAUSE AT DIFFERENT DEPTHS IN BARE SOIL PERKINS, OK - 1984

Date	Depth (mm) (1)			
	12.7	25.4	50.8	76.2
May 15	1			
16	0			
17	0			
18	0			
19	0			
20	0			
21	6	4		
22	1	1	2	
23	3	3	1	
24	0	4	2	
25	2	0	0	
26	2	3	2	1
27	1	3	3	1
28	1	2	3	2
29		0	5	7
30		3	3	3
31		1	1	2
June 01			2	1
02				0
03				0
04				7

(1) 25 pupae were used for each depth.

TABLE IX

PERCENTAGE OF *HELIOTHIS ZEA* EMERGING FROM DIFFERENT DEPTHS IN BARE SOIL PERKINS, OK - 1984

Date	Depth (mm)			
	12.7	25.4	50.8	76.2
May 15	6.0			
16	0.0			
17	0.0			
18	0.0			
19	0.0			
20	0.0			
21	35.0	17.0		
22	6.0	4.0	8.0	
23	18.0	12.0	4.0	
24	0.0	17.0	8.0	
25	12.0	0.0	0.0	
26	12.0	12.0	8.0	4.0
27	6.0	13.0	13.0	4.0
28	5.0	8.0	13.0	8.0
29		0.0	21.0	29.0
30		13.0	13.0	13.0
31		4.0	4.0	8.0
June 01			8.0	5.0
02				0.0
03				0.0
04				29.0

TABLE X

HELIOTHIS ZEA EMERGING FROM DIAPAUSE AT DIFFERENT DEPTHS IN ALFALFA PERKINS, OK - 1984

Date		Depth (mm) (1)			
		12.7	25.4	50.8	76.2
May	28	3			
	29	0			
	30	0			
	31	0			
June	01	0			
	02	0			
	03	0			
	04	5			
	05	3	3		
	06	3	4		
	07	4	1		
	08	2	1		3
	09	1	3	3	2
	10	1	4	3	1
	11	1	5	4	1
	12		0	1	1
	13		0	3	2
	14		2	2	3
	15			1	2

(1) 25 pupae were used per each depth.

TABLE XI

PERCENTAGE OF *HELIOTHIS ZEA* EMERGING FROM DIFFERENT DEPTHS IN ALFALFA PERKINS, OK - 1984

Date	Depth (mm)			
	12.7	25.4	50.8	76.2
May 28	13.0			
29	0.0			
30	0.0			
31	0.0			
June 01	0.0			
02	0.0			
03	0.0			
04	22.0			
05	13.0	13.0		
06	13.0	17.0		
07	17.0	5.0		
08	9.0	4.0		20.0
09	5.0	13.0	18.0	13.0
10	4.0	17.0	18.0	7.0
11	4.0	22.0	24.0	7.0
12		0.0	6.0	7.0
13		0.0	18.0	13.0
14		9.0	11.0	20.0
15			5.0	13.0

TABLE XII

OVERWINTERING *HELIOTHIS ZEA* EMERGENCE AND PHEROMONE TRAP CATCHES OF ADULT MALES AT STILLWATER, OK

Day of Year	Adults Emerged in Cages		Pheromone Trap Catches	
	1983	1984	1983	1984
May 01			6.28	1.14
02			5.86	6.71
03			1.86	1.28
04			0.14	0.57
05			21.86	1.28
06			2.43	1.28
07			7.28	2.00
08			7.86	0.00
09			8.28	0.00
10			11.86	5.43
11			12.57	5.00
12			40.00	9.57
13			15.71	9.57
14			3.71	10.00
15		1	3.86	12.86
16		0	4.57	13.14
17		0	15.43	14.00
18		0	15.43	13.29
19	2	0	17.57	7.57
20	0	0	16.71	7.71
21	0	10	12.14	7.86
22	0	4	12.28	5.86
23	9	7	11.57	7.71
24	4	6	18.57	4.71
25	5	2	31.71	1.29
26	2	8	31.00	33.00
27	7	8	31.71	33.27
28	15	11	10.43	33.14
29	13	12	10.57	2.87
30	10	9	11.00	22.00
31	6	4	11.14	21.00
June 01	5	3	11.00	7.27
02	0	0	11.43	69.29
03	4	0	15.28	69.43
04	5	5	12.71	69.43
05	2	6	12.00	18.27
06	0	7	13.71	4.57
07	0	5	3.28	2.29
08	0	6	3.43	6.00
09	1	9	8.00	35.57
10	0	9	7.71	36.00

TABLE XII (Continued)

Day of Year	Adults Emerged in Cages 1983	1984	Peromone Trap Catches 1983	1984
June 11	1	11	22.71	36.00
12	1	2	23.43	49.86
13	1	5	24.14	61.14
14	2	7	64.00	72.00
15	0	3	19.28	81.29
16	2		21.86	88.14
17	2		45.71	88.57
18	4		30.43	88.43
19	3		30.43	69.71
20	0		31.00	203.29
21	1		25.28	207.57
22	2		33.00	232.86
23	1		30.57	141.86
24	1		32.43	142.14
25	1		19.57	142.43
26	1		19.71	104.14

TABLE XIII

EMERGENCE OF HIBERNATING *HELIOTHIS ZEA* FROM BARE SOIL PERKINS, OK

Date		Percentage of Emergence			
		12.7mm		76.2mm	
		1983	1984	1983	1984
May	15		6		
	19	8	0		
	21	0	35		
	22	0	6		
	23	25	18		
	24	4	0		
	25	12	12		
	26	0	12	10	4
	27	4	6	0	4
	28	17	5	10	8
	29	12		5	29
	30	13		5	13
	31	0		20	8
June	01	0		15	5
	04	5		15	29
	05			5	
	07			5	
	11			5	
	14			5	

TABLE XIV

COMPARISON OF EMERGENCE OF *HELIOTHIS ZEA* IN DIFFERENT ENVIRONMENTS AT 76.2 mm DEPTH

Date	Percentage of Emergence			
	1983		1984	
	Bare Soil	Alfalfa	Bare Soil	Alfalfa
May 26	10		4	
27	0		4	
28	10		8	
29	5		29	
30	5		13	
31	20		8	
June 01	15		5	
04	15		29	
05	5			
08	0			20
09	5			13
10	0			7
11	5			7
12	0			7
13	0			13
14	5			20
15				13
23		33		
24		34		
27		33		

TABLE XV

EMERGENCE OF OVERWINTERING HELIOTHIS ZEA PUPAE FROM NATIVE AND LABORATORY POPULATIONS IN BARE SOIL IN 1984

Date	Native	Cumulative Percentage	Laboratory	Cumulative Percentage
May 22	1	10		
23	0	0	1	5
24	0	0	1	10
25	1	20	1	15
26	0	0	2	26
27	1	30	3	42
28	1	40	3	58
29	0	0	3	73
30	3	70	2	83
31	0	0	1	89
June 01	3	100	0	0
02			0	0
03			0	0
04			2	100

TABLE XVI

EMERGENCE OF OVERWINTERING *HELIOTHIS ZEA* PUPAE FROM NATIVE AND LABORATORY POPULATIONS IN ALFALFA IN 1984

Date	Native	Cumulative Percentage	Laboratory	Cumulative Percentage
June 05	2	14	7	25
06	1	21	3	36
07	1	28	5	54
08	3	50	2	61
09	2	64	4	75
10	1	71	3	86
11	1	79	2	93
12	2	93	0	93
13	0	93	0	93
14	0	93	1	97
15	1	100	1	100

TABLE XVII

COMPARISON OF EMERGENCE OF TWO OVERWINTERING POPULATIONS OF *HELIOTHIS ZEA* (1) (2) IN BARE SOIL *PERKINS*, OK - 1984

Date	Native	Laboratory	
	Unsexed	Females	Males
May 22	1		
23	0	1	
24	0	1	
25	1	1	
26	0	1	1
27	1	2	1
28	1	2	1
29	0	0	3
30	3	0	2
31	0	0	1
June 01	3	0	0
02		0	0
03		0	0
04		1	1

(1) All pupae were buried at 2.0" depth.

(2) A total of 10 pupae per each treatment was used.

TABLE XVIII

COMPARISON OF EMERGENCE OF TWO OVERWINTERING POPULATIONS OF *HELIOTHIS ZEA* (1) (2) IN ALFALFA
PERKINS, OK - 1984

Date	Native Unsexed	Laboratory Females	Laboratory Males
June 05	2	6	1
06	1	2	1
07	1	3	2
08	3	1	1
09	2	2	2
10	1	1	2
11	1	1	1
12	2		0
13	0		0
14	0		1
15	1		1

(1) All pupae were buried at 2.0" depth.

(2) A total of 20 pupae per each treatment was used.

TABLE XIX

EMERGENCE OF NONDIAPAUSING SORGHUM MIDGE (1)
RIO BRAVO - 1982

Date	Days of Cycle	CDD	Adults (Avge.)	Cum. Percent
July 05	11	186.4 (2)	1.2	1.6
06	12	201.8	13.8	20.4
07	13	216.5	9.2	32.9
08	14	231.2	2.8	36.7
09	15	245.6	2.6	40.3
10	16	260.8	10.8	55.0
11	17	275.8	10.8	69.7
12	18	290.3	10.8	84.4
13	19	306.0	5.0	91.4
14	20	321.0	1.4	93.1
15	21	336.2	1.4	95.0
16	22	351.4	1.2	96.6
17	23	367.4	0.0	96.6
18	24	382.6	0.0	96.6
19	25	397.6	0.0	96.6
20	26	413.3	0.0	96.6
21	27	428.5	0.6	97.4
22	28	442.2	0.4	98.0
23	29	456.7	0.4	98.6
24	30	472.2	0.0	98.6
25	31	487.9	0.2	98.9
26	32	503.6	0.2	99.2
27	33	519.6	0.0	99.2
28	34	524.8	0.6	100.0

(1) Planting date April 15.

(2) CDD taken from June 24.

TABLE XX

EMERGENCE OF NONDIAPAUSING SORGHUM MIDGE (1) 1983

Date	Days of Cycle	CDD	Adults (Avge.)	Cum. Percent
July 04	12	200.6 (2)	6.6	2.7
05	13	215.8	42.6	20.4
06	14	230.0	63.6	46.9
07	15	244.2	53.8	69.3
08	16	258.4	38.0	85.1
09	17	272.6	11.0	89.7
10	18	284.8	6.4	92.4
11	19	297.0	6.4	95.1
12	20	309.2	2.2	96.0
13	21	321.4	2.2	96.9
14	22	334.6	0.4	97.1
15	23	347.8	0.8	97.5
16	24	361.0	0.6	97.7
17	25	375.2	0.8	98.1
18	26	385.4	0.2	98.2
19	27	397.6	1.8	98.9
20	28	410.8	2.0	99.7
21	29	425.0	0.6	99.9
22	30	438.2	0.2	100.0

(1) Planting date April 20.

(2) CDD taken from June 22.

TABLE XXI

EMERGENCE OF NONDIAPAUSING SORGHUM MIDGE (1) 1984

Date	Days of Cycle	CDD	Adults (Avge.)	Cum. Percent
June 27	13	189.3 (2)	1.2	0.4
28	14	204.0	2.0	1.1
29	15	219.7	10.6	4.9
30	16	239.9	43.8	20.4
July 01	17	250.1	19.8	27.4
02	18	265.8	31.4	38.5
03	19	280.0	47.2	55.3
04	20	294.7	24.0	63.8
05	21	309.7	29.6	74.3
06	22	323.6	44.6	90.1
07	23	338.3	14.6	95.3
08	24	352.5	5.6	97.3
09	25	367.2	4.0	98.7
10	26	380.4	0.0	98.7
11	27	393.6	0.6	99.0
12	28	403.8	1.2	99.4
13	29	416.0	0.0	99.4
14	30	428.2	0.2	99.5
15	31	439.9	1.4	100.0

(1) Planting date April 13.

(2) CDD taken from June 14.

TABLE XXII

EMERGENCE OF NONDIAPAUSING SORGHUM MIDGE (1)
1984 B

Date	Days of Cycle	CDD	Adults (Avge.)	Cum. Percent
July 09	12	193.1 (2)	1.4	0.3
10	13	206.3	4.4	1.0
11	14	219.5	26.0	4.9
12	15	229.7	53.0	12.8
13	16	241.9	81.0	24.9
14	17	254.1	96.8	39.4
15	18	265.8	94.6	53.6
16	19	279.5	109.4	70.0
17	20	292.7	72.2	80.8
18	21	307.4	50.4	88.4
19	22	322.1	33.6	93.4
20	23	336.8	15.6	95.7
21	24	351.5	4.8	96.4
22	25	366.2	4.8	97.1
23	26	379.9	5.0	97.9
24	27	393.6	5.0	98.7
25	28	404.8	4.0	99.3
26	29	416.5	3.6	99.8
27	30	429.7	1.2	100.0

(1) Planting date April 27.

(2) CDD taken from June 27.

TABLE XXIII

EMERGENCE OF NONDIAPAUSING SORGHUM MIDGE DURING 1982-1984

Days of Life Cycle		Adult Average		
	1982	1983	1984	1984 B
11	1.2			
12	13.8	6.6		1.4
13	9.2	42.6	1.2	4.4
14	2.8	63.6	2.0	26.0
15	2.6	53.8*	10.6	53.0
16	10.8*	38.0	43.8	81.0
17	10.8	11.0	19.8	96.8
18	10.8	6.4	31.4	94.6*
19	5.0	6.4	47.2*	109.4
20	1.4	2.2	24.0	72.2
21	1.4	2.2	29.6	50.4
22	1.2	0.4	44.6	33.6
23	0.0	0.8	14.6	15.6
24	0.0	0.6	5.6	4.8
25	0.0	0.8	4.0	4.8
26	0.0	0.2	0.0	5.0
27	0.6	1.8	0.6	5.0
28	0.4	2.0	1.2	4.4
29	0.4	0.6	0.0	3.6
30	0.0	0.2	0.2	1.2
31	0.2	0.0	1.4	
32	0.2			
33	0.0			
34	0.6			

* 50% of emergence reached on this day.

TABLE XXIV

AVERAGE OF ADULTS OF SORGHUM MIDGE EMERGED FROM DIAPAUSE FROM TWO ENVIRONMENTS (1)
RIO BRAVO - 1982

Date		Cult. Land (2)	Johnsongrass (3)
March	08		0.3
	12		1.3
	15	1.5	1.6
	17	1.5	0.3
	19	3.0	0.6
	22	2.0	1.6
	24	2.0	1.0
	26	0.5	0.3
	29	0.0	1.0
	31	0.5	1.0
April	02	0.5	1.0
	05	0.5	0.3
	07	0.5	0.0
	09	0.0	0.6
	12	0.0	2.0
	14	0.0	0.6
	16	0.0	0.3
	19	0.0	0.3
	23	0.0	0.3
	26	0.0	0.3
	30	0.0	0.3
May	03	0.0	0.3
	05	0.0	0.3
	07	0.0	1.6
	10	0.0	2.0
	12	0.0	1.6
	14	0.5	2.0
	17	0.0	1.3
	19	0.0	2.0
	24	0.5	0.0
	26	1.0	2.3
	28	0.0	1.0
	31	0.0	0.3
June	07	0.5	

(1) Traps covered with black plastic were used.

(2) Average of 2 traps.

(3) Average of 3 traps.

TABLE XXV

AVERAGE OF ADULTS OF SORGHUM MIDGE EMERGED FROM DIAPAUSE FROM TWO ENVIRONMENTS
RIO BRAVO - 1983

Date		Cult. Land (1)	Johnsongrass (2)
Feb.	29		0.3
March	07	0.5	0.3
	09	0.0	1.0
	11	0.0	0.6
	14	0.0	0.3
	23	0.0	1.0
	28	0.0	0.3
	30	0.0	0.3
April	20	0.5	0.0
May	04	0.0	1.0
	06	0.5	0.6
	09	0.0	1.0
	11	0.0	0.3
	16	0.0	1.0
	18	0.0	0.3
	20	0.0	1.0
	23	0.0	1.0
	27	0.0	0.6
	30	0.0	2.0
June	01	0.0	0.3
	03	0.0	1.6
	06	0.5	0.6
	08	0.0	0.3
	10	0.0	1.0
	13	0.5	0.0
	15	0.0	0.3
	17	0.5	0.3

(1) Average of 2 traps.

(2) Average of 3 traps.

TABLE XXVI

AVERAGE OF ADULTS OF SORGHUM MIDGE EMERGED FROM DIAPAUSE FROM TWO ENVIRONMENTS
RIO BRAVO - 1984

Date		Cult. Land (1)	Johnsongrass (2)
Feb.	20		0.3
	22		0.3
March	12		0.3
	14		0.3
	18		0.3
	21		0.3
	23	1.5	2.6
	25	1.0	1.6
	28	0.5	4.3
	30		0.6
June	01		0.3
	04		0.3

(1) Average of 2 traps.

(2) Average of 3 traps.

APPENDIX B

FIGURES

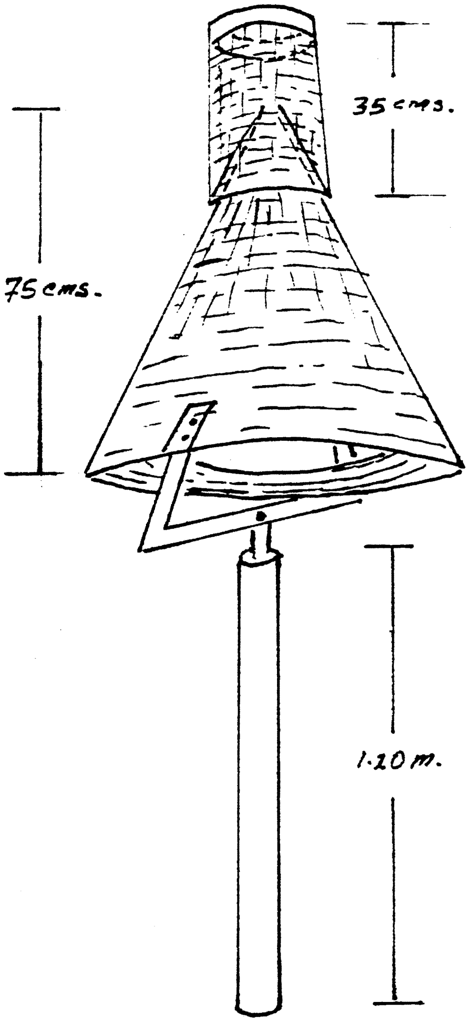

Figure 1. Cone Pheromone Trap Used for Monitoring Male Population

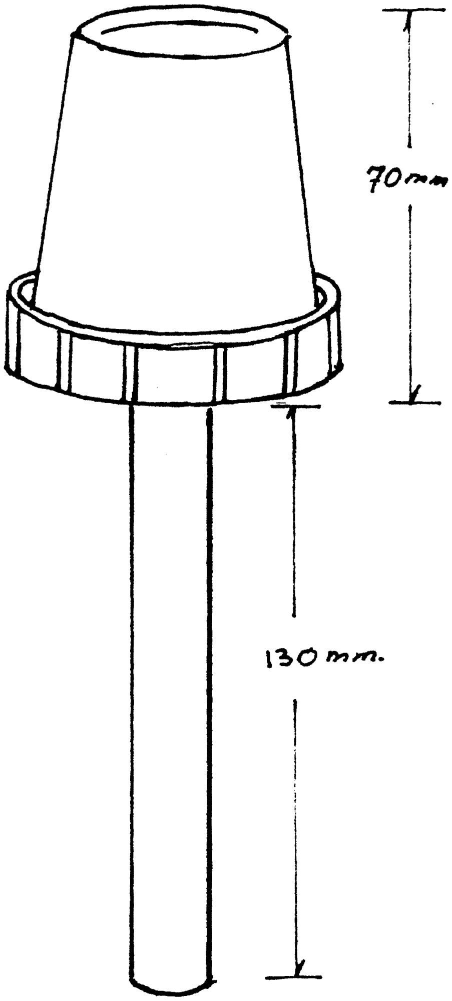

Figure 2. Plastic Cage for Overwintering Emergence Studies of *Heliothis Zea*

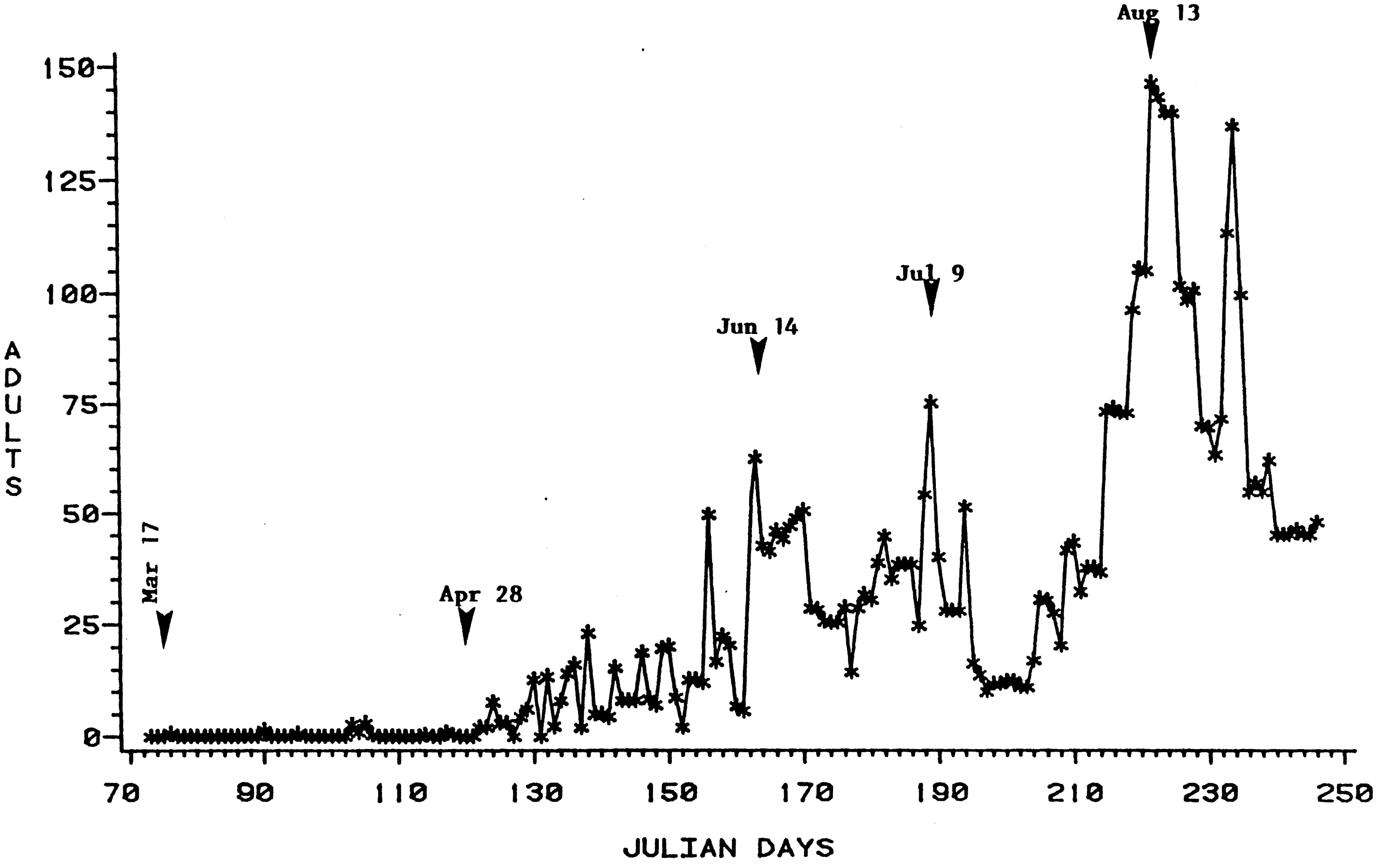

Figure 3. Daily Average of Male Bollworm Adults Captured with Pheromone Traps at Perkins in 1982

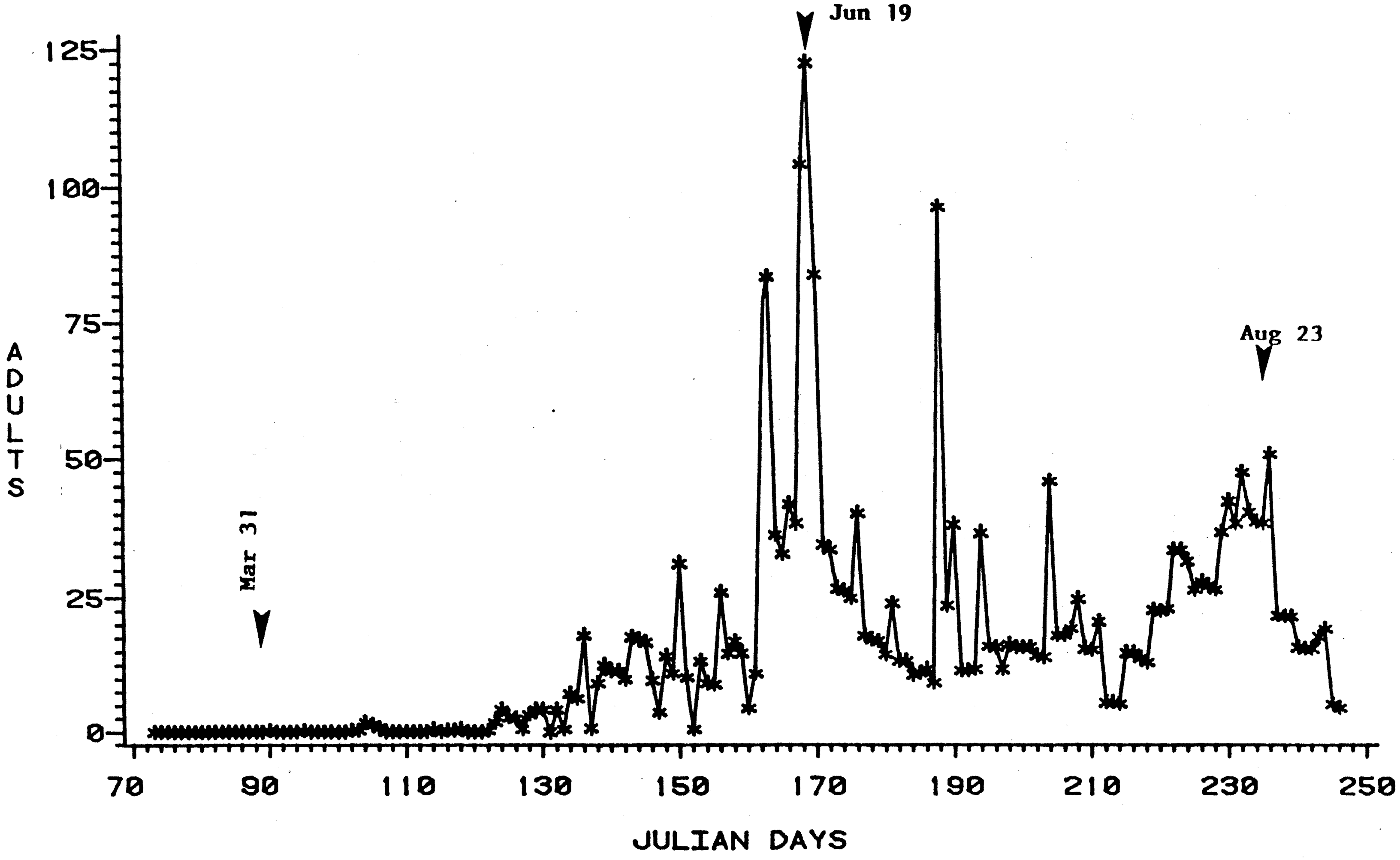

Figure 4. Daily Average of Male Bollworm Adults Captured with Pheromone Traps at Stillwater in 1982

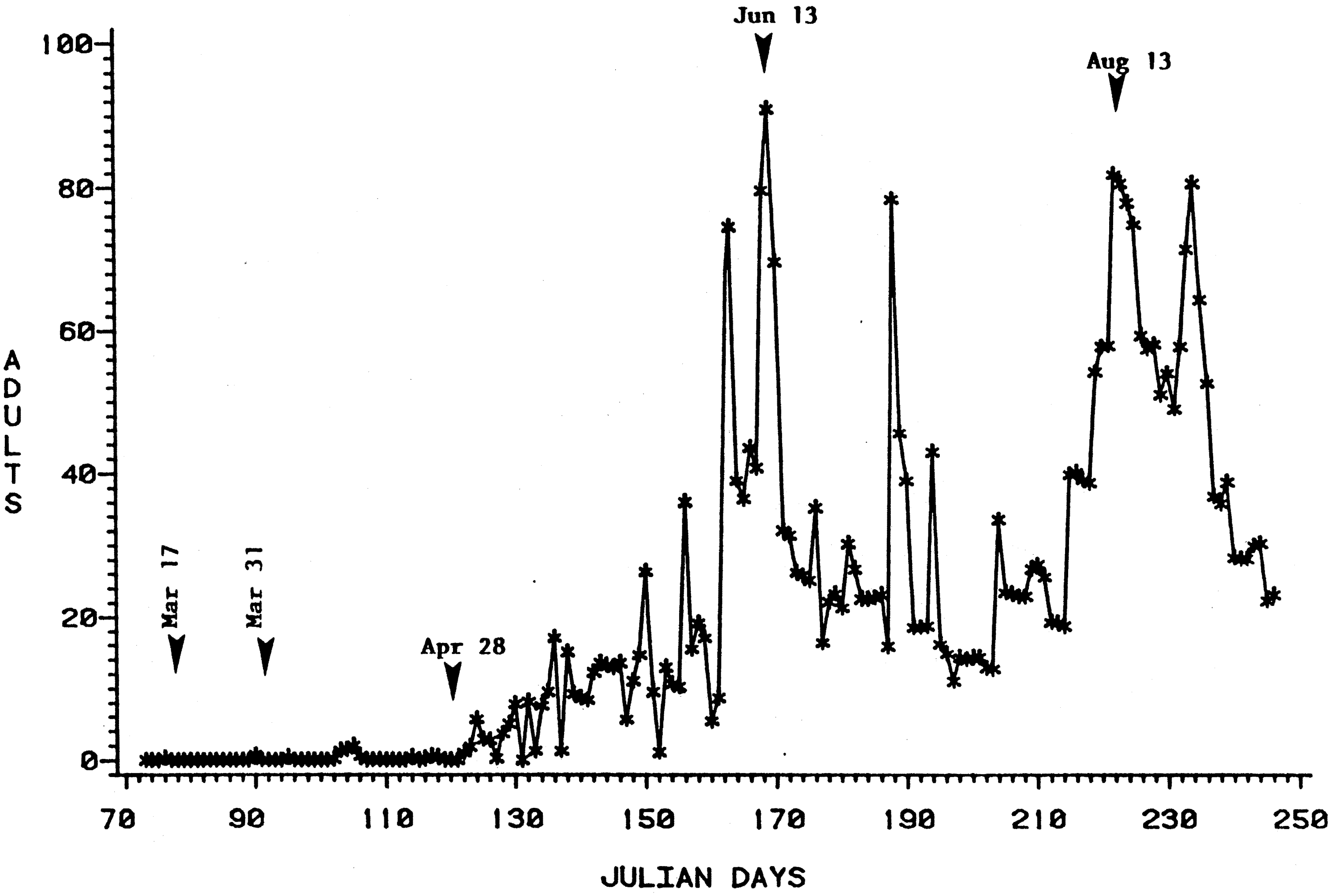

Figure 5. Daily Average of Male Bollworm Adults Captured with Pheromone Traps at Stillwater and Perkins in 1982

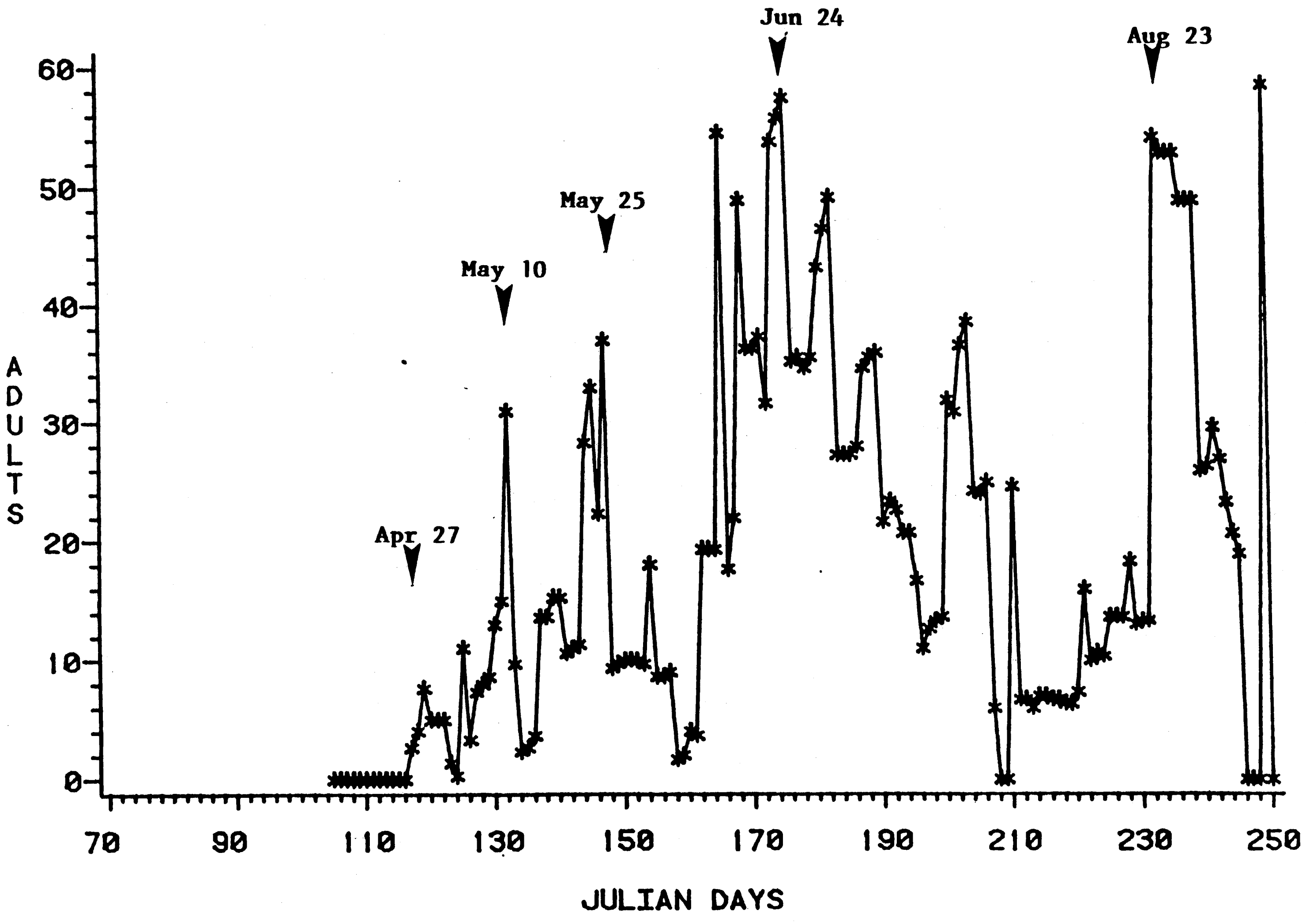

Figure 6. Daily Average of Male Bollworm Adults Captured with Pheromone Traps at Perkins in 1983

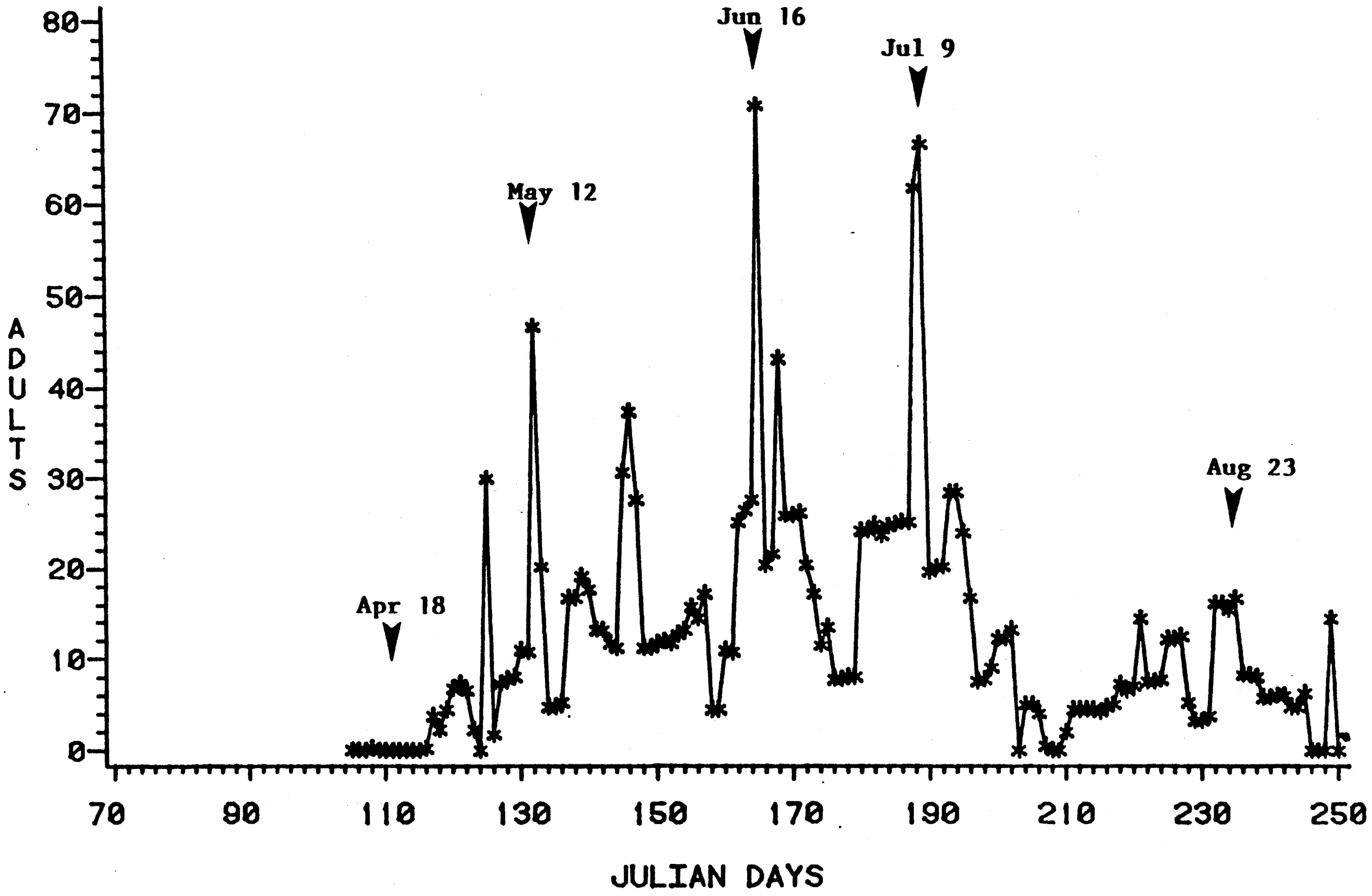

Figure 7. Daily Average of Male Bollworm Adults Captured with Pheromone Traps at Stillwater in 1983

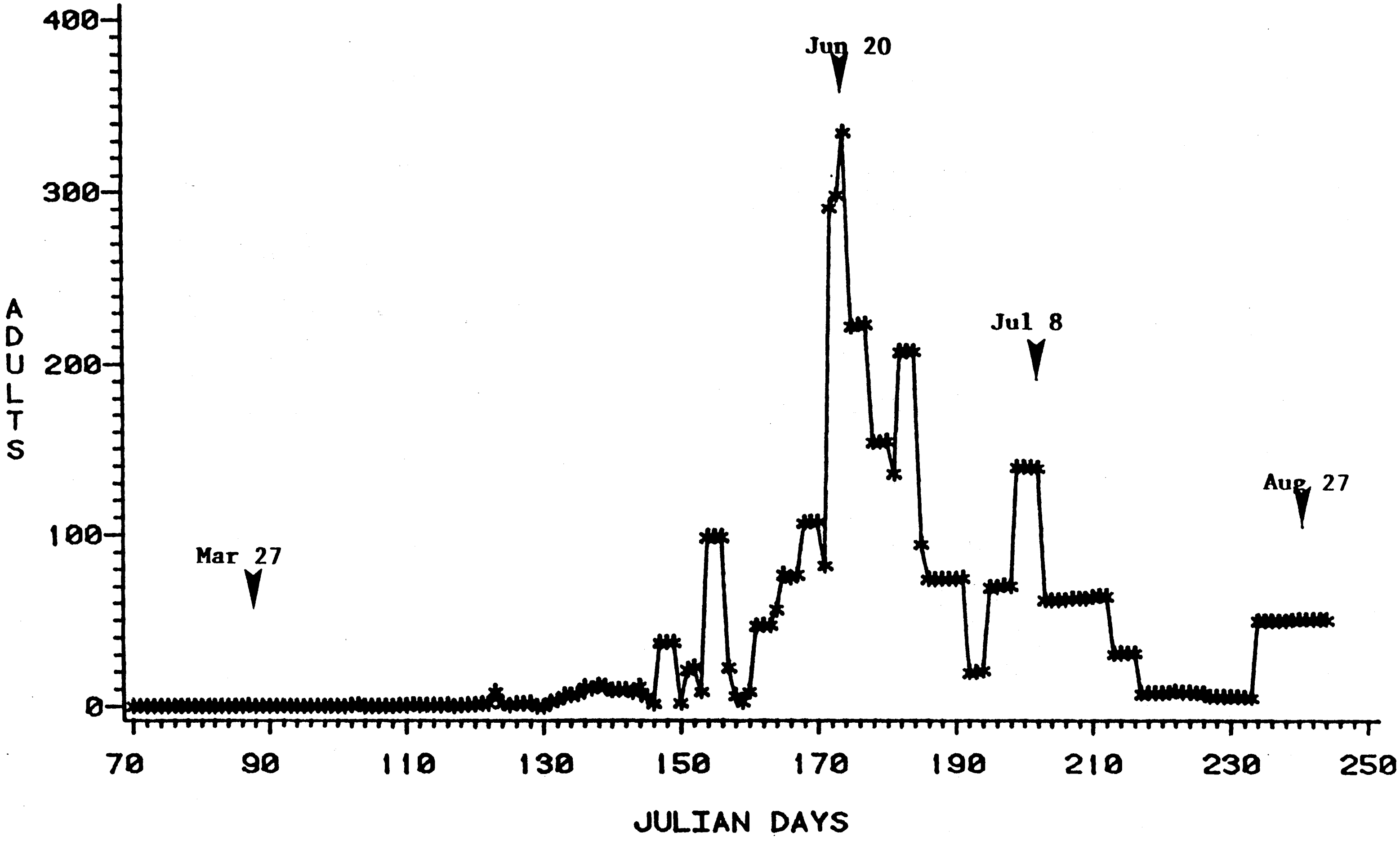

Figure 8. Daily Average of Male Bollworm Adults Captured with Pheromone Traps at Stillwater in 1984

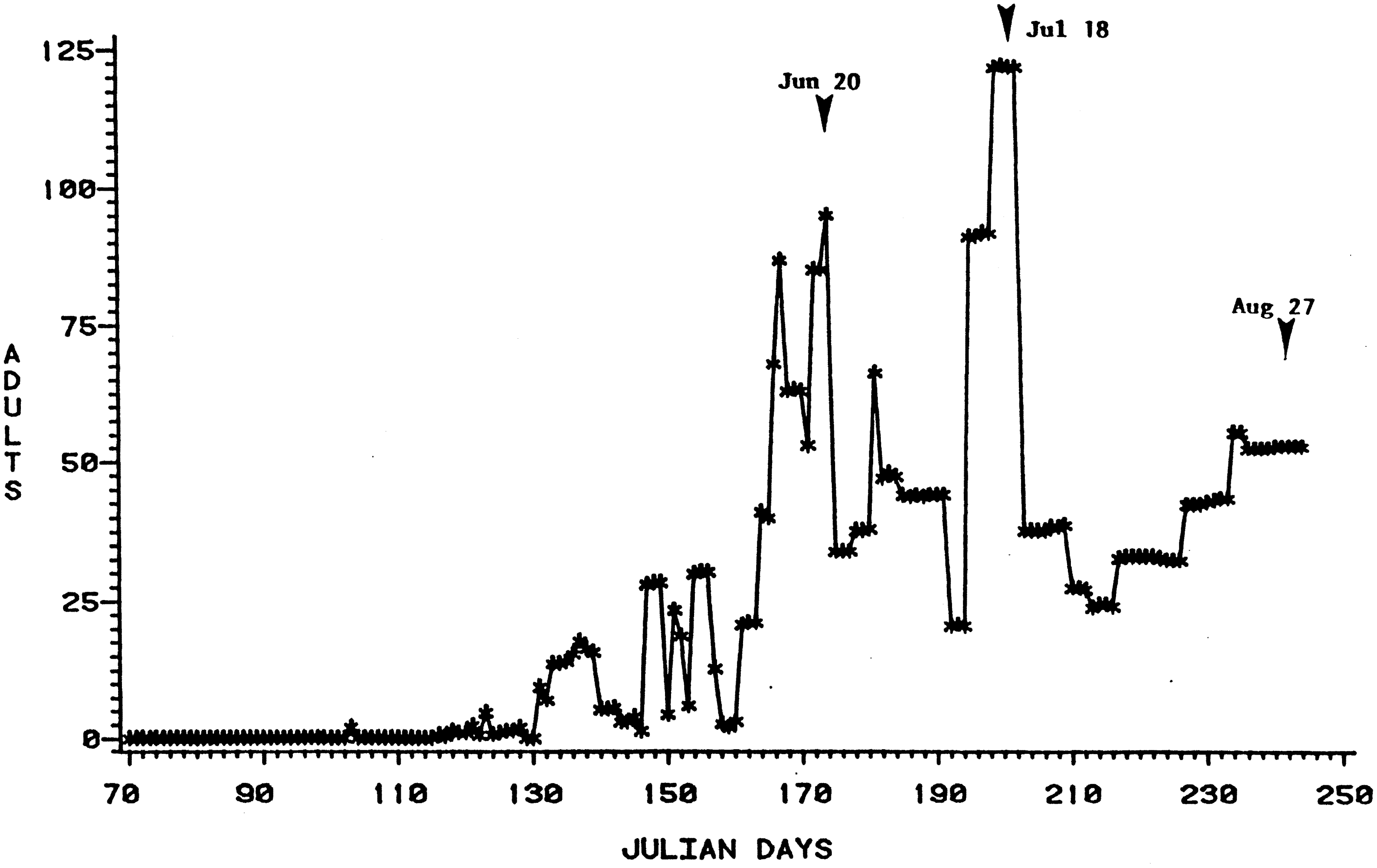

Figure 9. Daily Average of Male Bollworm Adults Captured with Pheromone Traps at Perkins in 1984

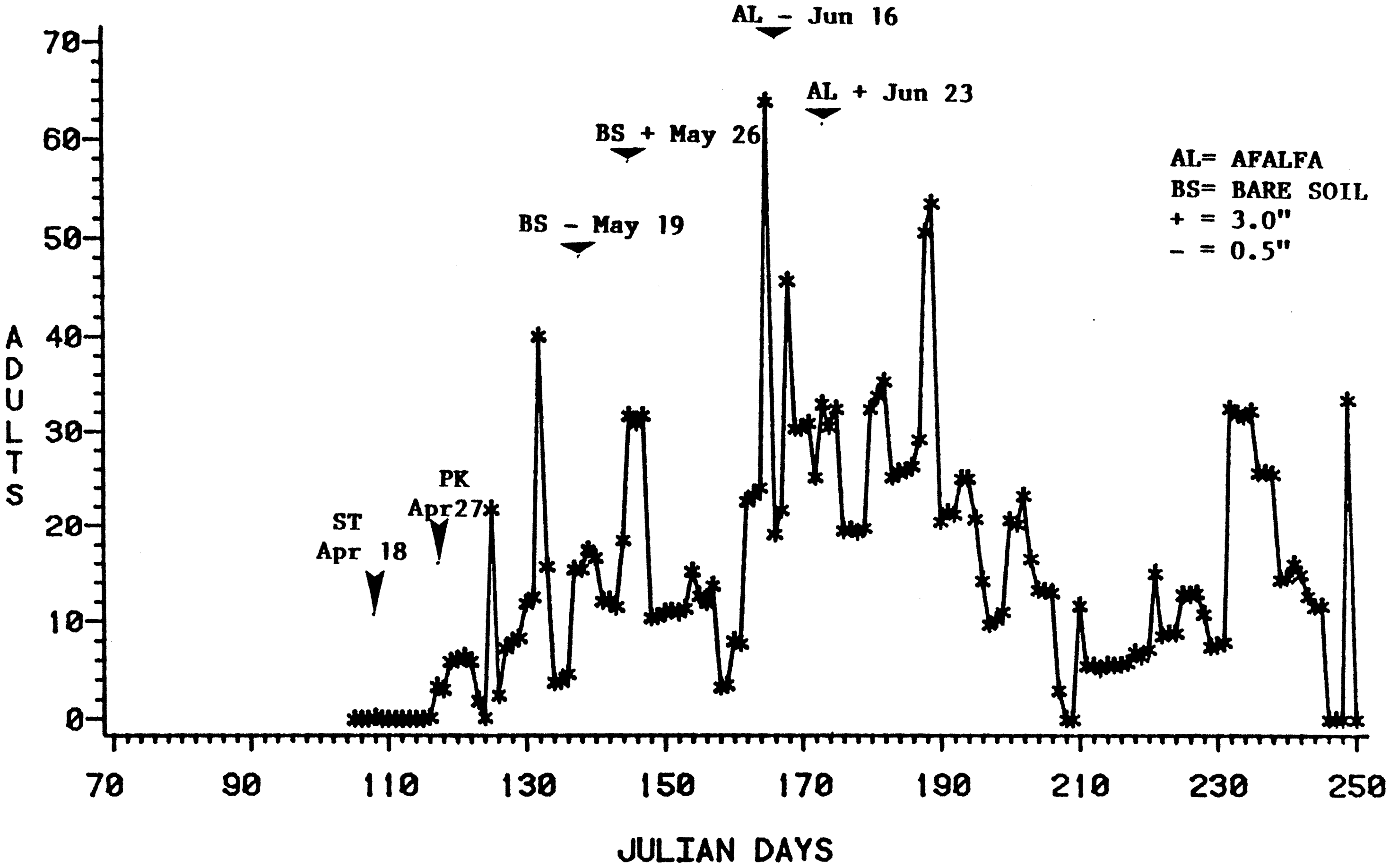

Figure 10. Daily Average of Male Bollworm Adults Captured with Pheromone Traps at Stillwater and Perkins in 1983

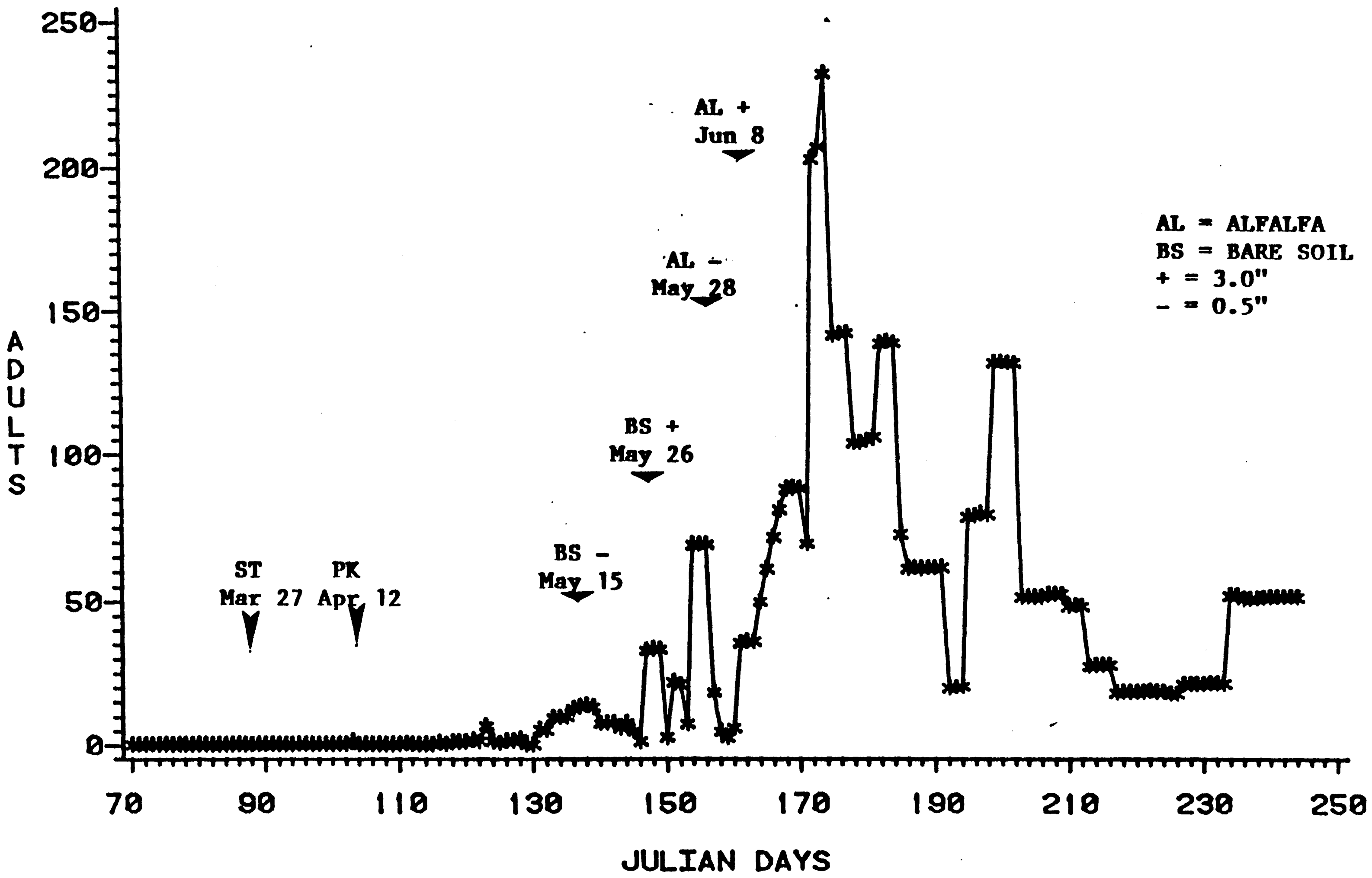

Figure 11. Daily Average of Male Bollworm Adults Captured with Pheromone Traps at Stillwater and Perkins in 1984

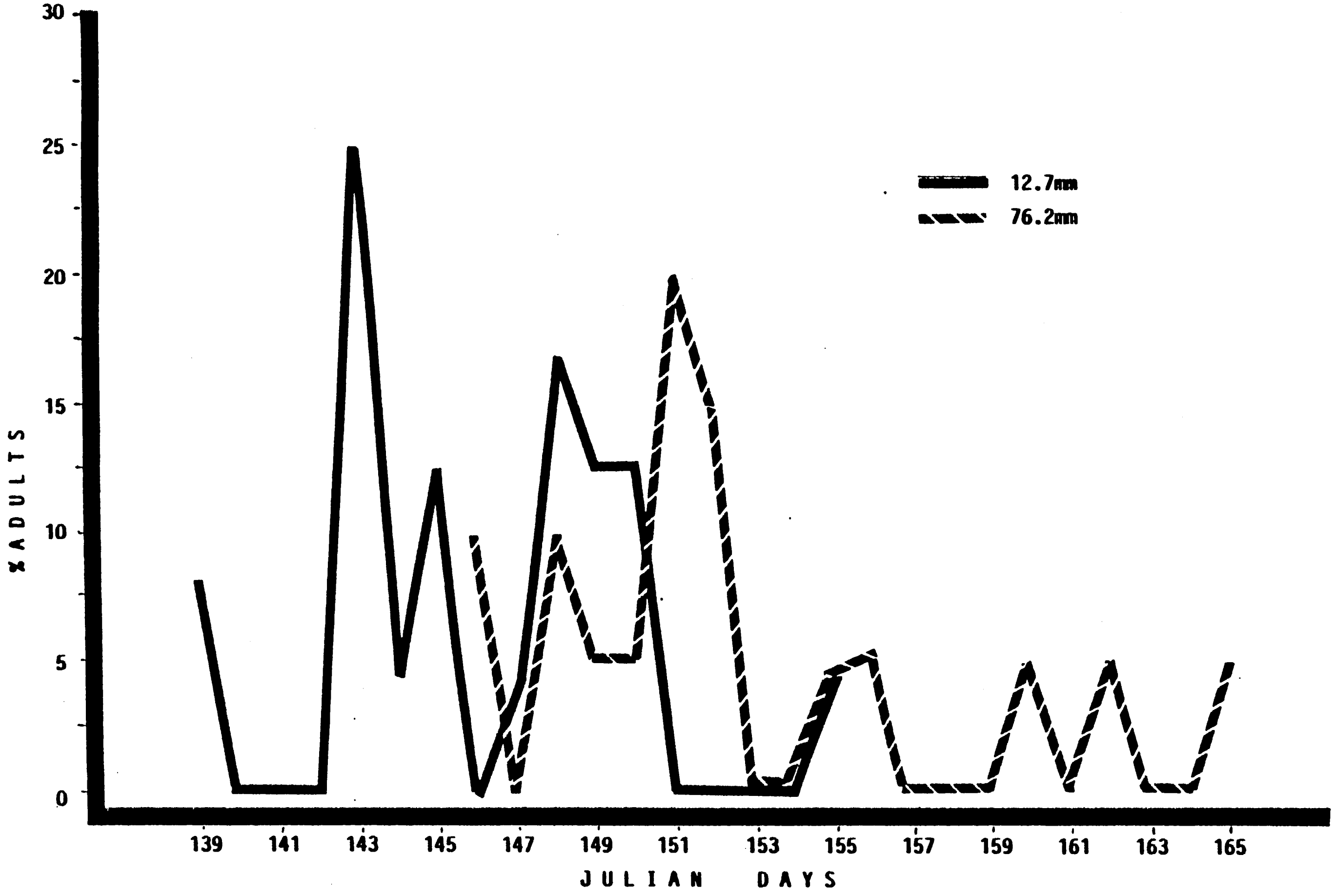

Figure 12. Emergence of Overwintering Bollworm on Bare Soil in 1983

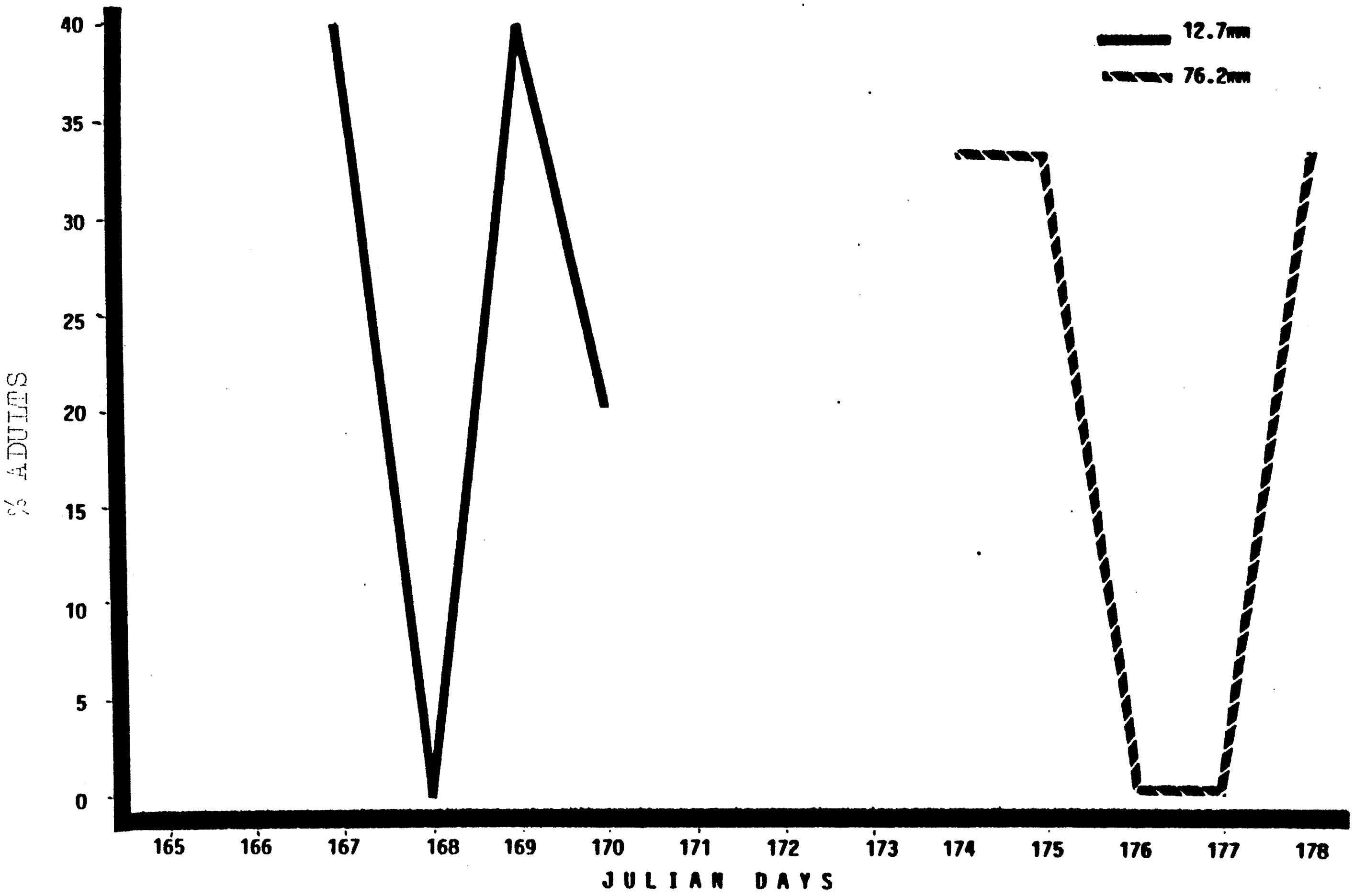

Figure 13. Emergence of Overwintering Bollworm on Alfalfa in 1983

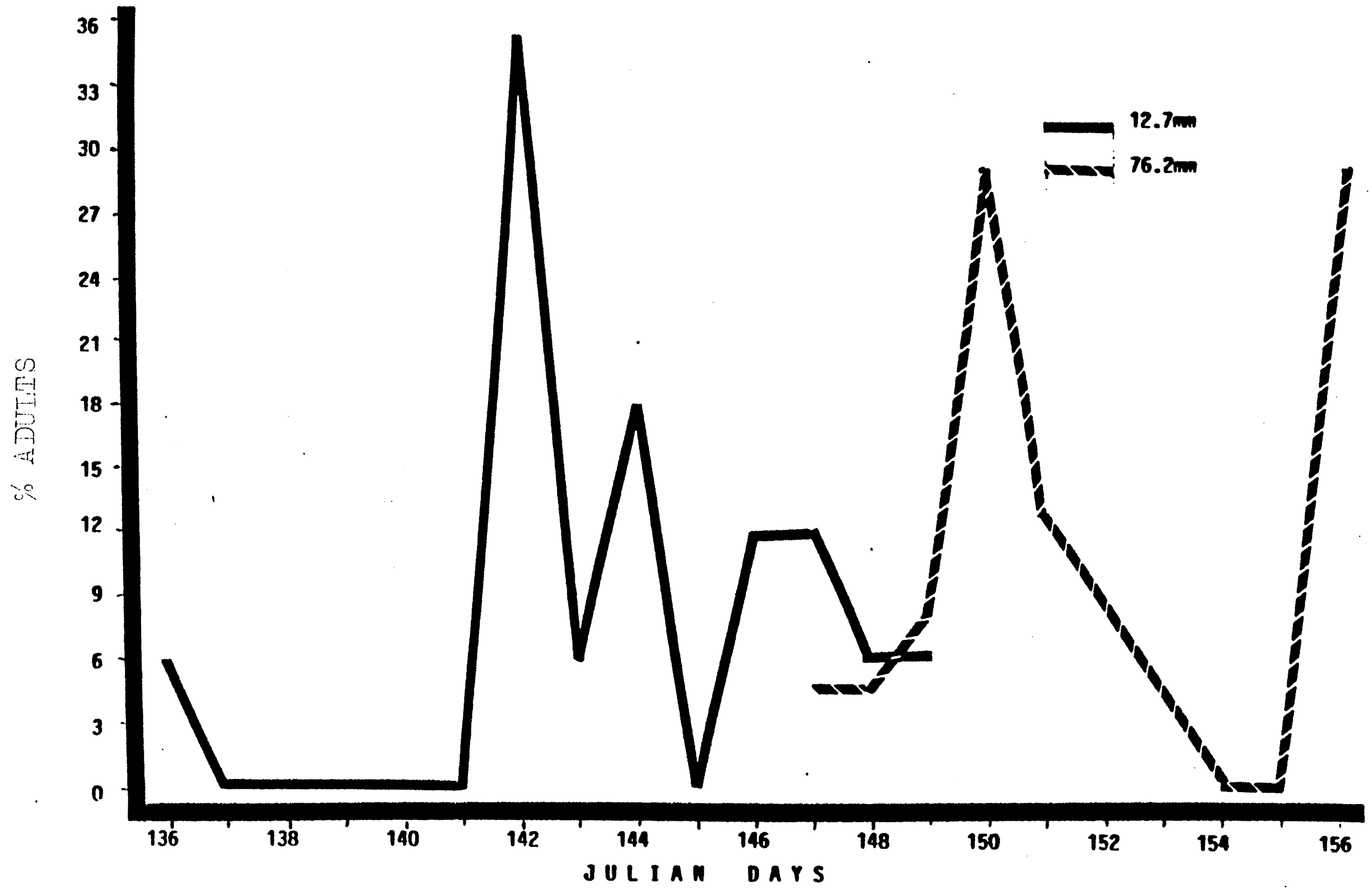

Figure 14. Emergence of Overwintering Bollworms on Bare Soil in 1984

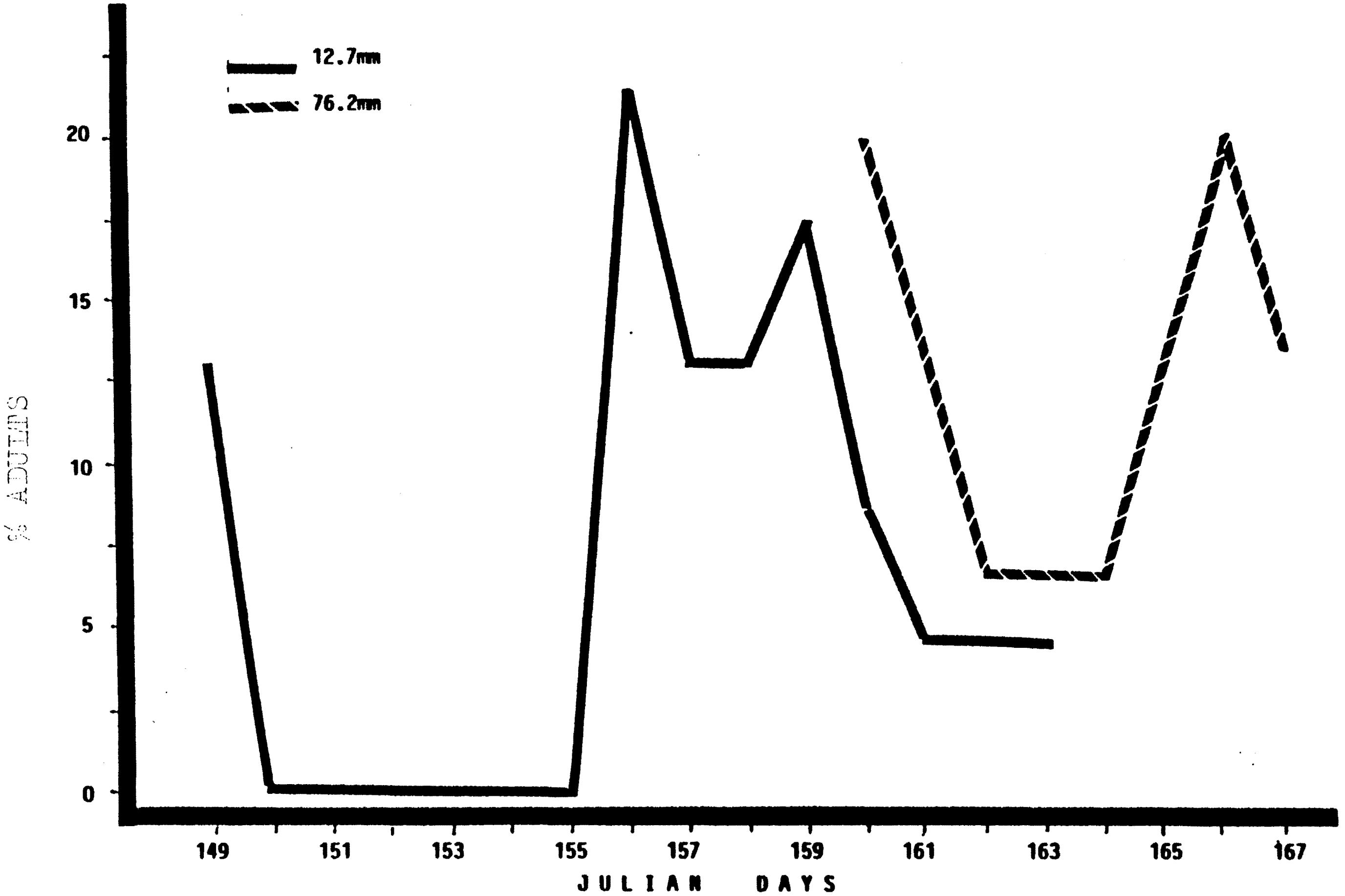

Figure 15. Emergence of Overwintering Bollworms on Alfalfa in 1984

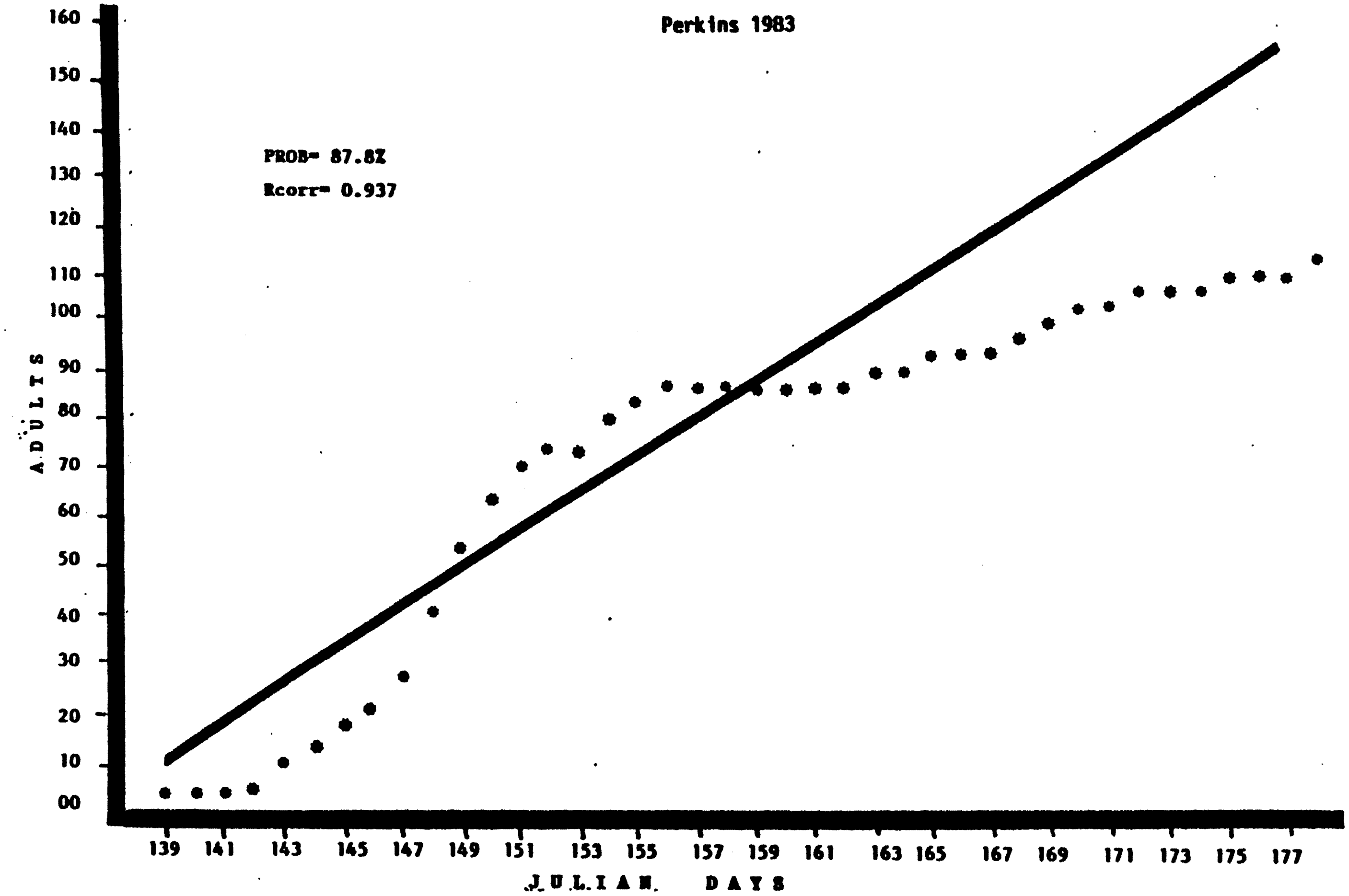

Figure 16. Cumulative Emergence of Overwintering Bollworms (Observed Vs. Predicted) in 1983

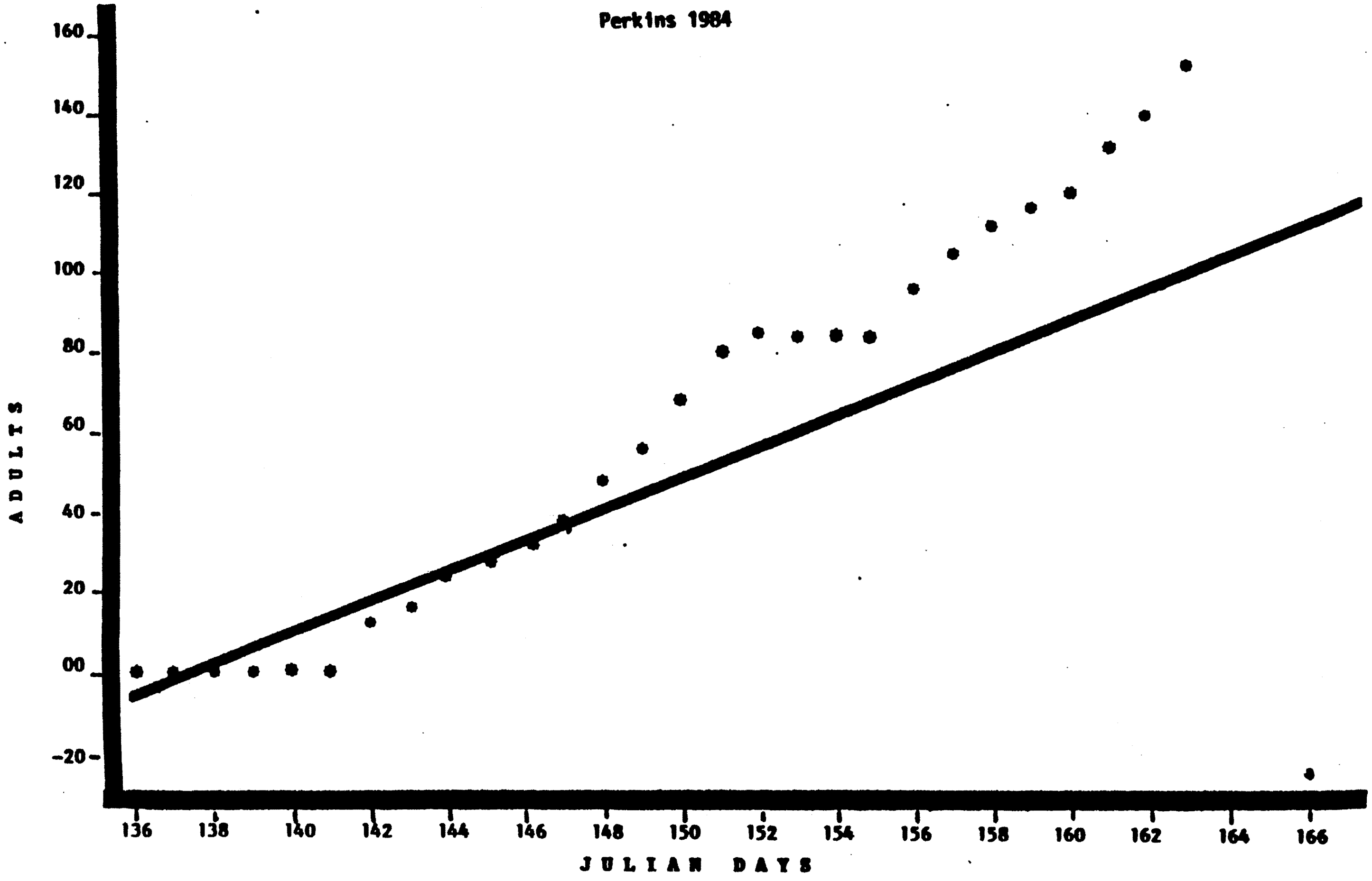

Figure 17. Cumulative Emergence of Overwintering Bollworms Observed in 1984 and its Estimation Based on Model of 1983

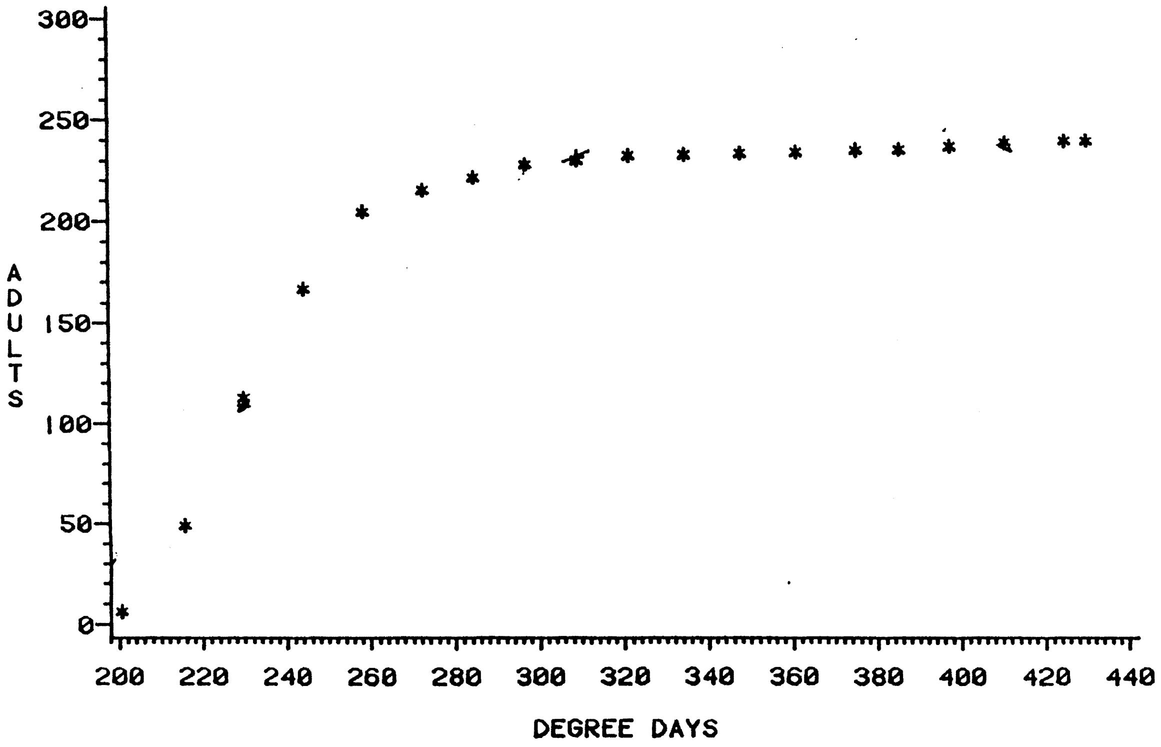

Figure 18. Cumulative Sorghum Midge Adults in 1983

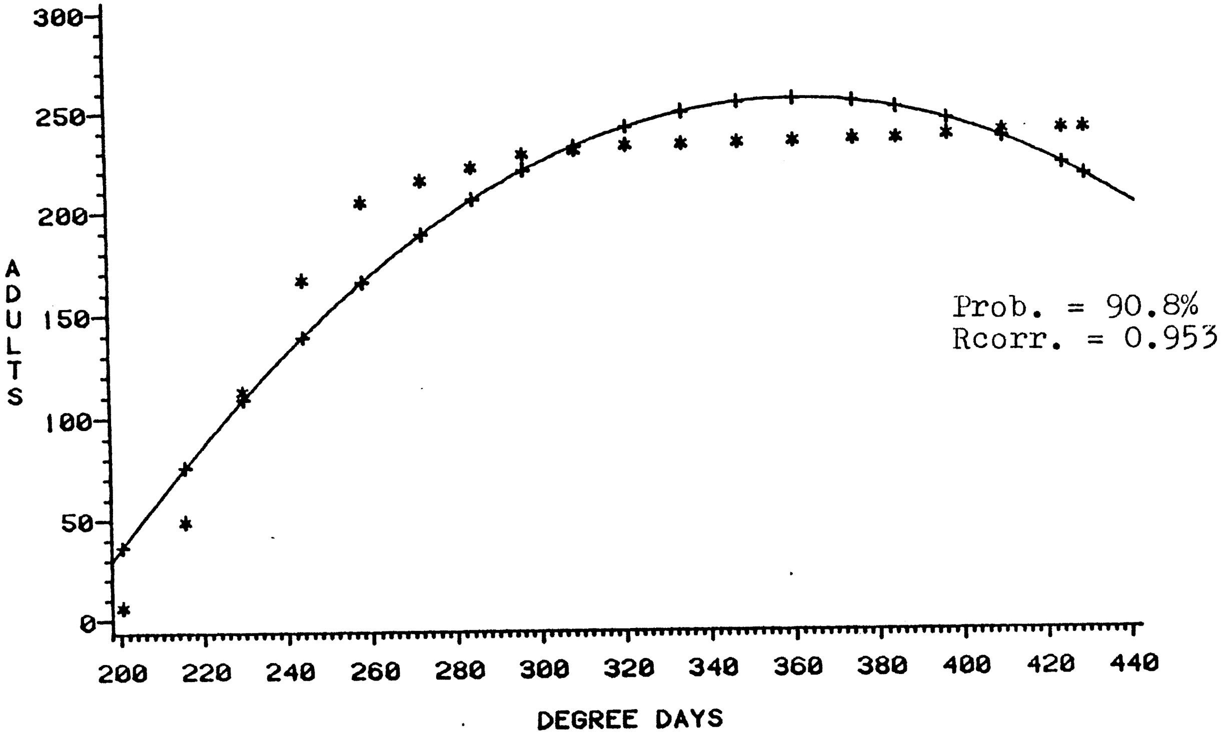

Figure 19. Cumulative Emergence of Nondiapausing Sorghum Midge Compared with the Model Prediction in 1983

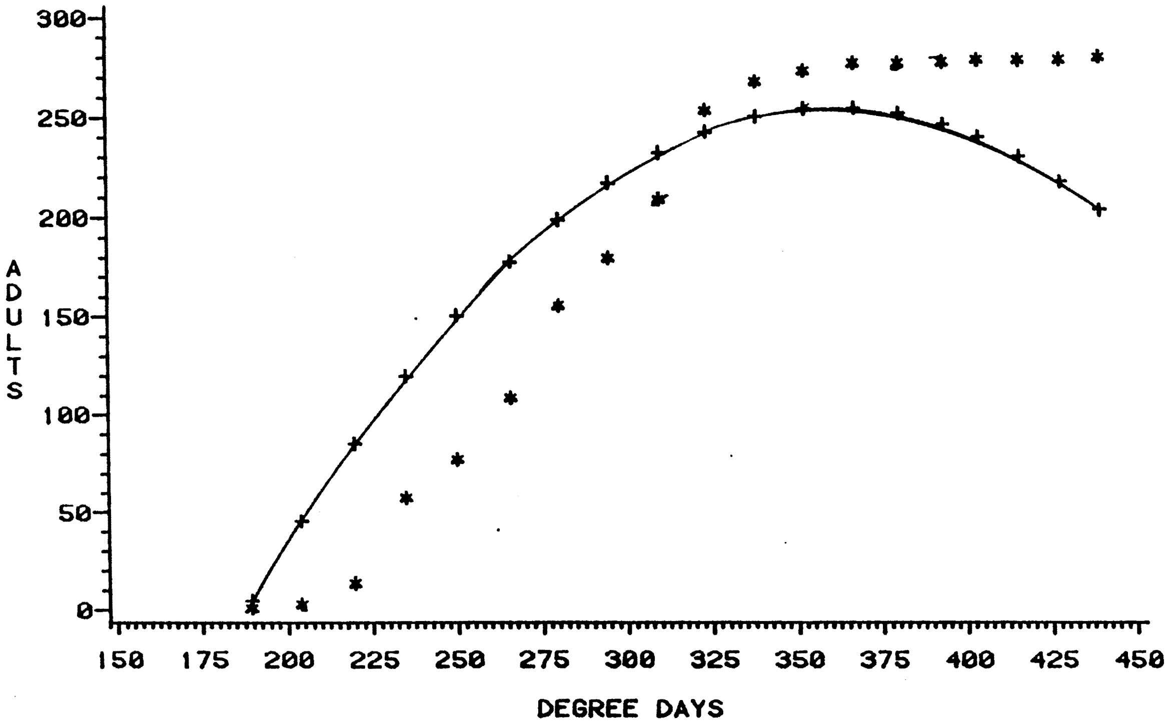

Figure 20. Cumulative Emergence of Nondiapausing Sorghum Midge of 1984 Compared with the Model Prediction of 1983

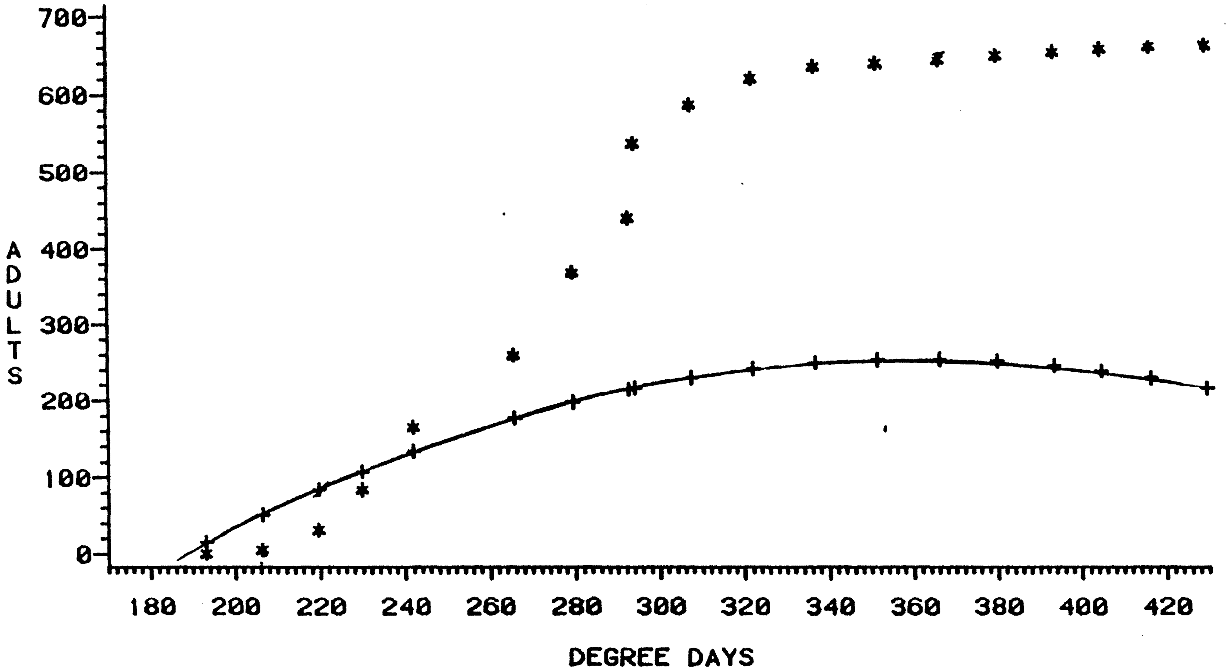

Figure 21. Cumulative Emergence of Nondiapausing Sorghum Midge of 1984B Compared with the Model Prediction of 1983

VITA

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