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I am submitting herewith a thesis written by Lynn J. Snodderly entitled "Effect of Chemical Control on Insect Populations Infesting Tomatoes: With Notes on the Behavior and Larval Development of *Heliothis zea* (Boddie)." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Biology.

Paris L. Lambdin

Paris L. Lambdin, Major Professor

We have read this thesis and recommend its acceptance:

Lyle E. Klostermeyer

Charles D. Pless

Accepted for the Council:

L Evans Roth

Vice Chancellor
Graduate Studies and Research

X

EFFECT OF CHEMICAL CONTROL ON INSECT POPULATIONS INFESTING TOMATOES: WITH NOTES ON THE BEHAVIOR AND LARVAL DEVELOPMENT OF *HELIOTHIS ZEA* (BODDIE)

A Thesis

Presented for the

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Lynn J. Snodderly

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TO KAREN

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ABSTRACT

Of the nine insecticides evaluated Ambush®, Cygon® and Pounce® most effectively suppressed aphid populations on tomatoes. Significantly lower fruitworm damage occurred on the carbamate and synthetic pyrethroid treatments than on the Cygon treatment or the untreated check.

The tomato fruitworm migrated an average of 10 cm a day on tomato plants while 69% of observed feeding occurred on the fruit and 31% on the foliage. Larvae were unable to survive on a diet solely of tomato fruit, while larvae reared on tomato foliage were significantly smaller than larvae reared on artificial diet. Adult females preferred to deposit eggs on the underside of leaves and on fruit.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

In a survey of Tennessee extension agents (Moore and Lambdin, unpublished data, 1977), the tomato fruitworm, *Heliothis zea* (Boddie), the potato aphid, *Macrosiphum euphorbiae* (Thomas), and the green peach aphid, *Myzus persicae* (Sulzer), were ranked as the most important pests to commercial producers in Tennessee. Marcovitch and Robert (1925) rated the tomato fruitworm as the worst tomato pest in Tennessee. Wilcox and Stone (1938) determined that one fruitworm destroyed an average of six fruit. The economic threshold level of the tomato fruitworm is low when compared to other host crops such as cotton and soybeans.

Information concerning fruitworm oviposition and larval development must be provided to establish a field survey method of fruitworm detection. This investigation was conducted to evaluate the efficacy of various insecticides for pest control on tomatoes, and to determine preferred oviposition sites, location and damage of tomato fruitworm larvae.

CHAPTER II

LITERATURE REVIEW

I. Aphid Control

Chemical Control. The green peach aphid, *Myzus persicae* (Sulzer), and the potato aphid, *Macrosiphum euphorbiae* (Thomas), seldom occur in densities which would directly impede tomato plant growth (Shorey and Hall, 1963). The authors did gain an effective reduction in population with a carbaryl dust, and sprays of diazinon and naled. York (1976) found that among the soil systemic insecticides tested Di-syston® and a 4.47 kg ai/ha rate of Temik® 15G controlled the green peach and potato aphid populations. Also Henne (1979) found a 3.36 kg ai/ha rate of Temik 15G to be superior in suppressing green peach aphid populations when compared with two rates of Furadan®.

The synthetic pyrethroids demonstrated good aphid control (Hofmaster, 1978; and Waddill, 1978). Hofmaster (1978) noticed that these compounds reduced potato aphid populations on tomatoes more effectively than on potatoes.

Shorey (1961) stated that an increase in the tolerance of *M. persicae* on peppers to malathion, parathion, diazinon and mevinphos had become apparent. Insecticide resistance in aphids was first reported by Boyce (1928) who induced it in the cotton aphid, *Aphis gossypii* Glover. Insecticide resistance in laboratory and field populations of aphids has been suggested and demonstrated (Michelbacher et al., 1954; Anthon, 1955; Klostermeyer et al., 1956; Landis and Schopp, 1958; Schopp and Landis, 1959; Chapman, 1960; Reynolds et al., 1960; Georghion, 1963; Carnegie, 1965; Needham and Sawicki, 1971; Sudderuddin, 1973; Needham and Devonshire, 1975; Hamilton and Attia, 1978; Attia and Hamilton, 1978).

Natural Control. Aphids serve as food for a great variety of insects, and much attention has been devoted to their natural enemies for control (Hagen and Bosch, 1968). Shands et al. (1972) reported 30 to 56% full season control of the green peach aphid and the potato aphid in potato plots by the predators, *Coccinella septempunctata* L. and *Chrysopa carnea* Stephens. They found that placement of chrysopid eggs in the plots resulted in better control of *M. persicae* than of *M. euphorbiae*. The reverse occurred when eggs or larvae of coccinellids were used. Shands and Simpson (1972) observed that the interplot movement of naturally occurring predators of aphids in small plots made their assessment difficult, and suggested that predator evaluations be conducted in field units.

The activity of the predaceous enemies of *M. persicae* in potato plots was investigated to quantify time-of-day effects on sampling (Mack and Simlowitz, 1979). They found that samples taken from three to seven o'clock p.m. contained the largest numbers for adults of *Hippodamia convergens* Guerin-Meneville and *Colemegilla maculata* (DeGeer), and from two to nine o'clock a.m. contained the largest means for *Chrysopa carnea* Stephens. They found coccinellid adults to be the most abundant predators collected and *H. convergens* to be the most prevalent species.

Certain species of the dipteran family Syrphidae are major enemies of aphids (Bombosch, 1962; Hagen and Bosch, 1968). Bombosch (1963; 1964) found syrphids in the field suppressed outbreaks of *Aphis fabae* Scopoli. However, oviposition by these predators was found to be influenced by the density of aphid populations and the amount of pollen and honeydew in the vicinity of the crop (Barlow, 1961; Wilkening et al., 1961; Sturken, 1964; Peschken, 1965; Tamaki et al., 1967).

Parasitism of aphids by hymenopterous species in the superfamily Ichneumonoidea was known by Leeuwenhoek in 1695 (Hagen and Bosch, 1968). The families Aphidiidae and Aphelinidae were acknowledged to be the most commonly observed cause of natural *M. persicae* mortality in the field (Mackauer and Way, 1976).

Evaluation of parasitism rates in insecticide field trials present complications due to both the general scarcity of free-flying adult parasites following insecticide application (Shands et al., 1965), and population trends in the host-parasite relationship (Hagen and Bosch, 1968; Emden and Williams, 1974).

A prediction system for the green peach aphid designed by Whalon and Smilowitz (1979) to formulate a potato pest management program was based on degree days, aphid immigration, natural enemy pressure and dynamic economic injury and threshold levels established by the authors. The system's first year predictions held close agreement with the first year's observed field population. Moore (1978) presented data concerning interactions of parasites, predators and soil systemic insecticides for aphid control.

Mechanical and Cultural Control. Wolfenbarger and Moore (1968) reported that aluminum mulches and strips placed in tomato plots significantly reduced aphid populations when compared to the control plots. Several investigations concerning the tendency of aphids to be repelled by aluminum mulches are found in the literature (Kring, 1964; Moore et al., 1964; Smith et al., 1964a; Smith et al., 1964b). Iark and Smith (1976) reported that the numbers of *M. euphorbiae* colonizing tomato plants were greater on plants spaced at one meter intervals than those spaced at 0.5 m intervals.

II. Tomato Fruitworm

The tomato fruitworm, *Heliothis zea* (Boddie) (=*armigera*), is considered to be among the most destructive of tomato crop pests (Metcalf et al., 1962; Oatman and Platner, 1971; Creighton et al., 1971; Creighton et al., 1973; and Ba-angood, 1977). Metcalf et al., (1962) stated that 5 to 25% of the yield in commercial tomato-growing areas are frequently lost due to the damage by *H. zea*. Marcovitch and Robert (1925) considered the tomato fruitworm as the worst tomato pest in Tennessee and recommended applications of lead arsenate for control.

Early Chemical and Cultural Control. In Florida, Rolfs (1893) reported 50% fruitworm damage to tomato fields, and suggested that corn be interplanted as a trap crop. Early investigations utilizing corn as a trap crop produced varied results (Quaintance, 1896; Watson, 1914; Marcovitch and Robert, 1925; Morril, 1925; White, 1939; Marcovitch and Stanley, 1941; and Pepper, 1943).

Marcovitch and Stanley (1941) observed that the lowest percentage of damaged fruits occurred on plants treated with a bait of cornmeal and 4% cryolite when compared to lead arsenate, copper, and a check plot.

DDT to Present. Michelbacher et al. (1948) demonstrated the effectiveness of certain chlorinated hydrocarbons applied to tomato plots in California. Barbers (1953) reported the tomato fruitworm was not responding to the chlorinated hydrocarbons as in the past in North Carolina.

Papers concerning lepidopteran resistance to DDT and related insecticides (McEwen and Chapman, 1952; Ivy and Scales, 1954; Lindquist and Dahn, 1956; Gaines, 1957; Chalfant and Chapman, 1958; Harcourt and Cass, 1959), in addition to the growing concern of the biomagnificational properties of these compounds which could drift to hay and pasture (Middlekauff et al., 1963), inspired field trials of alternative insecticide controls. Certain organophosphates, carbamates, and a microbial, *Bacillis thuringensis* Berliner (BT), were evaluated by Middlekauff et al. (1963), for control of caterpillars attacking tomatoes. They found carbaryl to be effective against the fruitworm. Shorey and Hall (1963) evaluated similar compounds for their effect on pest and beneficial species within tomato plots. BT exhibited fair control for several foliage feeding caterpillars, but fruitworm control was eratic. They also stated that parasitic Hymenoptera populations were lower in all treated plots than in the check plots. Harding (1971) evaluated thirteen chemicals and two formulations of BT for control of tomato insects. Phosvel®, Azodrin® and Monitor® gave the most effective fruitworm control. Creighton et al. (1971) applied treatments as sprays, dusts and baits including formulations of nuclear polyhedrosis virus obtained from *H. zea*. Their data indicated highly effective control of the tomato fruitworm with a spray of DDT and a spray mixture containing 44% carbaryl and 11% methyl parathion and with baits incorporating Sevin® or Gardona®. Nuclear polyhedrosis virus failed to protect the tomato fruit effectively. Creighton et al. (1973) determined that sprays of leptophos, methomyl and carbaryl plus BT and baits containing methomyl and carbaryl plus BT were effective as conventional sprays of DDT for control of the fruitworm. Kouskolekas (1976) evaluated eight insecticides for fruitworm control and concluded that Orthene® was the most effective compound, whereas diazinon gave poor results. York (1976) stated that excellent fruitworm control was achieved with Furadan, Curacron® and Orthene. Kennedy (1976) found Pydrin® and Azodrin performed more effectively than carbaryl for fruitworm control. Ba-angood (1977) obtained fruitworm control with Gardona.

Data from insecticide trials in Australia indicated that Orthene, Lannate® and Thiodan® were as effective as DDT for the tomato fruitworm (Smith, 1978). Attri et al. (1978) reported that phenthoate was significantly inferior to carbaryl for the control of *H. zea* on tomatoes. Kushwaha and Pal (1978) evaluated the persistance of carbaryl and Thiodan for fruitworm control, and found that residues of both compounds were below the fruitworms' tolerance limit within six days after application.

Recent reports indicate that excellent fruitworm control was obtained with various synthetic pyrethroids (Hofmaster, 1978; Kennedy and Wade, 1978; Kouskolekas and Hollingworth, 1978; Sorensen, 1978; Chalfant, 1979; Kouskolekas, 1979; Sorensen, 1979; Wadill, 1979; Wade and Kennedy, 1979; York and Walker, 1979).

Wade and Kennedy (1979) observed that a new carbamate, Larvin®, gave good fruitworm control, and reports by Chalfant (1979) presented data which support this observation.

Low Economic Threshold. Creighton et al. (1973) stated that tomato crops destined for the fresh market must be entirely free of fruitworm damage before they are accepted. An economic threshold was established for the tomato fruitworm in California at 0.25% infestation of green fruits or an ultraviolet-light-trap catch of five or more adults in two to three consecutive days (Lang and Kishiyama, 1978).

All tomato production in Tennessee is destined for the fresh market (USDA, 1978). Because the relative cost of fruitworm control is small when compared to the gross return of the crop (Fery and Cuthberth, 1973; Wellik et al., 1979), fresh market growers give little concern to alternative control measures.

Biological Control. Oatman and Platner (1971) evaluated mass releases of *Trichogramma pretiosum* Riley, an egg parasite of the fruitworm, as a possible control agent for *H. zea* on processed tomatoes.

For over two years, a 36% reduction of the damaged fruit resulted. Effective reductions in fruitworm damage were observed in Russia by three releases of *Trichogramma evanescans* Westwood for each generation of the fruitworm (Nasretdinov, 1978).

Plant Resistance. Plant resistance is the property that enables a plant to avoid, tolerate or recover from injury by insect populations that would cause greater damage to other plants of the same species under similar environmental conditions (Kogan, 1975). Reed et al. (1972) implicated 2,4-dihydroxy-7-methoxy-1, 4-benzoxazine3-one (DIMBOA), a compound found in ether-soluble extracts of certain corn lines, as an antibiotic resistance factor which influenced *H. zea* populations on corn. Maysin, a flavone glycoside, isolated from corn silks of the exotic strain Zapulote Chico, was shown to severely retard the growth of *H. zea* when incorporated into the artificial diet of the insect (Waiss et al., 1979). The authors suggested that the presence of this compound could be related to the natural resistance of corn against *H. zea*.

Phenetic resistance relates to morphological or structural plant features that impair normal feeding or oviposition by insects or contribute to the action of other mortality factors (Kogan, 1975). Widstrom et al. (1979) observed an apparent association between leaf trichomes and oviposition on corn by *H. zea* and suggested the association could be an evolutionary phenetic resistance response.

Canerday et al. (1969) observed that certain tomato cultivars differed in degree of fruitworm injury and noted that small-fruited processing cultivars were less susceptible than fresh-market cultivars.

There was a negative correlation, however, between fruit number and damage which could indicate that the differences between cultivars may have been caused by a dilution factor rather than true resistance. Fery and Cuthberth (1973) subjected several plant variables to a multiple regression analysis to determine the relative importance of the characteristics found to be associated with fruitworm damage. They found that vine size was negatively associated with fruitworm damage and accounted for 61.2% of the variation from their model. A total of 1,030 accessions of tomato were evaluated for resistance to the tomato fruitworm (Fery and Cuthberth, 1974a). Fruitworm damage among the accessions ranged from 13.1 to 77.3%. Fery and Cuthberth (1974b) investigated plant density in relationship to fruitworm damage and found a positive association between plant density and fruitworm damage with an increase in damage from 31.4 to 67.1% when plants were spaced 300 cm to 18.75 cm apart. Fery and Cuthberth (1975) reported an antibiotic factor in the leaves of *Lycopersicon hirsutum* Humb and Bonpl. and *Lycopersicon* f. *glabratum* C. H. Mull which was extractable with ethanol and lethal to larvae fed an artificial diet containing the extract. The authors concluded that this antibiosis factor could be bred into existing lines of *L. esculentum.* Campbell and Duffey (1979) isolated the alkaloid, α-Tomatine, from tomato foliage. Amounts of α-Tomatine equal to the concentration found in tomato foliage were incorporated into an artificial diet and fed to *H. zea* larvae. *Hyposoter exiguae* (Viereck), an ichneumonid parasite of the *H. zea* larvae, was toxified by the alkaloid. The parasites exhibited a prolonged larval period, reduced percentage of pupal eclosion, and shortened adult longevity.

Wilcox et al. (1956) stated that parasitization of the larvae of the tomato fruitworm by *H. exiguae* was of no value during the time that the fruit was present, since the larvae were not killed until after they had infested the fruit. The parasite cocoons were often present in the fruit; their presence being equally as objectionable as the larvae.

Documentation of the tomato fruitworm's behavior on its host is rare. Marcovitch and Robert (1925) observed under field conditions that the eggs were deposited mainly on the leaves. Wilcox and Stone (1938) observed that a single tomato fruitworm injured an average of six tomatoes during its development. Wilcox et al. (1956) published the most comprehensive study of the oviposition and early instar behavior found in the literature. They observed that most of the eggs were deposited on the under side of the leaves while none were observed on the fruit. They found in a laboratory study that after 24, 48, 72 and 96 hours respectively 2.5, 20, 40 and 100% of the larvae reached the fruit. The mean larval period was observed to be 30 (21-44) days.

More recently, Ongoren et al. (1977) reported that female *H. armigera* oviposited on the leaves, stems and fruits of tomato plants. Harcharan and Gurwattan (1977) observed that female *H. armigera* laid eggs on leaves, buds, flowers and fruit. The authors reported that young larvae fed on flower buds and tomato fruit. Ramos and Morallo-Rejesus (1978) observed that *H. armigera* larva showed variation in color and markings when fed tomatoes as compared to cotton or corn. Stoeva (1978) reported that larvae developed most rapidly when reared on corn and beans as compared to cotton, tobacco, and tomatoes. Doss (1979) confirmed this observation, and reported that the average duration of the larval stage was 21.4 days when reared on cotton, 15.0 days when reared on soybeans, 19.0 days when reared on corn and 23.9 days when reared on tomatoes.

CHAPTER III

MATERIALS AND METHODS

I. Field Trials

Six-week old tomato seedlings (cv. Walter) were transplanted, 21 April 1978 and 2 May 1979, into Holston loam soil at The University of Tennessee Plant Science Field Laboratory in Knox County, Tennessee. The plants were spaced 45.7 cm apart and rows were 101.6 cm apart. Treatments included the carbamates Ficam®, Larvin and Sevin; the organophosphates Bolstar®, Cygon, Knockout® and Mocap-plus®; the synthetic pyrethroids Ambush and Pounce. All were foliar applied except Mocap-plus which was soil incorporated. Rates used in the tests are given in the tables. Treatments were replicated five times in 1978 and four times in 1979 in a randomized complete block design. In both years, blocks were separated by 3.1 m alleyways (Fig. A-1, Appendix). Twenty-four hours prior to transplant, the systemic insecticide was soil incorporated to a depth of about 15 cm by a rotary tiller. Foliar insecticide applications were made on 19 July 1978, 13 June and 17 July 1979, with a 7.6 l CO_2 pressurized hand sprayer at 13.6 kg/2.5 cm^2 to point of runoff.

Maneb was applied weekly to the post bloom stage until harvest at 2.2 kg ai/ha in 1978 and chorothalonil at 2.2 kg ai/ha in 1979 for early blight control. During both years, the Florida weave staking method was used.

In June 1979, *Heliothis zea* larvae (age $\leq$ 24 hr.) reared from pupae received from the Bioenvironmental Insect Control Laboratory in Stoneville, Mississippi were released at the rate of five/plot.

Insect numbers were determined by visual counts from one randomly selected plant per plot. Fruitworm evaluation was based on percentage of damaged fruit. All data were analyzed statistically and methods of mean separation are given in the tables.

Oviposition Test 1. Observations of oviposition sites on tomato plants were conducted in the field in 1979. Two pairs of pupae were placed in field cages (Pless, 1968) containing from one to two tomato plants each (Fig. A-2, Appendix). Gravid females were confined 24 hours after initial oviposition was observed. Six plants were examined for egg deposition, measured and divided into three main regions (upper, middle and lower). Each region was divided into subunits consisting of the upper surface of the leaf, the lower surface of the leaf, the plant stem, the leaf petiole, and the fruit and calyx area. Numbers of eggs deposited on each subunit were subjected to analysis of variance and mean separation procedures.

Oviposition Test 2. Six mature greenhouse grown plants were placed in a 1.2m × 2.1m × 1.8m nylon mesh cage during February 1980 with six pair of sexed pupae. Evaluation procedures were as above.

Greenhouse Observations. Observations were conducted from 3 December 1979, through 18 January 1980, to determine damage and migration trends of the tomato fruitworm on mature tomato plants. *H. zea* used in this study were from laboratory stock. The laboratory colony was established from pupae received from the Bioenvironmental Insect Control Laboratory in Stoneville, Mississippi in June 1979, and maintained for about nine generations on a CSM based diet modified from Burton (1970). The only modification was the addition of 100 milligrams of benomyl to suppress the growth of *Aspergillis niger*. Larvae were reared separately until pupation in 100 × 15 mm standard plastic petri plates containing about 8 ml of diet. Adults were transferred to cages containing beer, and provided plastic tape on the inner surface of the cage for an oviposition substrate.

Forty-four tomato seedlings (cv. Walter) were grown to maturity in 9.5 ℓ pots containing equal parts Holston silt loam soil, sand and a one to one peat and perlite mixture. Each plant constituted one observation and was staked, randomly numbered and spaced about 30 cm apart on greenhouse benches. Lights placed above greenhouse benches were set to a 16 hr photophase corresponding to that of the rearing laboratory. First instar larvae (age $\leq$ 24 hr) were placed on the top one-half of each plant with release sites marked by adhesive backed tags. Twenty-four hr observations of trends in distance traveled, location, percentage of damaged fruits, fruit maturity, greenhouse temperature, and humidity were recorded. All data were submitted to an IBM 360 computer for analysis of means and standard error of the mean.

Laboratory Development and Consumption. Fifteen observations were made to determine larval development and consumption rates. Newly hatched larvae were transferred to freshly excised tomato leaves (cv. Walter) covered by 11.5 × 10 cm glass mantles. The petiole of each leaf was emmersed in a small vial of water plugged with cotton to prolong leaf freshness. Leaves were replaced as needed based on leaf freshness, surface area remaining and stadium development. Leaves were obtained from greenhouse maintained plants and leaf area measured both before and after exposure to larvae. Foliage consumption records were maintained from the third molt to the pupa stage. Larval molts were verified by discarded head capsules. Larvae were measured daily with an ocular micrometer until a length of about one cm and all remaining measurements were made with a ruler. Third and remaining instar larvae were weighted daily on a Christian Becker Chainomatic analytical balance. Comparative larvae development records were taken in the same manner for both tomato fruit and laboratory diet reared individuals.

CHAPTER IV

RESULTS AND DISCUSSION

I. Field Trials

Field Trials 1978. The effect of the soil systemic insecticide Mocap-plus on the early season aphid population is summarized in Table 1. Significant aphid reduction occurred on Mocap-plus treated plots until 19 June. The aphid population differed significantly from the untreated check only on 12 June.

Parasitized aphids "mummies" were not observed in the plots until 5 June (Table 2). Populations of syrphid larvae did not appear until 12 June (Table 3). Significant differences were not noted between Mocap-plus treatments and the untreated check.

A prespray count established a potato aphid population mean of 13.1 aphids/plant on 18 July. The population numbers are presented in Table 4. Significant differences were not observed among the plots until the 14 day count when Bolstar, Cygon and the high rate of Pounce were significantly lower than the untreated check. Ambush, Bolstar, Cygon and Pounce were significantly lower than all other treatments on the 21 day count. The high rate of Pounce was significantly lower than Ficam and Larvin on the 28 day count.

Only 1.9 green peach aphids/plant were present in the prespray count taken 17 July. The population numbers of the green peach aphid are presented in Table 5. Significant differences were not observed

TABLE 1. Effect of Mocap-plus on aphid populations prior to fruit set in tomato culture, at Knox County, Tennessee, 1978.

Treatments	ai kg/ha	$\bar{x}$ no. of aphids/plant at posttreatment period[a] 22 May	29 May	5 Jun	12 Jun	19 Jun
Mocap-plus	1.12	4.32	10.20*	19.20*	11.68*	5.80
Check	----	4.72	40.20	36.00	21.44	6.40

[a]Means in a column denoted by an asterisk differ significantly from untreated check ($P \leq 0.05$) LSD.

TABLE 2. Effect of Mocap-plus on parasitized aphids prior to fruit set in tomato culture, at Knox County, Tennessee, 1978.

Treatments	ai kg/ha	$\bar{x}$ no. of parasitized aphids/plant at posttreatment period[a] 22 May	29 May	5 Jun	12 Jun	19 Jun
Mocap-plus	1.12	0.00	0.00	4.56	1.44*	3.08
Check	----	0.00	0.00	4.24	3.72	3.64

[a]Means in a column denoted by an asterisk differ significantly from untreated check ($P \leq 0.05$) LSD.

TABLE 3. Effect of Mocap-plus on syrphid larvae populations prior to fruit-set in tomato culture, at Knox County, Tennessee, 1978.

Treatments	ai kg/ha	$\bar{x}$ no. of syrphid larvae/plant at posttreatment period[a] 22 May	29 May	5 Jun	12 Jun	19 Jun
Mocap-plus	1.12	0.00	0.00	0.00	0.60	1.46
Check	----	0.00	0.00	0.00	1.24	1.56

[a]No significant differences ($P \leq 0.05$) LSD.

TABLE 4. Effect of late season foliar applied insecticides on the potato aphid, *Macrosiphum euphorbiae* (Thomas), in Knox County, Tennessee, 1978.

Treatments	ai kg/ha	$\bar{x}$ no. of aphids/plant at posttreatment day[a] 1	7	14	21	28
Sevin	1.12	0.0 a	2.0 a	29.7 ab	227.2 cd	256.4 abc
Cygon	1.12	0.2 a	0.2 a	5.5 a	17.0 a	52.8 ab
Knockout	0.56	0.4 a	0.2 a	11.5 ab	57.8 bc	190.0 abc
Pounce	0.22	0.6 a	0.4 a	1.5 a	5.2 a	38.8 a
Bolstar	0.56	1.4 a	1.0 a	0.5 a	62.2 abc	103.8 abc
Ficam	0.56	2.0 a	5.6 a	44.5 ab	212.6 bcd	321.4 c
Pounce	0.11	2.6 a	0.0 a	39.0 ab	11.2 a	101.4 abc
Ambush	0.11	6.8 a	0.4 a	18.0 ab	39.0 ab	52.2 ab
Check	----	8.8 a	15.6 a	65.2 b	349.4 d	234.0 abc
Larvin	0.56	15.0 a	6.4 a	38.7 ab	334.4 d	277.0 bc

[a]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

TABLE 5. Effect of late season foliar applied insecticides on the green peach aphid, *Myzus persicae* (Sulzer), in Knox County, Tennessee, 1978.

	ai	$\bar{x}$ no. of aphids/plant at posttreatment day[a]				
Treatments	kg/ha	1	7	14	21	28
Knockout	0.56	0.0 a	0.0 a	0.7 a	26.4 a	76.8 abc
Sevin	1.12	0.0 a	0.4 a	7.2 a	32.2 a	52.6 abc
Cygon	1.12	0.0 a	0.0 a	0.0 a	7.8 a	8.8 a
Ambush	0.11	0.0 a	0.0 a	0.0 a	3.6 a	33.8 a
Pounce	0.11	0.2 a	0.0 a	4.0 a	15.6 a	16.6 a
Bolstar	0.56	0.2 a	0.2 a	0.2 a	6.4 a	28.6 ab
Larvin	0.56	0.4 a	0.6 a	2.2 a	78.6 ab	109.6 c
Pounce	0.22	0.4 a	0.0 a	0.0 a	1.8 a	5.8 a
Ficam	0.56	0.8 a	2.0 a	7.2 a	50.6 a	104.0 bc
Check	----	6.0 a	1.8 a	16.5 b	188.3 b	103.4 bc

[a]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

among the plots until the 14 day count when the untreated check was significantly higher than all treated plots. All treatments except Larvin were significantly lower than the untreated check on the 21 day count. Ambush, Cygon and Pounce were significantly lower than Ficam, Larvin and the untreated check during the 28 day count. The treatment population numbers for parasitized aphids are presented in Table 6. Significant differences in population numbers were not observed until the 7 day count when Ambush, Bolstar, Cygon and Pounce were significantly lower than the untreated check and all remaining treatments. Ficam, Larvin, Sevin and the untreated check were significantly higher from all remaining treatments on the 14 day count.

All treatments except Larvin were significantly lower than the untreated check on the 21 day count. The Ambush, Cygon, Knockout and Pounce populations were significantly lower than those of Larvin on the 28 day count.

Lacewing larvae, although present in small numbers in the check plots during the 1978 trials ($\bar{x}$ = 0.2/plant), were absent on all treatment plots.

Weekly means of *Hippodamia convergens* adults are presented in Table 7. The carbamates and all organophosphates with the exception of Cygon suppressed adult numbers during the 21 day count, while the number of adults found in the synthetic pyrethroid plots were not significantly different from those of the control. Ficam, Knockout, Larvin and Sevin significantly suppressed *H. convergens* adults when compared to the untreated check on the 28 day count.

TABLE 6. Effect of late season foliar applied insecticides on parasitized aphids in tomato plots, Knox County, Tennessee, 1978.

Treatments	ai kg/ha	$\bar{x}$ no. of parasitized aphids/plant at posttreatment day[a] 1	7	14	21	28
Pounce	0.11	0.6 a	0.2 a	0.5 a	0.2 a	0.4 a
Pounce	0.22	1.8 a	0.0 a	0.7 a	0.2 a	1.2 ab
Ambush	0.11	1.8 a	0.0 a	0.0 a	0.0 a	1.6 ab
Bolstar	0.56	1.2 a	0.2 a	0.0 a	0.0 a	4.8 abc
Ficam	0.56	0.0 a	0.6 ab	1.5 ab	0.6 a	5.2 bc
Cygon	1.12	1.0 a	0.0 a	0.5 a	0.0 a	0.4 a
Sevin	1.12	0.2 a	0.8 ab	1.7 ab	0.8 a	6.2 bc
Knockout	0.56	1.2 a	0.4 ab	0.7 a	0.2 a	4.0 abc
Larvin	0.56	1.4 a	0.6 ab	2.7 b	3.4 ab	6.8 c
Check	----	1.4 a	1.8 b	3.0 b	5.4 b	5.8 bc

[a]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

TABLE 7. Effect of late season foliar applied insecticides on adult *Hippodamia convergens* Guerin-Meneville in Knox County, Tennessee, 1978.

Treatments	ai kg/ha	$\bar{x}$ no. of adults/plant at posttreatment day[a] 1	7	14	21	28
Pounce	0.11	0.0 a	0.0 a	0.5 a	1.2 ab	3.5 ab
Pounce	0.22	0.0 a	0.0 a	0.2 a	0.7 ab	2.0 ab
Ambush	0.11	0.5 a	0.0 a	0.7 a	0.8 ab	1.8 ab
Ficam	0.56	0.0 a	0.1 a	0.3 a	0.2 a	0.8 a
Sevin	1.12	0.0 a	0.0 a	0.0 a	0.0 a	0.5 a
Cygon	1.12	0.2 a	0.0 a	0.2 a	0.5 a	1.6 ab
Larvin	0.56	0.0 a	0.0 a	0.0 a	0.0 a	0.2 a
Knockout	0.56	0.0 a	0.0 a	0.0 a	0.0 a	0.5 a
Bolstar	0.56	0.0 a	0.0 a	0.0 a	0.0 a	0.3 a
Check	----	0.0 a	0.1 a	0.3 a	1.8 a	4.4 b

[a]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

Populations of Syrphid larvae increased in late June and early July (Table 8), but declined in all plots during the trials (Table 9). There was no significant difference in plot populations until the 28 day count when the untreated check was higher than all treated plots. Adjacent corn plots which supported moderate populations of *Rhopalosiphum maidis* (Fitch) were tasseling. The greater pollen and honeydew source could have been responsible for attracting adult females.

Prediction equations for aphid and natural enemy populations plus climatic variables were derived from a multiple regression procedure (Table 10). For the aphid population, *H. convergens* was the single factor producing the highest r^2 value (0.713). Syrphid larvae and parasitized aphid numbers were the only other variables contributing to the model at the 0.05 level of significance. These variables accounted for 86.7% of the variation within the model.

When *H. convergens* was the dependent variable, the aphid population, Syrphid larvae, and precipitation accounted for 88.1% of the variation.

Five variables accounted for 86.3% of the variation when the Syrphid larvae variable was dependent. When hymenopterous parasites and *Chrysopa* sp. were the dependent variables, their highest r^2 values were 0.523 and 0.528 respectively. These low values combined with the few independent variables meeting the 0.05 level of significance could indicate ineffective sampling procedures or failure to include the correct variables in the model.

Highest yields occurred on the Cygon treated plots. Cygon, Ambush, Pounce, Bolstar and the untreated check were significantly superior to

TABLE 8. Weekly field survey insect population means on tomatoes in Knox County, Tennessee, 1978.[a]

Population	$\bar{x}$ no. of insects/plant at pretreatment period			
	26 June	4 July	10 July	17 July
Aphids	13.8	17.0	17.0	6.0
Parasitized Aphids	3.6	4.2	5.6	3.4
Syrphus sp.	1.6	1.2	2.2	2.0
H. Convergens	0.5	0.8	0.6	1.0
Chrysopa sp.	0.4	0.6	0.8	1.0

[a]Total numbers of insect populations from one randomly chosen plant per plot.

TABLE 9. Effects of late season foliar applied insecticides on syrphid larvae, in Knox County, Tennessee, 1978.

Treatments	ai kg/ha	$\bar{x}$ no. of syrphids/plant at posttreatment day[a] 1	7	14	21	28
Pounce	0.11	0.0 a	0.0 a	0.2 a	0.0 a	0.8 ab
Pounce	0.22	0.0 a	0.0 a	0.2 a	0.0 a	0.0 a
Ambush	0.11	0.0 a	0.0 a	0.4 a	0.0 a	0.4 a
Ficam	0.56	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
Sevin	1.12	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
Cygon	1.12	0.0 a	0.0 a	0.0 a	0.0 a	0.1 a
Larvin	0.56	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
Knockout	0.56	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
Bolstar	0.56	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
Check	----	0.0 a	0.0 a	0.0 a	0.3 a	1.8 b

[a]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

TABLE 10. Prediction equations from multiple regression pest-predator-prey interactions on control plots, 1978.[a,b]

Dependent Variable	Independent Variable	Prediction Equation	Percent Change $r^2 \times 100$
Aphids	x_1 = *H. convergens*	$y = -7.1 + 109.6x$	71.3%
	x_2 = Syrphid larvae	$y = 32.2 - 70.2x + 134.5x_2$	82.6
	x_3 = Aphid parasite	$y = -33.5 + 121.7x - 84.8x_2 + 24.6x_3$	86.7
H. convergens	x_1 = Aphids	$y = 0.2 + 0.006x$	71.3
	x_2 = Syrphid larvae	$y = -0.1 + 0.006x + 0.5x_2$	86.6
	x_3 = Precipitation	$y = -0.04 + 0.006x + 0.6x_2 - 0.1x_3$	88.1
Syrphid larvae	x_1 = *Chrysopa* sp.	$y = 0.3 + 1.7x$	45.7
	x_2 = *H. convergens*	$y = 0.2 + 1.6x + 0.3x_2$	61.4
	x_3 = Aphids	$y = 0.2 + 1.2x + 0.7x_2 - 0.004x_3$	72.9
	x_4 = Aphid parasites	$y = -0.3 + 1.0x + 0.7x_2 - 0.004x_3 + 0.2x_4$	80.9
	x_5 = Precipitation	$y = -0.4 + 1.0x + 0.7x_2 - 0.005x_3 + 0.2x_4 + 0.2x_5$	86.3
Aphid parasites	x_1 = *H. convergens*	$y = 3.0 + 0.7x$	29.2
	x_2 = Temperature	$y = -6.3 + 0.7x + 0.1x_2$	49.6
	x_3 = Syrphid larvae	$y = -5.6 + 0.5x + 0.1x_2 + 0.4x_3$	52.3
Chrysopa sp.	x_1 = Syrphid larvae	$y = 0.05 + 0.3x$	45.7
	x_2 = Temperature	$y = -1.1 + 0.2x + 0.01x_2$	52.8

[a]Only variables meeting the 0.5 significance level were included in the model.

[b]Multiple regression analysis by procedure stepwise, SAS 1979.

the soil systemic plots incorporating Mocap-plus (Table 11). Significant fruitworm damage and phytotoxicity was not observed in 1978.

Field Trials 1979 (Early Season Trials). One soil applied and six foliar applied insecticides were evaluated for their effect on early season insect populations in 1979. The treatment effect means of the potato aphid populations are presented in Table 12.

The foliar applied treatments did not differ significantly by the 4 day count, however, Larvin and Sevin did not differ from the untreated check on the 1 day count. Aphid numbers were significantly higher on the Ficam treated plots when compared to Ambush, Cygon and Pounce, but did not differ significantly from all remaining treatments or the untreated check on the 7 day count. On the 14 day count there was no significant difference among treatments nor among the Mocap-plus, Sevin and untreated check plots. The Cygon and Ambush treated plots maintained the lowest potato aphid populations on the 21 day count which were significantly lower than all treatments except Pounce. The Cygon treated plots were significantly lower from all other treatments and the untreated check on the 28 day count.

Population numbers of the green peach aphid are presented in Table 13. There was no significant differences observed in any plots until the 7 day count when no treatments except Ambush, Cygon, Larvin and Pounce differed from the untreated check. On the 14 day count only Cygon differed significantly from the untreated check. With the exception of Ficam, the Ambush and Cygon plots were significantly

TABLE 11. Effects of foliar and soil-applied insecticides on tomato yield. Knox County, TN., 1978.

Treatments	ai kg/ha	Mean[ab]
Cygon	1.12	5078.40 a
Ambush	0.11	4685.68 a
Pounce	0.11	4615.75 a
Bolstar	0.56	4594.23 a
Check	----	4556.57 a
Ficam	0.56	4508.15 ab
Larvin	0.56	4508.15 ab
Pounce	0.22	4373.66 ab
Knockout	0.56	4271.45 ab
Sevin	1.12	3878.73 ab
Mocap-plus	1.12	2985.71 b

[a]All treatment means converted to kg/ha prior to analysis.

[b]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

TABLE 12. Effect of early season soil and foliar applied insecticides on the potato aphid, *Macrosiphum euphorbiae* (Thomas), in Knox County, Tennessee, 1979.

Treatments	ai kg/ha	$\bar{x}$ no. of Aphids/plant at posttreatment day[a] 1	4	7	14	21	28
Cygon	1.12	0.75 a	9.00 a	2.50 a	10.50 a	29.50 a	99.00 a
Ficam	0.56	5.25 a	26.50 ab	60.00 bcd	72.75 a	67.75 bc	302.50 b
Ambush	0.11	11.00 a	9.00 a	11.25 a	36.00 a	54.00 ab	263.75 b
Pounce	0.11	12.75 a	17.00 a	8.50 a	48.50 a	77.25 bc	279.75 b
Larvin	0.56	19.75 abc	32.75 ab	24.50 ab	65.00 a	92.25 c	279.25 b
Sevin	1.12	31.25 abc	44.75 ab	34.75 abc	182.75 ab	94.25 c	227.75 b
Mocap-plus	1.12	51.00 c	59.75 bc	75.50 cd	170.00 ab	138.50 d	363.75 bc
Check	----	44.00 bc	86.00 c	92.25 d	308.75 b	180.25 e	440.75 c

[a]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

TABLE 13. Effect of an early season soil systemic and foliar applied insecticides on the green peach aphid, *Myzus persicae* (Sulzer), in Knox County, Tennessee, 1979.

Treatments	ai kg/ha	$\bar{x}$ no. of aphids/plant at posttreatment day[a] 1	4	7	14	21	28
Cygon	1.12	0.00 a	6.25 a	3.00 a	0.00 a	4.50 a	31.00 a
Ficam	0.56	1.00 a	18.50 a	8.00 abc	17.80 ab	24.00 ab	42.50 ab
Sevin	1.12	3.00 a	13.25 a	9.50 abc	25.75 ab	59.50 bcd	27.00 a
Ambush	0.11	3.75 a	4.25 a	4.25 ab	13.00 ab	14.00 a	45.75 ab
Larvin	0.56	5.00 a	2.25 a	7.00 ab	15.50 ab	63.00 cd	90.50 ab
Pounce	0.11	8.25 a	14.00 a	0.50 a	17.00 ab	29.00 abc	73.50 ab
Mocap-plus	1.12	8.50 a	15.00 a	18.75 bc	27.50 ab	75.00 d	134.25 b
Check	----	11.25 a	16.25 a	23.25 c	41.00 b	65.75 cd	130.50 b

[a]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

different from all remaining plots on the 21 day count. On the 28 day count only Cygon and Sevin differed significantly from the untreated check.

The population means of parasitized aphids are presented in Table 14. All foliar applied plots differed significantly from Mocap-plus, while Cygon and Ambush were significantly different from the untreated check on the 1 day count. All foliar applied treatments were significantly lower than the control on the 4 and 7 day counts. Cygon and Pounce differed significantly from the control on the 14 day count. All foliar treatments differed significantly from the Mocap-plus plots, while Cygon and Ambush were significantly lower than the untreated check on the 21 day count. On the 28 day count all foliar treatments differed significantly from the untreated check.

The population numbers for adult *Hippodamia convergens* are presented in Table 15. All foliar applied treatments differed significantly from the control on the 1 and 14 day counts. On the 7 day count the Mocap-plus numbers were significantly higher than those of all foliar applied treatments. There were no significantly differences among plots for the 21 and 28 day counts.

The population numbers of Syrphid larvae are presented in Table 16. There was no significant differences among plots on the 1 day count. Cygon, Ficam, Larvin and Sevin differed significantly from the Mocap-plus plots on the 4 day count. All foliar applied treatments differed significantly from the untreated check on the 7 and 14 day counts. Cygon, Ficam, Larvin, Pounce and Sevin were significantly

TABLE 14. Effect of early season soil systemic and foliar applied insecticides on parasitized aphids in Knox County, Tennessee, 1979.

Treatments	ai kg/ha	$\bar{x}$ no. of parasitized aphids/plant at posttreatment day[a]					
		1	4	7	14	21	28
Cygon	1.12	0.75 a	1.75 a	0.00 a	1.75 a	6.50 a	16.50 a
Ambush	0.11	1.00 a	3.25 ab	1.75 a	12.80 bc	10.00 a	18.25 ab
Ficam	0.56	1.50 ab	4.00 ab	3.75 a	9.00 abc	18.75 ab	22.75 ab
Pounce	0.11	1.50 ab	0.00 a	2.25 a	3.50 a	15.75 ab	24.50 ab
Larvin	0.56	1.75 ab	4.00 ab	1.50 a	6.25 abc	17.50 ab	20.50 ab
Sevin	1.12	1.75 ab	3.50 ab	3.25 a	15.50 c	17.50 ab	20.50 ab
Mocap-plus	1.12	5.50 c	8.75 bc	10.50 b	15.25 c	35.00 c	43.75 bc
Check	----	4.00 bc	12.50 c	15.25 b	15.67 c	28.50 bc	62.75 c

[a]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

TABLE 15. Effect of early season soil and foliar applied insecticides on adult *Hippodamia convergens* Guerin-Meneville in Knox County, Tennessee, 1979.

Treatments	ai kg/ha	$\bar{x}$ no. of adults/plant at posttreatment day[a] 1	4	7	14	21	28
Ambush	0.11	0.0 a	0.2 a	0.2 a	0.2 a	1.0 a	3.0 a
Pounce	0.11	0.0 a	0.0 a	0.0 a	0.0 a	1.7 a	2.0 a
Ficam	0.56	0.0 a	0.2 a	0.0 a	0.2 a	2.2 a	2.5 a
Cygon	1.12	0.0 a	0.0 a	0.2 a	0.0 a	1.0 a	2.0 a
Sevin	1.12	0.0 a	0.0 a	0.2 a	0.7 a	3.0 a	3.5 a
Larvin	0.56	0.0 a	0.5 a	0.2 a	0.2 a	2.7 a	3.0 a
Mocap-plus	1.12	0.5 ab	0.2 a	1.0 b	0.5 a	3.0 a	4.0 a
Check	----	1.0 b	0.5 a	0.7 ab	1.5 b	3.5 a	4.2 a

[a]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

TABLE 16. Effect of early season soil and foliar applied insecticides on syrphid larvae in Knox County, Tennessee, 1979.

Treatments	ai kg/ha	$\bar{x}$ no. of larvae/plant at posttreatment day[a] 1	4	7	14	21	28
Ambush	0.11	0.2 a	0.2 ab	0.2 ab	0.0 a	1.5 ab	0.5 ab
Pounce	0.11	0.0 a	0.2 ab	0.2 ab	0.0 a	0.7 a	1.0 ab
Ficam	0.56	0.2 a	0.0 a	0.0 a	0.2 a	0.2 a	0.2 ab
Cygon	1.12	0.0 a	0.0 a	0.0 a	0.0 a	0.2 a	1.0 ab
Sevin	1.12	0.7 a	0.0 a	0.2 ab	0.5 a	0.0 a	0.0 a
Larvin	0.56	0.0 a	0.0 a	0.0 a	0.0 a	0.5 a	0.2 ab
Mocap-plus	1.12	1.0 a	0.7 b	1.0 bc	1.5 ab	2.0 ab	2.7 ab
Check	----	0.2 a	0.2 ab	1.2 c	4.0 b	2.7 b	3.2 b

[a]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

different from the untreated check on the 21 day count. Only Sevin was significantly different from the untreated check on the 28 day count, while no treatments differed significantly during this period.

Field Trials 1979 (Late Season Trials). Population numbers of the potato aphid are presented in Table 17. Cygon was significantly lower than Sevin, while all treatments differed significantly from the untreated check on the 1 day count. Cygon was significantly lower than Larvin, Sevin and the untreated check on the 4 day count. With the exception of Pounce, Cygon was significantly lower than all plots on the 7 day count. Cygon was significantly lower than Larvin and Sevin on the 14 day count. Ambush, Larvin and the untreated check were significantly higher than Cygon on the 21 day count. No differences were apparent on the 28 day count.

Population numbers for the green peach aphid are presented in Table 18. All treatments were significantly different from the untreated check on the 1 day count. On the 4 day count the population numbers of Sevin and the untreated check were significantly higher than all remaining treatments. Ambush, Cygon and Pounce were significantly lower than Sevin on the 7 day count. Ambush, Cygon and Ficam were significantly lower than Larvin and the untreated check on the 14 day count. There was no significant differences apparent on the 21 day count, however, Cygon and Pounce were significantly lower than Ficam and Larvin on the 28 day count.

The mean number of parasitized aphids on 18 July exceeded all previously recorded counts, but declined by 15 August (Table 19). On the 1 and 4 day counts all treatments were significantly lower than the

TABLE 17. Effect of late season foliar applied insecticides on the potato aphid, *Macrosiphum euphorbiae* (Thomas), in Knox County, Tennessee, 1979.

Treatments	ai kg/ha	$\bar{x}$ no. of aphids/plant at posttreatment day[a] 1	4	7	14	21	28
Cygon	1.12	9.00 a	6.50 a	2.25 a	3.75 a	1.50 a	44.75 a
Ambush	0.11	41.25 ab	53.75 ab	58.75 b	31.25 ab	34.75 bc	62.50 a
Ficam	0.56	70.50 ab	39.25 ab	52.50 b	23.75 ab	16.00 ab	48.25 a
Pounce	0.11	87.50 ab	43.75 ab	25.25 ab	33.75 ab	28.25 abc	56.25 a
Larvin	0.56	110.00 ab	93.00 bc	67.50 b	73.75 c	36.25 bc	52.00 a
Sevin	1.12	123.75 b	112.50 c	76.25 b	48.75 bc	15.00 ab	71.75 a
Check	----	308.75 c	111.25 c	58.75 b	37.50 ab	50.25 c	45.00 a

[a]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

TABLE 18. Effect of late season foliar applied insecticides on the green peach aphid, *Myzus persicae* (Sulzer), in Knox County, Tennessee, 1979.

Treatments	ai kg/ha	$\bar{x}$ no. of aphids/plant at posttreatment day[a] 1	4	7	14	21	28
Cygon	1.12	0.00 a	5.25 a	0.00 a	0.00 a	0.00 a	4.75 a
Pounce	0.11	20.25 ab	4.25 a	0.75 a	7.00 ab	4.50 a	8.25 a
Ambush	0.11	23.00 ab	0.00 a	1.50 a	0.50 a	14.25 a	17.00 ab
Sevin	1.12	26.50 ab	29.25 cb	22.00 b	10.50 ab	4.25 a	31.50 b
Ficam	0.56	27.25 ab	0.00 a	14.00 ab	2.25 a	7.25 a	31.75 b
Larvin	0.56	35.75 ab	16.75 ab	8.50 ab	20.75 b	4.25 a	21.50 ab
Check	----	121.25 c	60.00 d	6.75 ab	16.25 b	10.75 a	11.75 ab

[a]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

TABLE 19. Effect of late season foliar applied insecticides on parasitized aphids in Knox County, Tennessee, 1979.

Treatments	ai kg/ha	$\bar{x}$ no. of parasitized aphids/plant at posttreatment day[a]					
		1	4	7	14	21	28
Cygon	1.12	5.00 a	2.50 a	1.00 a	0.00 a	0.25 a	15.25 ab
Ambush	0.11	10.00 ab	5.25 a	3.25 ab	3.25 ab	4.00 abc	10.00 a
Larvin	0.56	15.25 ab	5.25 a	11.25 cd	9.75 c	4.75 abc	13.50 ab
Pounce	0.11	15.25 ab	5.00 a	4.50 abc	4.00 ab	6.00 bc	8.75 a
Sevin	1.12	17.50 b	8.00 a	9.75 bcd	5.50 b	2.25 ab	22.00 c
Ficam	0.56	18.50 b	3.50 a	7.75 abcd	2.50 ab	0.00 a	12.50 ab
Check	----	40.25 c	34.00 b	13.00 d	10.00 c	8.00 c	19.00 bc

[a]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

untreated check. Ambush, Cygon and Pounce were the only treatments significantly lower than the untreated check on the 7 day count. All treatments, with the exception of Larvin, were significantly lower than the untreated check on the 14 day count. Cygon, Ficam and Sevin were significantly lower than the untreated check on the 21 day count. Ambush and Pounce were significantly lower than the untreated check on the 28 day count.

The populations of adult *Hippodamia convergens* declined as the aphid populations decreased. Population numbers of *H. convergens* adults are presented in Table 20. All treatments were significantly lower from the untreated check on the 1 and 4 day counts. There was no significant difference among plots on the 7 day count. With the exception of Ambush, all treatments were significantly different from the untreated check on the 14 day count. There were no significant differences apparent on the 21 day count. On the 28 day count, Ficam and Sevin were significantly lower than Cygon.

Population numbers of Syrphid larvae are presented in Table 21. All treatments were significantly different from the untreated check on the 1 and 4 day counts. On the 7 day count, all treatments, with the exception of Ambush, were significantly lower than the untreated check on the 14 day count. There were no apparent differences among plots on the 21 and 28 day counts.

The 1979 prediction equations for all populations and climatic variables are presented in Table 22. All population means were derived from the check plots and subjected to a multiple regression analysis.

TABLE 20. Effect of late season foliar applied insecticides on adult *Hippodamia convergens* Guerin-Meneville in Knox County, Tennessee, 1979.

Treatments	ai kg/ha	$\bar{x}$ no. of adults/plant at posttreatment day[a] 1	4	7	14	21	28
Ambush	0.11	0.0 a	0.2 a	0.0 a	0.5 ab	0.0 a	2.0 ab
Pounce	0.11	0.5 ab	0.2 a	1.0 a	0.0 a	0.2 a	0.7 ab
Ficam	0.56	0.5 ab	0.5 a	0.2 a	0.2 a	0.5 a	0.2 a
Cygon	1.12	0.0 a	0.7 a	0.2 a	0.0 a	0.0 a	2.2 b
Sevin	1.12	0.7 ab	0.0 a	0.2 a	0.0 a	0.0 a	0.5 a
Larvin	0.56	0.7 ab	0.0 a	1.2 a	0.0 a	0.2 a	1.0 ab
Check	----	4.5 c	2.1 b	0.5 a	2.2 b	0.0 a	1.5 ab

[a]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

TABLE 21. Effect of late season foliar applied insecticides on syrphid larvae in Knox County, Tennessee, 1979.

Treatments	ai kg/ha	$\bar{x}$ no. of larvae/plant at posttreatment day[a] 1	4	7	14	21	28
Ambush	0.11	0.5 a	0.0 a	0.8 ab	1.5 b	0.0 a	0.4 a
Pounce	0.11	0.2 a	0.2 a	0.4 a	1.7 b	0.5 a	0.8 a
Ficam	0.56	0.0 a	0.0 a	0.2 a	0.4 ab	0.2 a	1.2 a
Cygon	1.12	0.0 a	0.0 a	0.4 a	0.4 ab	0.0 a	0.5 a
Sevin	1.12	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.2 a
Larvin	0.56	0.0 a	0.0 a	0.2 a	0.2 ab	0.0 a	0.6 a
Check	----	3.0 b	2.5 b	1.2 b	1.7 b	0.7 a	1.0 a

[a]Means in a column not followed by same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

TABLE 22. Prediction equations from multiple regression pest-predator-prey interactions on control plots, 1979.[a,b]

Dependent Variable	Independent Variable	Prediction Equation	Percent Change $r^2 \times 100$
M. euphorbiae	x_1 = Aphid parasite	$y = -4.4 + 7.0x$	72.0%
	x_2 = *Chrysopa* sp.	$y = 28.3 + 6.8x - 14.6x_2$	77.5
M. persicae	x_1 = Aphid parasite	$y = -2.2 + 2.0x$	78.9
	x_2 = Temperature	$y = 190.3 + 2.0x - 2.9x_2$	89.9
	x_3 = *J. spinosus*	$y = 128.1 + 2.2x - 1.9x_2 - 3.3x_3$	92.0
Hymenopterous parasites	x_1 = *M. persicae*	$y = 5.4 + 0.4x$	78.9
	x_2 = *J. spinosus*	$y = 0.7 + 0.4x + 2.5x_2$	90.8
	x_3 = Syrphid larvae	$y = -2.5 + 0.3x + 1.9x_2 + 4.9x_3$	95.6
Syrphid larvae	x_1 = *H. convergens larvae*	$y = 0.5 + 0.7x$	67.9
	x_2 = Precipitation	$y = 0.2 + 0.6x + 0.3x_2$	83.8
H. convergens larvae	x_1 = *Chrysopa* sp.	$y = 0.4 + 2.6x$	57.4
	x_2 = *M. persicae*	$y = -4.9 + 3.3x + 0.09x_2$	77.1
	x_3 = Wind speed	$y = -17.3 + 3.5x + 0.1x_2 + 0.9x_3$	82.7
H. convergens adults	x_1 = Syrphid larvae	$y = 0.04 + 1.0x$	67.9
	x_2 = Precipitation	$y = 0.05 + 1.3x - 0.4x_2$	76.5
Chrysopa sp.	x_1 = Temperature	$y = -26.7 + 0.4x$	73.5
	x_2 = Syrphid larvae	$y = -29.6 + 0.5x - 0.6x_2$	80.7

[a] Only variables meeting the 0.5 significance level were included in the model.

[b] Multiple regression analysis by procedure stepwise, SAS 1979.

Parasitized aphids produced the highest r^2 value (0.22) when the *M. euphorbiae* variable was dependent. The addition of the lacewing larvae variable effected a change in the r^2 value by 0.055. These were the only variables which met the 0.05 level of significance. The hymenopterous parasites, temperature and stilt bug variables accounted for 92.0% of the variation when *M. persicae* was the dependent variable.

Treatment effect means for fruitworm damage and yield are presented in Table 23. All treatments were significantly lower than the untreated check, while the damage in the Cygon plots was significantly higher than in the Larvin or Pounce plots. The highest yields occurred in the Ambush plots which were significantly higher than those of Pounce. Phytotoxicity was not observed in 1979.

Oviposition. The mean number of eggs deposited on each subunit for each test is presented in Table 24. The lower leaf surface of the middle portion of the plants was the preferred oviposition site for each test, but was not significantly greater than the fruit. Wilcox (1956) reported that from a similar test no oviposition was observed on the fruit, but that 68% were deposited on the lower surface of the leaves. A large portion of the eggs were deposited on the inner surface of the cages in both tests.

Of 535 eggs deposited on six tomato plants in the 1979 field cage test, 47.3, 27.5 and 25.3% were deposited on the middle, top and bottom regions respectively. While the lower leaf surface, stem, upper leaf surface, petiole and fruit comprised 36.8, 20.2, 18.6, 13.6 and 10.7% of the respective plant surface sites. In the 1980 greenhouse

TABLE 23. Effect of 1979 foliar applied insecticides on tomato yield and fruitworm damage.[a]

Treatments	ai kg/ha	Fruitworm Damage[b]	kg/ha Yield
Pounce	0.11	0.4 a	3126.9 a
Larvin	0.56	2.4 a	3637.9 ab
Ambush	0.11	4.0 ab	3994.4 b
Ficam	0.56	6.1 ab	3194.2 ab
Sevin	1.12	6.2 ab	3369.0 ab
Cygon	1.12	13.3 b	3839.7 ab
Check	----	37.7 c	3436.3 ab

[a]Means in a column not followed by the same letter are significantly different ($P \leq 0.05$) Duncan's Multiple Range Test.

[b]Percentage of damaged fruits.

TABLE 24. Effect of tomato plant regions on oviposition response of *Heliothis zea* (Boddie) in Knox County, Tennessee, 1979 and 1980.

Oviposition Site	$\bar{x}$ no. of eggs/plant subunits[a] 1979 Field Cage	1980 Greenhouse Cage
MIDDLE Lower leaf surface	16.8 a	17.7 a
fruit	9.6 ab	11.8 abc
TOP Lower leaf surface	8.8 b	10.2 bcd
MIDDLE stem	7.6 b	4.2 cd
BOTTOM Lower leaf surface	7.2 b	13.8 ab
TOP Upper leaf surface	7.2 b	7.7 bcd
BOTTOM Upper leaf surface	6.0 b	6.0 bcd
TOP stem	5.4 b	4.3 cd
BOTTOM stem	5.0 b	2.0 d
MIDDLE petiole	4.8 b	7.5 bcd
BOTTOM petiole	4.4 b	6.5 bcd
MIDDLE Upper leaf surface	3.4 b	8.8 bcd
TOP petiole	3.0 b	4.2 cd

[a]Means in a column not followed by the same letter are significantly different (P = 0.05) Duncan's Multiple Range Test.

test, 628 eggs were recorded of which 47.8, 27.0 and 25.1% were deposited on the middle, bottom and top portions of plants. The lower leaf surface, upper leaf surface, petiole, fruit and stem respectively comprised 39.8, 21.4, 17.4, 11.3 and 10.0% of the oviposition sites.

Migration and Damage. The daily migration means are presented in Table 25 on a week to week basis. The mean temperature and relative humidity of the greenhouse was 23.6 ± 5.8°C and 73.3 ± 1.9% during the observational period. The daily means of migration trends upward, downward and laterally for the entire larval period were 3.0 ± 0.2, 3.7 ± 0.3 and 3.3 ± 0.2 cm respectively.

From 1300 observations of larval feeding sites 69.3% occurred on the fruit (Table 26). Of the damaged fruit, 36.4% of the damage was in the calyx area. The mean number of fruit damaged per larva was 3.2 ± 0.2. This is lower than the six fruit per larva reported by Wilcox and Stone (1938).

Laboratory Development and Consumption. Larval development expressed for numbers of instar, instar duration and respective weight is presented in Table 26. Numbers of instars completed varied from five to seven when reared on tomato foliage (Table 27). Development rates of fruit reared larvae are presented in Table 28. All larvae died prior to pupation. However, two larvae completed eight instars and one developed through the ninth instar. Larval development rates of diet reared larvae are presented in Table 29. There was no larval mortality in the diet reared larvae and no variation in the number of instars.

TABLE 25. Mean distance of plant migration of *Heliothis zea* (Boddie) on tomatoes per 24 hr. observations in Knox County, Tennessee 1979 and 1980.[a]

Migration Direction	First Week		Second Week		Third Week		Fourth Week		Fifth Week		Total	
	N	$\bar{x}$	N	$\bar{x}$	N	$\bar{x}$	N	$\bar{x}$	N	$\bar{x}$	N	$\bar{x}$
Upwards	308	3.9 ± 0.5	308	1.1 ± 0.2	308	2.7 ± 0.5	283	4.2 ± 0.6	93	3.4 ± 1.0	1300	3.0 ± 0.2
Downwards	308	4.2 ± 0.5	308	1.8 ± 0.4	308	3.3 ± 0.7	283	4.9 ± 0.8	93	5.9 ± 1.6	1300	3.7 ± 0.3
Laterally	308	4.5 ± 0.3	308	1.8 ± 0.2	308	2.2 ± 0.3	283	4.7 ± 0.4	93	4.3 ± 0.7	1300	3.3 ± 0.2

[a]Means and standard error of the mean computed by procedure means SAS 79.

TABLE 26. Location of feeding sites for *Heliothis zea* (Boddie) larvae on tomato plants in Knox County, Tennessee, 1979 and 1980.[ab]

Site	First Week	Second Week	Third Week	Fourth Week	Fifth Week	Total
Stem	15.25	1.95	4.54	4.24	6.45	6.54
Leaf	36.69	7.48	10.72	22.97	17.20	19.23
Petiole	5.52	0.97	0.00	0.00	0.00	1.54
Blossom	1.50	2.92	2.27	5.65	8.61	3.38
Fruit	41.04	86.68	82.47	67.14	67.74	69.31

[a]All data expressed as percent.

[b]Percentages computed by procedure frequency SAS 79.

TABLE 27. The larval development and rate of consumption of tomato fruitworm when fed tomato foliage.

Stage	N	mg Weight[a]	days Duration	cm^2 Consumption[b]	% Mortality
1st Instar	15	----	3.1 ± 0.2	----	0
2nd Instar	15	----	3.5 ± 0.4	----	0
3rd Instar	15	4.1 ± 0.4	4.3 ± 0.5	3.5 ± 0.9	0
4th Instar	15	26.8 ± 3.6	3.5 ± 0.3	2.8 ± 6.4	0
5th Instar	15	96.0 ± 19.6	4.1 ± 0.2	97.3 ± 14.2	0
6th Instar	11	237.4 ± 24.3	3.9 ± 0.3	162.7 ± 14.6	0
7th Instar	1	605.0	2.0	87.7	0
Maximum[c]	15	550.0 ± 12.3	----	----	0
Pharate Pupa	15	453.2 ± 20.3	2.6 ± 0.2	----	0
Pupa	13	334.3 ± 12.3	----	----	13

[a]Weight recorded at the beginning of each stage.

[b]Leaf consumption recorded at the completion of each instar.

[c]"Maximum" refers to the maximum weight of the terminal instar.

TABLE 28. Tomato fruitworm larval development when fed tomato fruit.[a]

Instar	N	mg Weight[a]	days Duration	% Mortality
First	15	----	3.3 ± 0.2	0
Second	15	----	3.3 ± 0.2	0
Third	14	3.0 ± 0.3	3.7 ± 0.2	7
Fourth	13	25.1 ± 4.5	4.5 ± 0.3	13
Fifth	12	70.4 ± 9.4	4.6 ± 0.3	20
Sixth	11	116.6 ± 15.2	4.4 ± 0.2	27
Seventh	8	197.8 ± 21.2	3.4 ± 0.3	47
Eighth	2	300.5 ± 87.5	3.1 ± 0.1	87
Nineth	1	276.0	----	100

[a]Weight recorded at the beginning of each instar.

TABLE 29. Tomato fruitworm larval development when fed artificial diet.

Stage[a]	N	mg Weight[b]	days Duration	% Mortality
1st Instar	15	----	3.5 ± 0.1	0
2nd Instar	15	----	2.5 ± 0.1	0
3rd Instar	15	7.9 ± 0.6	2.9 ± 0.2	0
4th Instar	15	37.8 ± 3.3	4.1 ± 0.1	0
5th Instar	15	232.7 ± 17.7	4.1 ± 0.2	0
Maximum	15	727.3 ± 14.7	----	0
Pharate Pupa	15	595.9 ± 8.2	4.3 ± 0.2	0
Pupa	15	470.2 ± 7.5	----	0

[a]"Maximum" refers to the maximum weight of the terminal instar.

[b]Weight recorded at the beginning of each instar.

The mean laboratory temperature and humidity throughout the study was 28.9 ± 2.2C° and 85.8 ± 1.0%. The maximum weight, pupa weight, pupa length and pharate pupa weight means of the foliage reared larvae were all significantly lower than those of the diet reared larvae ($P \leq 0.05$) LSD. Daily leaf consumption in relation to larval weight is described by a linear regression function (Fig. 1) which allowed estimation of leaf area consumption based on mean larval weight.

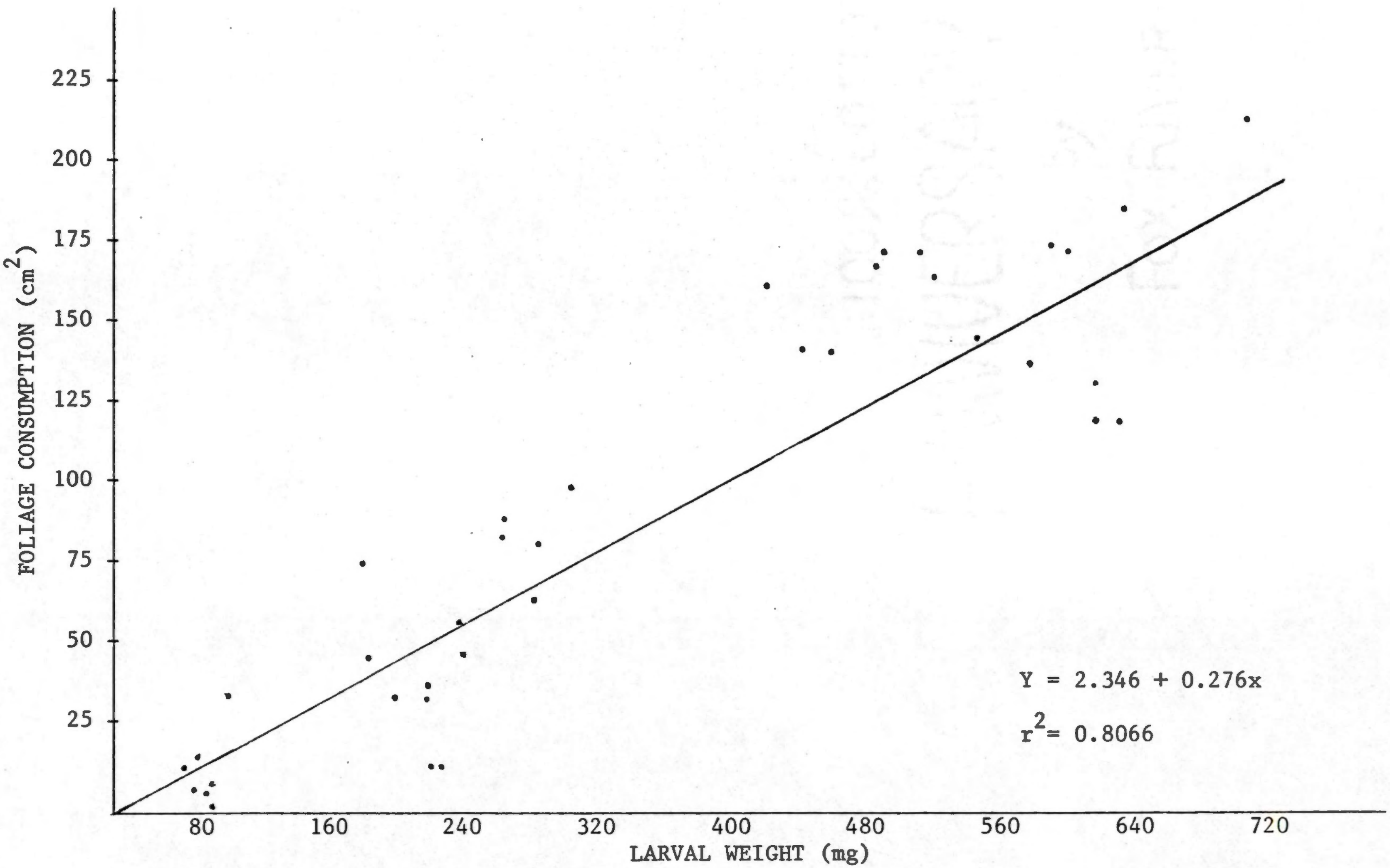

Figure 1. The association of tomato foliage consumption by *Heliothis zea* (Boddie) in relation to larval weight.

CHAPTER V

CONCLUSIONS

Cygon most effectively controlled aphids for both seasons. However, Ambush and Pounce also effectively reduced aphid population numbers. Cygon, although significantly superior to the control, was inferior to the carbamates and synthetic pyrethroids for fruitworm control. Applications of Pounce or Ambush if incorporated every third week with the fungicide program should provide satisfactory pest control on tomatoes.

Data obtained from biological observations on the tomato fruitworm suggest for optimal larval development substances not present in the fruit may be required. In many cases, larvae which were previously observed in the fruit, were found consuming portions of the calyx or aborted flower buds above or close by the damaged fruit. Later, they returned to the fruit or found another in which to burrow. The weekly increase in percent flower bud consumption (Table 28) suggested that these sites contain nutrients which were necessary for larval development. Pollen, a protein source, frequently adhered to the sticky epidermal hairs on leaves and stems of the tomato plant. The excised leaves used in the development and foliage consumption study could have possessed an adequate amount of pollen necessary for larval development.

Adult females laid eggs more frequently on the fruit and ventral surface of leaves in the midregion of the plant. When staked and tied, most of the fruit on the determinate cultivar "Walter" occurred in the midportion of the plant. The ovipositional behavior of adult females was to deposit eggs on the undersides of the leaves which was probably to protect them from desiccation. Placement of the eggs on or near the fruit may have been to avoid predation of early instar larvae. This assumption is based on data gathered from the migration study which indicates a higher level of predation for exposed larvae feeding on foliage than that of larvae burrowed in the fruit.

The young larvae were most active during the first week of their development than the second or third weeks. Foliage consumption during the first week of development was not detectable; however, the frequency of larval feeding on the fruit increased over 100% by the second week. Thus, insecticide applications would be most effective if applied upon fruitworm egg detection.

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APPENDIX

Plate I. Tomato plots and oviposition.

Figure A-1. 1979 Tomato plots at The University of Tennessee Plant Science Field Laboratory, Knoxville, Tennessee.

Figure A-2. Field ovipositional cages.

Figure A-3. *Heliothis zea* egg on tomato leaf (112×).

Figure A-4. *Heliothis zea* eggs on tomato fruit.

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Plate II. Early instar fruitworm.

Figure A-5. First instar larva (*Heliothis zea*) burrowing into fruit, under calyx.

Figure A-6. Early instar larva (*Heliothis zea*) burrowed into petiol.

Figure A-7. Early instar larva (*Heliothis zea*) feeding on young foliage.

Figure A-8. *Heliothis zea* larva penetrating tomato fruit cuticle.

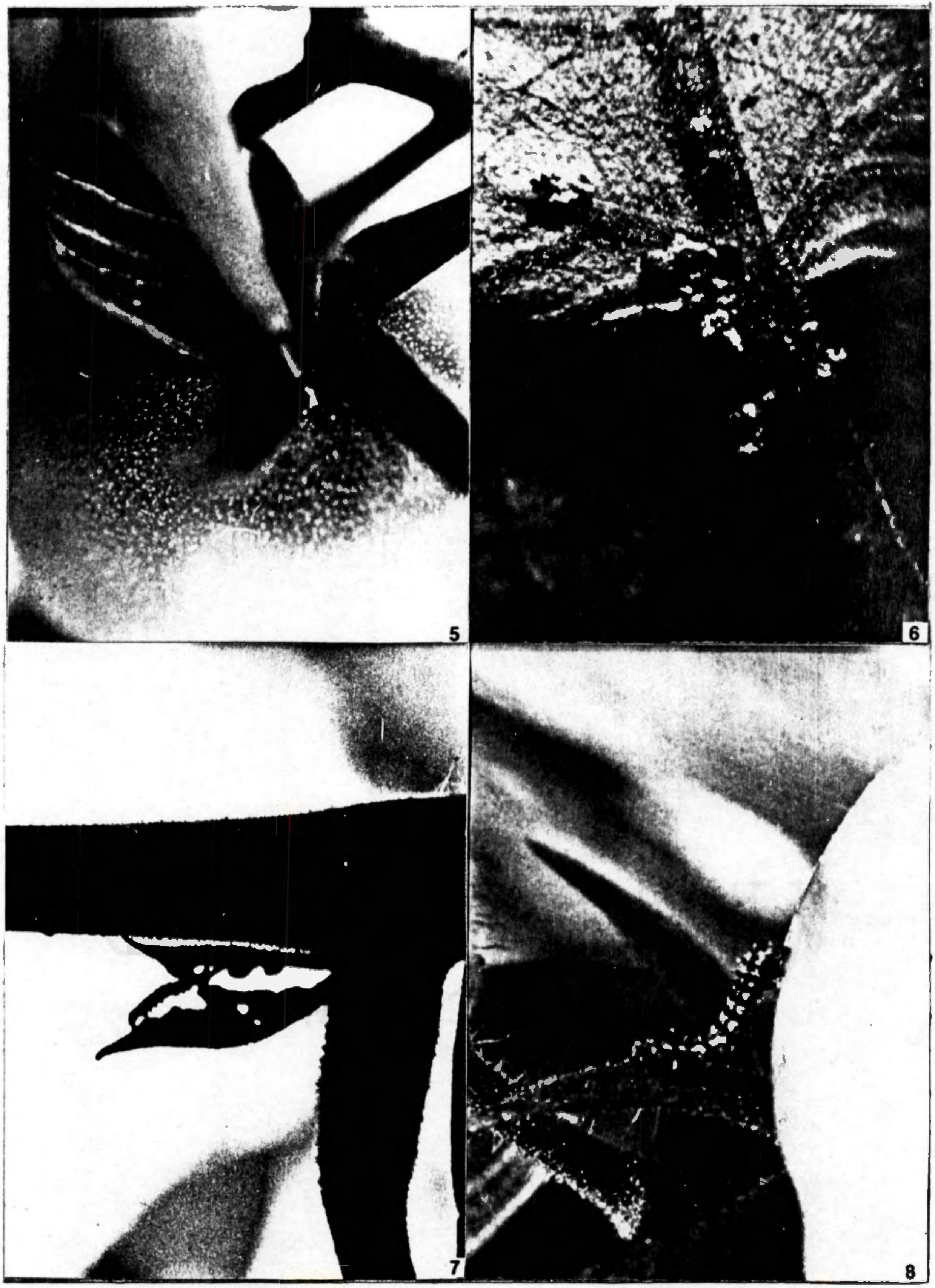
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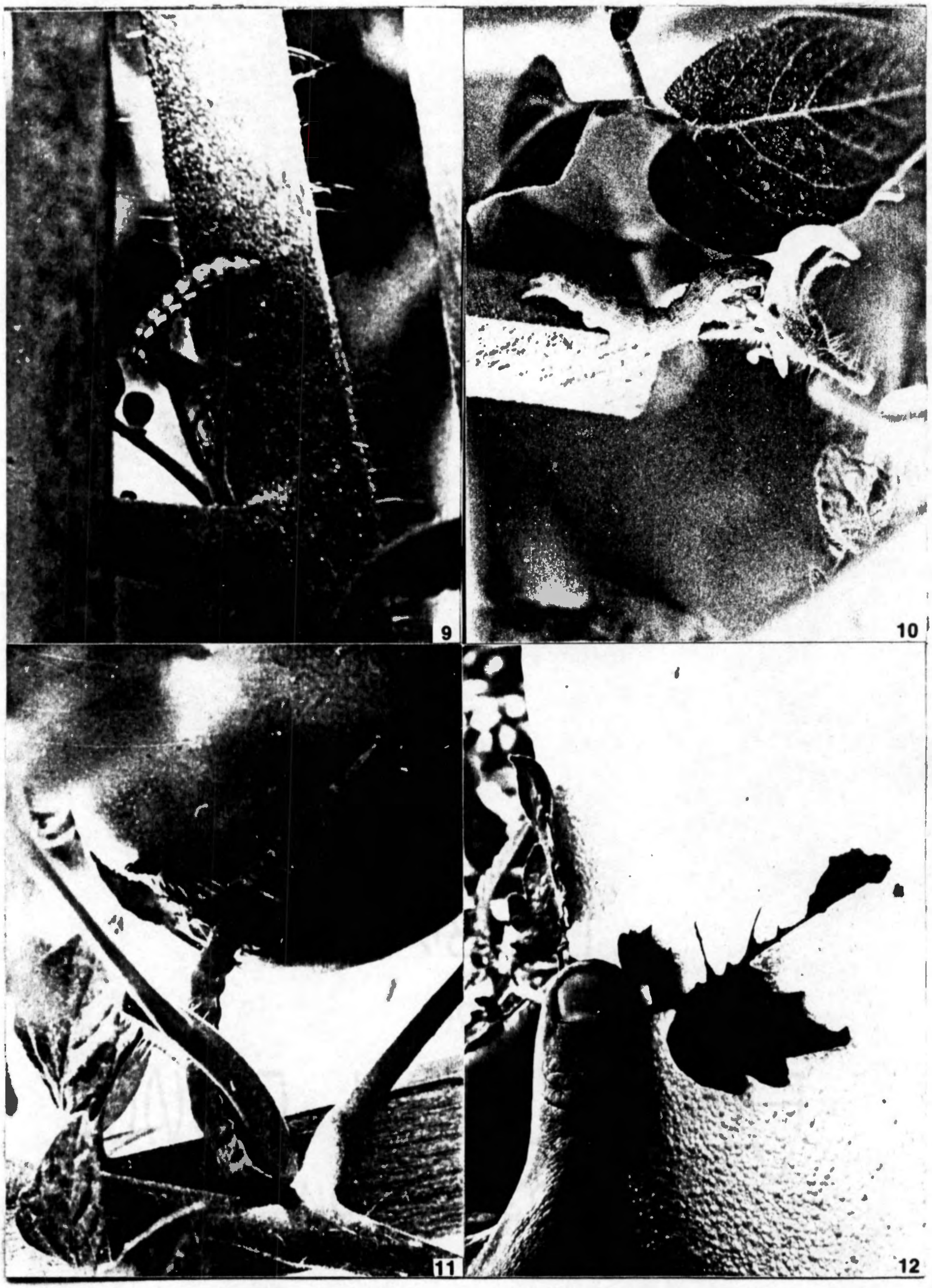
Plate III. Late instar fruitworm.

Figure A-9. *Heliothis zea* larva burrowing into tomato stem.

Figure A-10. *Heliothis zea* larva feeding on tomato flower.

Figure A-11. Late instar larva (*Heliothis zea*) feeding on tomato fruit.

Figure A-12. Tomato foliage damage by late instar larva (*Heliothis zea*).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VITA

Lynn J. Snodderly was born in Knox County, Tennessee on September 20, 1950, the son of Charles Hugh and Louise Davis Snodderly. He graduated from Jefferson High School in Jefferson City, Tennessee in 1968. While a student at Jefferson High School he was a member of the Key Club and Treasurer of the Future Farmers of America. He graduated from Carson-Newman College with a Bachelor of Science Degree in Biology in May 1973.

He received an assistantship from the Agricultural Biology Department at The University of Tennessee, Knoxville in January 1978, and entered graduate school with a major in Agricultural Biology. He received a Master of Science degree in Agricultural Biology in June 1980.

He is a member of the Entomological Society of America, the Tennessee Entomological Society, Gamma Sigma Delta, Phi Kappa Phi and the Tennessee Farm Bureau.

He is married to the former Nancy Karen Webster and resides in Strawberry Plains, Tennessee in Jefferson County.