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Date April 26, 1995

IMPACT OF SELECTED INSECTICIDES ON *Lygus lineolaris* AND BENEFICIAL ARTHROPODS ASSOCIATED WITH COTTON

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Jennifer M. Bannister

May 1995

DEDICATION

This thesis is dedicated in loving

memory of my father,

Ralph G. Bannister.

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ABSTRACT

Production of cotton, an important commodity in the United States, provides numerous jobs, as well as fiber, oil, and cottonseed meal for feed. In 1994, 234,000 hectares of cotton were harvested in Tennessee, contributing approximately $227,448,000 to the state's economy.

Cotton, a plant native to the West Indies, was introduced into the United States during colonial times. Some pests of cotton have been imported on other plants, while others use cotton as an alternate host, such as *Lygus lineolaris*, the tarnished plant bug (TPB), which damages cotton bolls and causes significant yield reductions.

Reliance on chemical methods to control pests of cotton has led to problems with integrating other management strategies and reducing selection pressures. Knowledge of the insecticide and its impact on the pest species and beneficial arthropods is essential to selecting and implementing pest management programs.

Because of the importance of cotton to the nation's economy, and because of the impact of pests, it is necessary to utilize efficient means of control for these pests. Research was conducted at the West Tennessee Experiment Station in 1993 and 1994 to evaluate the impact of selected insecticides on TPB. The objectives of this research were to: 1) determine the impact of recommended insecticides on TPB in field cage tests, 2) determine

the effects of selected early-season insecticides on beneficial arthropod populations, and 3) evaluate the resistance of TPB to selected insecticides in West Tennessee.

Efficacy tests showed that acephate, dicrotophos, malathion, and oxamyl consistently provided initial and residual control of TPB with lower rates of acephate, dicrotophos, and malathion achieving percent mortalities not significantly different from recommended rates. Azinphosmethyl and dimethoate, when used in combination, provided higher mortalities than when each was applied alone.

Insecticides applied for management of an insect pest may cause outbreaks of secondary pests, resurgences of primary pests, and/or reduce the survivorship of beneficial arthropods that are necessary for pest control. Insecticides that are commonly applied early-season for TPB management did cause reductions in beneficial arthropod densities at 1 and 3 days after treatment; however, overall densities showed an increase by 7 days after treatment.

Until recently, pest management included multiple applications of broad-spectrum insecticides. This philosophy led to insecticide resistance in many key pests. Increased pest resistance limits the effectiveness of many pesticides. Resistance studies performed in low, medium, and high cotton-producing sites in West Tennessee provided base-line information necessary for future determinations of LC_{50} values. The range of concentrations tested produced LC_{50} values for acephate and malathion. These values show that selection pressures are present in West Tennessee.

Insecticides are valuable tools in pest management. By monitoring the efficacy and resistance status of an insecticide, effective management practices can be employed. From this research, acephate and malathion can be used to achieve high levels of mortality; however, the possible development of resistance to these insecticides in areas of West Tennessee exists. This research suggests that early-season pests, such as TPB, can be managed using pesticides without harming beneficial arthropod populations that aid in late-season pest control. This type of information regarding insecticides depended upon for pest management supports incorporation of chemical control methods into integrated management programs.

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CHAPTER I

LITERATURE REVIEW

Cotton, *Gossypium hirsutum* L., is an important commodity in the United States accounting for 4.4 million to 6 million hectares of farmland per year (Reynolds et al. 1982). The milling of cotton has increased 76% from 1983 to 1993. The United States mill consumption of cotton in 1993, which is determined by total United States demand for cotton products and the competitiveness of the textile industry, totals approximately 10.3 million bales, a 5% increase from 1992 (Worsham 1994). It is hypothesized that cotton mill usage in 1994 will total approximately 10.2 million bales. Cotton is important not only for its fiber, but for cottonseed oil which is used in cooking, and cottonseed meal used for dairy feed.

Cotton is not known to be indigenous to the United States; seed was imported from around the world. Records of cotton growth in the Virginia colony dated 1607 provide evidence of the introduction of cotton to the United States during the colonization period (Brown and Ware 1958). The cotton species grown today is believed to be native to the West Indies (Frisbie et al. 1989).

Unlike *Gossypium barbadense* (L.) or Sea Island cotton, which during the colonial period was only grown in coastal areas, *G. hirsutum* was successfully grown inland and became known as 'Upland' cotton (Brown and Ware 1958). 'Upland' cotton was adaptable to the soils in the region and produced substantial yields with fibers appropriate for spinning (Frisbie et al. 1989). Due to natural crosses and plant breeding efforts, many types of Upland cotton, including those commonly planted today (e.g., Deltapine, Coker, Stoneville, and Acala) have been developed (Brown and Ware 1958).

The insects that infest cotton, an introduced plant, were either introduced from other countries via imported plants, or native insects that moved from other plants onto cotton (Brown and Ware 1958). Insects were not an annual problem in cotton until the end of the nineteenth century (Frisbie et al. 1989).

In 1892, the boll weevil, *Anthonomus grandis grandis* Boheman, entered Texas from Mexico and by 1920 was established in cotton along the Atlantic coast (Frisbie et al. 1989). Inorganic insecticides, such as lead arsenate, calcium arsenate, sulfur, and nicotine, were applied as dusts to cotton for pest management. Calcium arsenate was the only insecticide found to effectively control the boll weevil (Brown and Ware 1958). Other insecticides were used to control other pest species. After World War II, cotton yields increased due to the use of fertilization and the organochlorine insecticides (Frisbie et al. 1989). Development of organochlorine insecticides was followed by the development of organophosphates, carbamates, pyrethroids, and other classes of organic insecticides.

At least 100 species of insects and mites attack cotton with few attacking consistently and seriously enough to be classified as key pests (Reynolds et al. 1982). Among the key pests of cotton are the boll weevil, bollworm, *Helicoverpa zea* Boddie, tobacco budworm, *Heliothis virescens* F., and *Lygus* bugs. The tarnished plant bug (TPB), *Lygus lineolaris* Palisot de Beauvois, is an example of a cotton pest that visits cotton as an alternate host. Young (1986) compiled a list of 385 host plants of *L. lineolaris*, of which at least 130 were economically important plants. TPB move into cotton only after preferred wild host plants have matured and died (Cleveland 1982).

Due to the movement of TPB into cotton from alternate hosts, extensive studies have examined the host plant range of TPB in the Delta region of Mississippi. To better understand and manage TPB in cotton, the wild host plants and seasonal distribution of TPB in the Mississippi Delta were determined (Snodgrass et al. 1984). Populations of TPB found on wild host plants throughout the year decreased during the winter due to reproductive diapause and the maturation of hosts.

Depending on geographical location, TPB adults may hibernate in weed or crop debris. Adults resume activity in the spring, at which time females oviposit into host plant tissues. In the spring, eggs hatch 1.5 to 3 weeks after oviposition. The rate of egg hatch increases as temperature increases (Ridgway and Gyrisco 1960). Nymphs, which also feed on host plant sap, develop through five instars in a 3-week period. The first several generations of TPB develop on preferred hosts and move into cotton after these hosts have matured (Carter et al. 1982). By understanding the development of TPB on wild host plants, management strategies can be aimed at host plant sites before movement into economically important crops, such as cotton.

The major wild host plants of TPB are difficult to determine due to the geographical distribution and development of the insect, as well as maturity times of plants. The primary wild host plant in Arkansas and Mississippi was found to be fleabane, *Erigeron* spp. (Tugwell et al. 1976, Cleveland 1982). Horseweed, *Conyza canadensis* (L.) Cronq, is also an important wild host of TPB in these areas but is of less concern because of its late-season development. Movement of TPB into cotton from horseweed occurs when the cotton is less susceptible to damage by TPB (Cleveland 1982).

Determination of major wild host plants of TPB in relation to damage caused in cotton fields is dependent on the development of cotton. In Tennessee, cotton is planted from late April to mid May. Under favorable growing conditions, cotton grows and develops following a predictable pattern (El-Zik et al. 1989). Cotton seedlings emerge 4 days to 4 weeks after planting, depending upon growing conditions (Tharp 1965). Floral buds or squares first appear 35 to 45 days after emergence. Within 25 days, these squares advance to full bloom (El-Zik et al. 1989, Tharp 1965). Blooms last for 3 days with pollination usually occurring on the first day of bloom (Tharp 1965). The boll develops from the fertilized ovule. Boll development, from open bloom to boll splitting, occurs 40 to 80 days after planting, depending on variety, and climate (Tharp 1965).

The type of injury caused by TPB is dependent on the preferred feeding site of the insect. Since TPB move into cotton as their primary hosts mature, the feeding sites are dependent on the growth stage of the cotton plant (Tugwell et al. 1976). Cotton may be attacked by TPB late in the season during the boll stage and the large square stage. However, attacks during these stages of cotton development do not significantly affect lint yields (Tugwell et al. 1976).

Feeding by TPB during the early boll stage is characterized by dull, dark spots on the boll surface. Bolls fed on by TPB can be smaller and appear malformed. In some cases, seed quality may be reduced, and lint may be discolored (Pack and Tugwell 1976). Feeding by TPB on large squares may not be externally apparent until bloom. At this stage, feeding results in anther damage, which can lead to the shedding and malformation of bolls (Pack and Tugwell 1976).

TPB also can attack growth terminals and cause damage to cotton plants in the presquare stage. This type of damage may cause terminal abortion. However, aborted terminals did not reduce cotton yields as demonstrated by Tugwell et al. (1976). Under controlled conditions, feeding by TPB on presquaring cotton caused growth abnormalities similar to those that occurred in the field (Hanny et al. 1977). Abnormalities due to feeding on presquaring cotton include: swollen nodes, shortened internodes, deformed leaves, and excessive main stem branching. Infestations and damage which occur at this time of plant development also may result in delayed fruiting (Hanny et al. 1977).

Cotton plants are most susceptible to damage by TPB from the 4- to 6-leaf stage through the small or pinhead square stage (Scales and Furr 1968). They found that uncontrolled movement of adult TPB from secondary hosts that occur during bloom could significantly reduce the number of blooms produced during the growing season, therefore reducing yields.

Recognizing TPB damage at the small square stage is difficult. Damage by TPB to small squares (less than 3 mm) was described as large areas of necrosis on the staminal column (Mauney and Henneberry 1979). However, when monitoring in the field, recognition of TPB damage to small squares may be mistaken for naturally shed squares. The loss of small squares affected yields depending on the time of loss (Tugwell et al. 1976). Yields were affected when pinhead squares were removed during peak squaring.

In 1994, $343,067,693 were lost to insect pests throughout the cotton-growing states. *Lygus* spp. ranked 3rd among cotton pests, accounting for 1.16% of the total yield losses (6.03%) and $65,996,438 in economic losses. Losses to *Lygus* spp. ranked behind the bollworm/ budworm complex (1.80%) and the boll weevil (1.75%) (Williams 1995).

In Tennessee, in 1994, *Lygus* spp. ranked 2nd among cotton pests, accounting for 2.26% of the total yield losses (6.63%), and infested 180,000 hectares of the 234,000 hectares harvested. *Lygus* spp. were responsible for $5,728,000 in economic losses in Tennessee in 1994 (Williams 1995).

Several means of TPB management, including cultural and chemical methods, have been suggested. The most frequently used method of TPB management is the application of synthetic insecticides. In the 1960s, chemical mixtures containing DDT were successful for control of *Lygus* spp. and other pests (Reynolds et al. 1982). With the removal of DDT from the market in 1973, organophosphates and carbamates became the predominant insecticide classes used for insect control.

The most serious problem caused by the extensive reliance on insecticides is resistance. Continued use of DDT and other organochlorine insecticides led to resistant boll weevils throughout the cotton area in the early 1960s (Reynolds et al. 1982). Organophosphates and carbamates were the insecticides of choice until the late 1960's when tobacco budworm resistance to organophosphates was reported (Reynolds et al. 1982). The occurrence of pyrethroid-resistant tobacco budworms has been documented in some areas of the cotton belt (Kostroun and Plapp 1993).

Lygus bugs have been shown to be resistant to organochlorine insecticides (Reynolds et al. 1982). Resistance mechanisms to organophosphates and carbamates in *Lygus hesperus* Knight, the western pest species of *Lygus*, have been evaluated in the western United States. Because of the possible development of resistance, management practices are directed toward an integrated pest management (IPM) approach which involves the use of cultural, mechanical, and chemical tactics in combination with economic thresholds. In addition to reduction of resistance, these practices increase yields and reduce environmental contamination.

Resistance of pests to organophosphates has led to an increased use of pyrethroids and *Bacillus thuringiensis* (Berliner). Late-season pests, such as the bollworm and tobacco budworm, can be managed with pyrethroids. The use of organophosphates for management of early-season pests reduces the selection pressure and development of resistance to pyrethroids in pests that are present early in the season but cause damage late in the season.

Insecticides also can affect beneficial arthropod populations, which naturally aid in reducing pest densities. Insecticides are effective in reducing pest densities; however, sublethal effects and death also can occur within beneficial arthropod populations. By eliminating beneficial species, farmers encourage the resurgence of pest species.

Bollworms and budworms were recognized as key pest species of cotton in the mid-1970s. The insecticides used for the bollworm/budworm complex aided in reducing the populations of boll weevils, but allowed movement of TPB into cotton early in the season (Parrott et al. 1985). Successful management strategies for other cotton pests provide the opportunity for TPB to become a key pest of cotton.

Several cultural control methods can be used to manage TPB. Because TPB move to cotton from other hosts, planting near these hosts should be avoided. Weeds should be controlled before and during the cotton season to eliminate preferred hosts in or around a field. Destruction of weeds or alternate hosts during the season may result in TPB movement into cotton (Carter et al. 1982).

Strip planting of alfalfa, another cultural control method, also has been suggested for management of TPB. TPB prefer alfalfa to cotton and therefore, will feed and reproduce within the alfalfa. At harvest, cotton residues should be destroyed to eliminate overwintering sites (Carter et al. 1982).

Tolerant cultivars also are a means of cultural control. Cultivars tolerant to TPB feeding do exist. Cultivars sensitive to damage by TPB early in the season compensated for the loss with greater production later in the season (Laster and Meredith 1974). Nectariless cotton has been shown to support lower populations of TPB than nectaried cotton varieties; nectaried varieties produce nectar which would attract insects (Tingey 1976).

Because TPB has the opportunity to become a key pest of cotton, studies should be conducted so that resistance to insecticides does not become a major problem. By evaluating the effectiveness of insecticides against TPB, and discontinuing the use of non-effective insecticides, resistance can remain minimal. Beneficial arthropods must be considered when chemical control methods are employed. Effects of insecticides on beneficial arthropod populations should be monitored to select insecticides that will fit into IPM programs.

The objectives of this research were to:

1. determine the impact of recommended insecticides on *L. lineolaris* in cotton (Chapter 2),
2. determine the effects of selected early-season insecticides on beneficial arthropod populations (Chapter 3), and
3. evaluate the resistance of *L. lineolaris* to selected insecticides in West Tennessee (Chapter 4).

CHAPTER II

IMPACT OF RECOMMENDED INSECTICIDES ON *Lygus lineolaris*, THE TARNISHED PLANT BUG, IN COTTON

i. INTRODUCTION

In 1994, *Lygus* spp. ranked 3rd among cotton pests within the cotton-growing states, accounting for 1.16% of the total yield reduction. In Tennessee in 1994, *Lygus* spp. ranked 2nd and accounted for 2.26% of the total yield reduction (Williams 1995). *Lygus lineolaris* (Palisot de Beauvois), the tarnished plant bug (TPB), is a serious pest of cotton in the eastern United States. This insect pest is most commonly controlled with insecticides applied early in the cotton-growing season. The use of insecticides for early-season pest management, however, can reduce beneficial arthropod populations. This reduction in natural enemies may result in greater pest densities, and may increase the selection pressure for resistance in other pests occurring throughout the season (Scott et al. 1987, DeBach and Rosen 1991).

Until recently, pest management included multiple applications of broad-spectrum insecticides to control all cotton pests (Nemec et al. 1993). This philosophy led to insecticide resistance in many key pests. Insecticide applications must be properly managed to reduce resistance problems. To manage pyrethroid resistance in late-season pests, primarily the bollworm, *Helicoverpa zea* (Boddie), and the tobacco budworm *Heliothis virescens* (F.), organophosphates are applied for management of early-season pests (Nemec et al. 1993). This practice reduces the exposure of and selection pressure on late-season pests which can be successfully controlled with pyrethroids.

Research to determine the efficacies of insecticides are necessary due to the dependence on organophosphates for management of TPB. Studies such as these can aid in determining if resistance is developing in a pest so that producers can be informed of necessary changes in management practices. Resistance development from continued applications also supports the resurgence of other key pests and secondary pests.

Field evaluations of insecticides are important for several reasons. First, they help to monitor the response of insects to a particular rate of insecticide. Second, chemical companies and cooperators also use field trials to determine the effectiveness of new insecticides against a particular pest, and at what rate they are most effective. Researchers and industry personnel use the results of such studies to determine application rates on insecticide labels. The objectives of this study were to:

1. determine the efficacy of early-season insecticides applied for management of TPB at rates equal to and below those recommended by the University of Tennessee Agricultural Extension Service, and

2. determine the efficacy of insecticides that are currently under review to be labeled for management of TPB.

ii. MATERIALS AND METHODS

In 1993 and 1994, a series of tests was conducted at the West Tennessee Experiment Station, Jackson, TN, to determine the efficacy of insecticides recommended for control of TPB in cotton. The insecticides and rates evaluated are listed in Table 1. Each year, treatments were replicated three times in a randomized complete block design.

a. 1993

Fertilizer (15:15:15 at 48.2 kg/ha of N:P:K) was applied on April 12, and again (34:0:0 at 38.6 kg/ha of N:P:K) on May 17. 'Stoneville 453' cotton seed was planted on May 17, at 17.05 kg/ha in 96.5 cm rows and a depth of 2.54 cm. Aldicarb (0.57 kg AI/ha) and pentachloronitrobenzene (PCNB) (11.36 kg/ha) were applied in furrow at planting for insect and disease control, respectively. Fluometuron (2.37 liters/ha) and pendimethalin (0.85 kg AI/A) were applied preemergence at planting for weed control.

Plots were two rows (96.5 cm spacing) by 6.1 m. Sleeve cages, made of organza and having both ends open, were placed on two plants per plot and pulled down to the base of the plant. Treatments were applied July 12 (Test 1), July 28 (Test 2), August 5 (Test 3), and August 11 (Test 4). Applications were made with a two-row CO_2 backpack sprayer calibrated to deliver 56.78 liters/ha at 276 kPa and 4.83 km/hr. The sleeve cages were pulled up from the

Table 1. Insecticides and rates (kg AI/ha) evaluated for efficacy on tarnished plant bug (West Tennessee Experiment Station, Jackson, TN, 1993 and 1994).

Treatment	Rate (kg AI/ha)
1993 -- Test 1 and Test 2	
Untreated	----
Acephate 90S	1.02
Azinphosmethyl 2L	0.28
Chlorpyrifos 4E	0.22
Dicrotophos 8E	0.23
Dimethoate 2.67EC	0.28
Malathion 5EC	1.42
Methyl parathion 4E	0.28
Oxamyl C-LV	0.20
Sulprofos 6EC	0.28
1993 -- Test 3 and Test 4	
Untreated	----
Acephate 90S	1.02
Acephate 90S	0.77
Acephate 90S	0.51
Acephate 90S	0.26
Azinphosmethyl 2L	0.38
Azinphosmethyl 2L & Dimethoate 2.67EC	0.28 & 0.17
Azinphosmethyl 2L & Dimethoate 2.67EC	0.14 & 0.20
Cyfluthrin 2	0.04
Dicrotophos 8E	0.20
Dicrotophos 8E	0.17
Malathion 5EC	1.42
Malathion 5EC	1.24
Malathion 5EC	1.07
Methyl parathion 4EC	0.28

Table 1. (Continued)

Treatment	Rate (kg AI/ha)
1994 -- Test 1 and Test 2	
Untreated	----
Acephate 90S	1.02
Azinphosmethyl 2L	0.28
Azinphosmethyl 2L & Dimethoate 2.67EC	0.28 & 0.17
Azinphosmethyl 2L & Dimethoate 2.67EC	0.14 & 0.23
Chlorpyrifos 4EC	0.22
Cyfluthrin 2EC	0.04
Dicrotophos 8EC	0.23
Dimethoate 2.67EC	0.28
Malathion 5EC	1.42
Methyl parathion 4EC	0.28
Oxamyl C-LV	0.20
Sulprofos 6EC	0.28
1994 -- Test 3 and Test 4	
Untreated	----
Azinphosmethyl 2L & Chlorpyrifos 4EC	0.14 & 0.17
Azinphosmethyl 2L & Dimethoate 2.67EC	0.14 & 0.17
Ethyl parathion 4.67EC	0.28
Fipronil 80WP	0.06
Imidacloprid 2F	0.05
Methyl parathion 25CS	0.28
Methyl parathion 40CS	0.28
Methyl parathion 3.75EC	0.28
Methyl parathion 4EC	0.28
Methyl parathion 4EC & Dimethoate 2.67EC	0.28 & 0.23
Profenofos 8EC	0.28

base of the plants, and five field-collected TPB adults were aspirated into each cage.

All TPB were collected from an alfalfa field located on the West Tennessee Experiment Station. TPB were collected 24 hours prior to use but in some instances TPB were collected as cages were infested. TPB were held overnight in glass jars (3.8 liter) with organza lids. An aspirating tube was inserted into the jar and five adult TPB were withdrawn. The cages were secured at the top with a twist tie and labeled as to treatment and replication. After 48 hours, the cotton plants were removed from the field using pruning clippers and taken into the laboratory where the number of living and dead TPB were recorded.

Forty-eight hours after treatment, another organza sleeve cage was placed onto one plant per plot, as previously described, to evaluate residual activity (Residual Tests 1 and 2). Five field-collected TPB adults, collected as described above, were aspirated into the cage, which was then secured at the top and labeled. Cotton plants were removed from the field 24 hours after infestation and taken to the laboratory where the number of living and dead TPB was recorded.

Some of the insecticides which provided over 95% control in the first series of tests were re-evaluated to assess their efficacy below recommended rates (Tests 3 and 4) (Table 1). These tests were performed as described previously except that residual activity was not tested.

b. 1994

Fertilizer (15:15:15 at 42 kg/ha of N:P:K) was applied on April 13, and again (34:0:0 at 38.2 kg/ha of N:P:K) on April 27. Stoneville 453 cotton seed was planted on May 2, in 96.5 cm rows at 17.05 kg/ha and a depth of 2.54 cm. Aldicarb (3.98 kg/ha) and PCNB (9.09 kg/ha) were applied in furrow at planting for insect and disease control, respectively. On May 9, fluometuron (3.55 liters/ha), pendimethalin (1.77 liters/ha), and metolachlor (1.18 liters/ha) were applied for weed control.

Plots were four rows (96.5 cm spacing) by 6.1 m. Organza sleeve cages were placed onto four plants per plot and pulled down to the base of the plant. Treatments were applied July 19 (Test 1), July 27 (Test 2), August 2 (Test 3), and August 15 (Test 4). Treatments were applied using an International Harvester 660 Highboy with a four row boom at 5 km/hr. The boom was equipped with three hollowcone TXVS 4 nozzles per row with one nozzle over the row and two nozzles on drops, and delivered 14.29 liters/min at 276 kPa. Sleeve cages were then pulled up from the base of the plants, and ten field-collected TPB adults were aspirated into each of two of the four cages. The remaining two cages were used to study the residual effects of the insecticide.

All TPB were collected from an alfalfa field on the West Tennessee Experiment Station. TPB were collected 24 hours prior to use and in some instances TPB were collected as cages were infested. TPB were held in modified colony cages as described by Snodgrass and McWilliams (1992). An aspirating tube was inserted into the cage and ten adult TPB were withdrawn. Sleeve cages were secured at the top with a twist tie and labeled as to treatment and replication. After 48 hours, the cotton plants were cut off below the sleeve cage using pruning clippers and taken to the laboratory where the number of living and dead TPB were recorded.

Forty-eight hours after treatment, ten field-collected adult TPB, collected as previously described, were placed in each of the remaining two sleeve cages to evaluate residual activity. The number of living and dead TPB was recorded after 24 hours of exposure to the treated plants. A second series of tests (Tests 3 and 4) was conducted to assess the impact of insecticides that are currently under review to be labeled for management of TPB (Table 1). Insecticides in the mixtures containing azinphosmethyl, chlorpyrifos, dimethoate, and methyl parathion 4EC in Tests 3 and 4 are currently labeled for TPB management. These tests were performed as described for recommended insecticides.

The arcsin transformation of the data for all experiments was analyzed using General Linear Models. Means were separated using Tukey's Studentized Range Test ($P \leq 0.05$) (SAS 1989).

iii. RESULTS AND DISCUSSION

a. 1993

In Test 1, the mortalities from all treated plots except the azinphosmethyl-treated plot were significantly different from the mortalities in the untreated plots after 48 hours of exposure to the insecticides (Table 2). However, mortality in the azinphosmethyl-treated plot was not significantly different from the mortality displayed in the chlorpyrifos- and oxamyl-treated plots. Similar results occurred in Test 2; after 48 hours of exposure to the insecticide, mortalities in all treated plots except the dimethoate-treated plots were significantly different from the mortalities in the untreated plots. Averaged analyses of these tests show that mortalities found in all treated plots were significantly different from the mortality in the untreated plots.

In Test 2, acephate provided 100% control of TPB. The mortalities of TPB in azinphosmethyl-, chlorpyrifos-, dicrotophos-, malathion-, methyl parathion-, oxamyl-, and sulprofos-treated plots were not significantly different from those in the acephate-treated plot. Mortality of TPB was greater than 95% in the dicrotophos-, malathion-, and methyl parathion-treated plots, while azinphosmethyl, chlorpyrifos, oxamyl, and sulprofos provided 79-93% control.

No significant differences among treatments were detected in Residual Test 1 (Table 3). Significant differences among treatments were detected in Residual Test 2. However, these differences were not separated by Tukey's

Table 2. Initial efficacy (% mortality) of insecticides recommended for management of the tarnished plant bug on cotton (West Tennessee Experiment Station, Jackson, TN, 1993).

TREATMENT	kg AI per ha	Test 1 Jul 14[a]	Test 2 Jul 30	Average Tests 1 & 2
Untreated	----	27.8 ± 11.9c[b,c]	0.00 ± 0.0b	15.2 ± 7.6c
Acephate 90S	1.02	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a
Azinphosmethyl 2L	0.28	69.4 ± 5.2bc	85.8 ± 4.6a	77.6 ± 4.3b
Chlorpyrifos 4E	0.22	77.5 ± 12.4ab	93.3 ± 6.7a	85.4 ± 7.1ab
Dicrotophos 8E	0.23	100.0 ± 0.0a	96.0 ± 4.0a	98.1 ± 1.8a
Dimethoate 2.67EC	0.28	95.8 ± 4.2a	6.9 ± 4.5b	51.4 ± 13.7b
Malathion 5EC	1.42	100.0 ± 0.0a	96.7 ± 3.3a	98.2 ± 1.8a
Methyl parathion 4E	0.28	100.0 ± 0.0a	97.2 ± 2.8a	98.5 ± 1.5a
Oxamyl C-LV	0.20	88.3 ± 5.3ab	79.2 ± 7.4a	84.1 ± 4.9ab
Sulprofos 6EC	0.28	95.0 ± 5.0a	82.5 ± 8.1a	88.2 ± 5.2ab

a) Sampling date 48 hours after treatment.
b) Mortality is listed in terms of % dead ± SE. The letters following are from Tukey's Studentized Range Test of the arcsin transformation of the % dead ($P<0.05$).
c) Means within a column followed by the same letter are not significantly different.

Table 3. Residual efficacy (% mortality) of insecticides recommended for management of the tarnished plant bug on cotton (West Tennessee Experiment Station, Jackson, TN, 1993).

TREATMENT	kg AI per ha	Residual Test 1 Jul 15[a]	Residual Test 2 Jul 31	Average Residual Tests 1 & 2
Untreated	----	86.7 ± 13.3a[b,c]	6.7 ± 6.7c[d]	46.7 ± 19.1a
Acephate 90S	1.02	91.7 ± 8.3a	80.0 ± 20.0a	85.8 ± 10.0a
Azinphosmethyl 2L	0.28	73.3 ± 17.6a	40.0 ± 20.0bc	56.7 ± 14.1a
Chlorpyrifos 4E	0.22	77.5 ± 2.5a	20.0 ± 11.6c	43.0 ± 15.5a
Dicrotophos 8E	0.23	41.7 ± 19.2a	34.4 ± 8.7bc	38.1 ± 9.6a
Dimethoate 2.67EC	0.28	66.7 ± 17.6a	0.0 ± 0.0c	33.3 ± 16.9a
Malathion 5EC	1.42	86.7 ± 6.7a	66.7 ± 17.6ab	76.7 ± 9.5a
Methyl parathion 4E	0.28	100.0 ± 0.0a	0.0 ± 0.0c	50.0 ± 22.4a
Oxamyl C-LV	0.20	73.3 ± 13.3a	67.8 ± 24.4ab	70.6 ± 12.5a
Sulprofos 6EC	0.28	63.3 ± 18.6a	12.5 ± 12.5c	45.8 ± 13.8a

a) Sampling date 72 hours after treatment.
b) Mortality is listed in terms of % dead ± SE. The letters following are from Tukey's Studentized Range Test of the arcsin transformation of the % dead ($P<0.05$).
c) Means within a column followed by the same letter are not significantly different.
d) $P<0.05$. Letters are from Least Square Means Pairwise Comparisons.

Studentized Range Test. Least squares means were estimated and the resulting probability matrix was used to determine significant differences among the means. Least squares means showed that the mortalities found in acephate-, malathion-, and oxamyl-treated plots were significantly greater than the mortalities found in the untreated, chlorpyrifos-, dimethoate-, methyl parathion-, and sulprofos-treated plots. In Residual Test 2, the insecticides which provided significantly greater control than the untreated plots were also those that yielded the greatest control in Tests 1 and 2 (i.e., acephate and malathion).

The averaged analyses of both residual tests showed no significant differences among treatments. The highest averaged mortality of TPB was found in acephate- and malathion-treated plots.

In Test 3, the highest percent mortality occurred in malathion-treated plots at all rates (Table 4). In Test 4, all treated plots yielded significantly higher mortality than the untreated plots. Averaged analyses show that malathion, dicrotophos, and acephate could be used at lower rates and still yield 80% or greater mortality.

b. 1994

No significant differences were found among the mortalities of the untreated and treated plots for Test 1 (Table 5). Acephate-, azinphosmethyl/dimethoate- (both rates), cyfluthrin-, dimethoate- (alone), and

Table 4. Efficacy (% mortality) of insecticides recommended for management of the tarnished plant bug on cotton for rates at and below recommended rates (West Tennessee Experiment Station, Jackson, TN, 1993).

TREATMENT	kg AI per ha	Test 3 Aug 7[a]	Test 4 Aug 13	Average Tests 3 & 4
Untreated	----	0.00 ± 0.0d[bc]	31.7 ± 11.7c	15.8 ± 5.1d
Acephate 90S	1.02	80.0 ± 8.9abc	100.0 ± 0.0a	90.0 ± 3.6ab
Acephate 90S	0.77	60.8 ± 12.1abcd	100.0 ± 0.0a	80.4 ± 5.7ab
Acephate 90S	0.51	80.0 ± 7.3abc	----	----
Acephate 90S	0.26	27.5 ± 6.6cd	----	----
Azinphosmethyl 2L	0.38	46.1 ± 13.6bcd	73.3 ± 11.2b	59.7 ± 6.5b
Azinphosmethyl 2L & Dimethoate 2.67EC	0.28 0.17	----	100.0 ± 0.0a	----
Azinphosmethyl 2L & Dimethoate 2.67EC	0.14 0.23	----	100.0 ± 0.0a	----
Cyfluthrin 2	0.04	----	90.0 ± 6.8ab	----
Dicrotophos 8E	0.23	69.2 ± 15.2abc	100.0 ± 0.0a	84.6 ± 5.9ab
Dicrotophos 8E	0.20	46.7 ± 15.2bcd	100.0 ± 0.0a	73.3 ± 7.5bc
Dicrotophos 8E	0.17	83.9 ± 3.3abc	96.7 ± 3.3a	90.3 ± 2.0ab
Malathion 5EC	1.42	96.7 ± 4.0a	100.0 ± 0.0a	98.3 ± 1.2a
Malathion 5EC	1.24	96.7 ± 3.3a	100.0 ± 0.0a	98.3 ± 1.2a
Malathion 5EC	1.07	83.3 ± 9.5a	----	----
Methyl parathion 4EC	0.28	83.9 ± 6.1abc	96.7 ± 3.3a	90.3 ± 2.0ab

a) Sampling date after treatment.
b) Mortality is listed in terms of % dead ± SE. The letters following are from Tukey's Studentized Range Test of the arcsin transformation of the % dead ($P<0.05$).
c) Means within a column followed by the same letter are not significantly different.

Table 5. Initial efficacy (% mortality) of insecticides recommended for management of the tarnished plant bug on cotton (West Tennessee Experiment Station, Jackson, TN, 1994).

Treatment	kg AI per ha	Test 1 Jul 21[a]	Test 2 Jul 29	Average Tests 1 & 2
Untreated	----	73.7 ± 10.9abc[bc]	45.6 ± 11.7b	59.6 ± 8.7c
Acephate 90S	1.02	98.3 ± 1.7ab	94.3 ± 4.1a	96.3 ± 2.2a
Azinphosmethyl 2L	0.28	73.5 ± 10.2bc	83.1 ± 5.7ab	78.3 ± 5.8abc
Azinphosmethyl 2L & Dimethoate 2.67EC	0.28 0.17	98.6 ± 1.4ab	87.4 ± 5.3ab	93.0 ± 3.1a
Azinphosmethyl 2L & Dimethoate 2.67EC	0.14 0.23	98.8 ± 1.2ab	94.3 ± 4.1a	96.6 ± 2.2a
Chlorpyrifos 4EC	0.22	42.7 ± 8.9c	80.6 ± 10.8ab	61.7 ± 8.8bc
Cyfluthrin 2	0.04	100.0 ± 0.0a	75.3 ± 7.6ab	87.7 ± 5.2ab
Dicrotophos 8EC	0.23	93.2 ± 5.0ab	94.6 ± 2.5a	93.9 ± 2.7a
Dimethoate 2.67EC	0.28	98.3 ± 1.7ab	75.2 ± 15.6ab	86.8 ± 8.3ab
Malathion 5EC	1.42	98.3 ± 1.7ab	93.0 ± 4.5a	95.7 ± 2.4a
Methyl parathion 4EC	0.28	92.9 ± 3.4ab	75.8 ± 12.5ab	84.3 ± 6.7abc
Oxamyl C-LV	0.20	87.2 ± 10.9ab	94.1 ± 4.5a	90.6 ± 5.7a
Sulprofos 6EC	0.28	82.3 ± 5.5abc	79.7 ± 12.5ab	81.0 ± 4.3abc

a) Sampling date 48 hours after treatment.
b) Mortality is listed in terms of % dead ± SE. The letters following are from Tukey's Studentized Range Test of the arcsin transformation of the % dead ($P<0.05$, unless otherwise indicated).
c) Means within a column followed by the same letter are not significantly different.

malathion-treated plots yielded 98% control and higher of TPB. Several significant differences were detected in Test 2. Acephate-, azinphosmethyl (0.14 kg/ha)/dimethoate (0.23 kg/ha)-, dicrotophos-, malathion-, and oxamyl-treated plots displayed significantly greater mortality of TPB (93.0-94.6% mortality) than the untreated plots.

Averaged analyses yielded results similar to those obtained from the individual tests. Acephate-, azinphosmethyl/dimethoate (both rates)-, cyfluthrin-, dicrotophos-, dimethoate-, malathion-, and oxamyl-treated plots provided significantly greater mortality than the untreated plots.

No significant differences were found among treatments in Residual Test 1 (Table 6). Significant differences among treatments were detected in Residual Test 2. However, these differences were not separated by Tukey's Studentized Range Test. The probability matrix generated from estimating least squares means was used to determine significant differences among the means. Acephate-, cyfluthrin-, malathion-, and oxamyl-treated plots had significantly greater mortality of TPB than the untreated plots. These insecticides also displayed significantly greater mortality than the untreated plots in the initial series of tests (Tests 1 and 2).

Few differences were observed among treatments in Test 3 (Table 7). Mortalities of TPB in azinphosmethyl (0.14kg/ha)/dimethoate (0.17 kg/ha)-, fipronil-, and methyl parathion 25CS-treated plots were significantly greater

Table 6. Residual efficacy (% mortality) of insecticides recommended for management of the tarnished plant bug on cotton (West Tennessee Experiment Station, Jackson, TN, 1994).

Treatment	kg AI per ha	Residual Test 1 Jul 22[a]	Residual Test 2 Jul 30	Average Residual Tests 1 & 2
Untreated	----	5.1 ± 3.0a[b]	10.0 ± 5.3c[c]	8.00 ± 3.3b
Acephate 90S	1.02	16.6 ± 7.2a	46.4 ± 9.6ab	34.5 ± 7.8a
Azinphosmethyl 2L	0.28	10.6 ± 6.1a	28.9 ± 9.2bc	21.6 ± 6.5a
Azinphosmethyl 2L & Dimethoate 2.67EC	0.28 0.17	9.1 ± 3.7a	26.0 ± 11.2bc	19.2 ± 7.2a
Azinphosmethyl 2L & Dimethoate 2.67EC	0.14 0.23	9.7 ± 5.5a	36.5 ± 7.7abc	24.3 ± 6.3a
Chlorpyrifos 4EC	0.22	5.1 ± 3.0a	27.8 ± 11.3bc	18.7 ± 7.6a
Cyfluthrin 2	0.04	----	53.0 ± 14.3a	----
Dicrotophos 8EC	0.23	----	22.5 ± 8.3c	----
Dimethoate 2.67EC	0.28	----	27.0 ± 7.4bc	----
Malathion 5EC	1.42	----	50.5 ± 7.7ab	----
Methyl parathion 4EC	0.28	----	10.8 ± 5.5c	----
Oxamyl C-LV	0.20	3.3 ± 2.1a	46.7 ± 11.6ab	25.0 ± 8.6a
Sulprofos 6EC	0.28	----	19.7 ± 9.7c	----

a) Sampling date 72 hours after treatment.

b) Mortality is listed in terms of % dead ± SE. The letters following are from Tukey's Studentized Range Test of the arcsin transformation of the % dead ($P<0.05$).

c) Means separated by Least Square Means Pairwise Comparisons. Means within a column followed by the same letter are not significantly different.

Table 7. Initial efficacy (% mortality) of insecticides selected for management of the tarnished plant bug on cotton (West Tennessee Experiment Station, Jackson, TN, 1994).

Treatment	kg AI per ha	Test 3 Aug 4[a]	Test 4 Aug 17	Average Tests 3 & 4
Untreated	---	36.1 ± 12.7b[bc]	14.7 ± 6.9b	25.4 ± 7.6c
Azinphosmethyl 2L & Chlorpyrifos 4EC	0.14 0.17	64.8 ± 11.7ab	50.6 ± 17.0ab	57.7 ± 10.1abc
Azinphosmethyl 2L & Dimethoate 2.67EC	0.14 0.17	91.7 ± 8.3a	48.4 ± 16.3ab	70.0 ± 10.9ab
Ethyl parathion 4.67EC	0.28	----	40.0 ± 10.0ab	----
Fipronil 80WP	0.06	93.6 ± 4.6a	88.3 ± 9.8a	91.0 ± 5.2a
Imidacloprid 2F	0.05	81.1 ± 6.2ab	14.7 ± 9.0b	50.9 ± 11.6bc
Methyl parathion 25CS	0.28	95.8 ± 4.2a	----	----
Methyl parathion 40CS	0.28	54.1 ± 16.4ab	----	----
Methyl parathion 3.75EC	0.28	----	41.4 ± 19.1ab	----
Methyl parathion 4EC	0.28	----	23.1 ± 14.1b	----
Methyl parathion 4EC & Dimethoate 2.67EC	0.28 0.23	----	66.7 ± 16.1ab	----
Profenofos 8EC	0.28	57.0 ± 15.0ab	23.3 ± 6.2b	38.6 ± 8.9bc

a) Sampling date 48 hours after treatment.
b) Mortality is listed in terms of % dead ± SE. The letters following are from Tukey's Studentized Range Test of the arcsin transformation of the % dead ($P<0.05$).
c) Means within a column followed by the same letter are not significantly different.

than mortality in the untreated plots. In Test 4, only the mortality of TPB in the fipronil-treated plots was significantly greater than in the untreated plots. Averaged analyses of these data provided similar results.

Results of the residual tests of selected insecticides were similar to the initial series shown in Table 7 (Table 8). Averaged analyses of these residual data show that mortality of TPB was significantly greater in fipronil-treated plots than in the untreated plots.

iv. SUMMARY

In 1993, no differences in the activity (ability of an insecticide to kill) of acephate, dicrotophos, chlorpyrifos, malathion, methyl parathion, and sulprofos were observed after 48 hours of exposure to the insecticides. The averaged range of control expressed as percent mortality for these insecticides was 85.4-100.0%. These insecticides provided good initial control of adult TPB; however, only acephate and malathion provided good residual control (85.8% and 76.7%, respectively).

Acephate, dicrotophos, and malathion applied below recommended rates controlled TPB. Azinphosmethyl or dimethoate alone did not cause as much TPB mortality as they did when used in combination. Cyfluthrin, which was tested only once, provided good initial control. In these evaluations, acephate

Table 8. Residual efficacy (% mortality) of insecticides selected for management of the tarnished plant bug on cotton (West Tennessee Experiment Station, Jackson, TN, 1994).

Treatment	kg AI per ha	Residual Test 3 Aug 5[a]	Residual Test 4 Aug 18	Average Residual Tests 3 & 4
Untreated	---	4.20 ± 2.8b[bc]	24.6 ± 16.9ab	13.5 ± 8.0b
Azinphosmethyl 2L & Chlorpyrifos 4EC	0.14 0.17	7.70 ± 3.9b	17.3 ± 11.3ab	12.5 ± 5.9b
Azinphosmethyl 2L & Dimethoate 2.67EC	0.14 0.17	3.60 ± 3.3b	24.6 ± 11.5ab	15.1 ± 7.0b
Ethyl parathion 4.67EC	0.28	----	65.0 ± 21.8a	----
Fipronil 80WP	0.06	59.6 ± 13.2a	66.5 ± 17.9ab	57.5 ± 10.8a
Imidacloprid 2F	0.05	22.6 ± 11.9b	37.8 ± 11.2ab	30.2 ± 8.1ab
Methyl parathion 25CS	0.28	9.40 ± 4.8b	----	----
Methyl parathion 40CS	0.28	9.50 ± 3.5b	----	----
Methyl parathion 3.75EC	0.28	----	47.4 ± 13.6ab	----
Methyl parathion 4EC	0.28	----	14.0 ± 5.5ab	----
Methyl parathion 4EC & Dimethoate 2.67EC	0.28 0.23	----	33.9 ± 20.9ab	----
Profenofos 8EC	0.28	12.3 ± 7.0b	3.20 ± 2.0b	7.80 ± 3.7b

a) Sampling date 72 hours after treatment.

b) Mortality is listed in terms of % dead ± SE. The letters following are from Tukey's Studentized Range Test of the arcsin transformation of the % dead ($P<0.05$).

c) Means within a column followed by the same letter are not significantly different.

and malathion provided good initial and residual mortality and also were effective at below recommended rates.

In 1994, no differences were observed in the activity of acephate, dicrotophos, malathion, oxamyl, and the azinphosmethyl/dimethoate tank mix, at both rates, after 48 hours of exposure to the insecticides. The averaged range of control, expressed as percent mortality, for these insecticides was 93.0-96.6%. These insecticides provided good initial control of adult TPB; however, only cyfluthrin and malathion, which caused 87.7% mortality in the initial test, provided at least 50% residual control (50.5 and 53.0%, respectively).

Of the insecticides not labeled for TPB control, methyl parathion 25CS provided 95.8% initial control but only 9.4% residual control. Fipronil, which should be strongly considered for labeling against TPB, provided an average of 91.0% control with 57.5% residual control. From both series of tests, azinphosmethyl and dimethoate, when used in combination provided better control than when applied separately.

From these tests, acephate, malathion, and azinphosmethyl/dimethoate (0.14 & 0.17 kg AI/ha) provided more than 95% initial mortality as well as adequate residual control. Oxamyl, a carbamate insecticide, could be used in place of organophosphates, for control of TPB. The use of oxamyl also would aid in reducing organophosphate resistance in TPB and late-season pests.

In comparing the two years of this study, acephate, malathion, and oxamyl consistently provided good initial and residual control of TPB. The combination of azinphosmethyl and dimethoate in both years caused higher mortality than either azinphosmethyl or dimethoate alone. The pyrethroid, cyfluthrin, which was not extensively evaluated, appears to be effective for controlling TPB. However, pyrethroids are not recommended as early-season treatments because such treatments might increase the likelihood of pyrethroid resistance in late-season pests (Georghiou 1990). The high mortalities of TPB in acephate-, dicrotophos-, and oxamyl-treated plots for initial and residual studies may be influenced by the systemic properties of these insecticides. After absorption into the plant, these insecticides are transported through the plant to provide protection.

The effect an insecticide has on an insect pest can be altered by environmental conditions, such as wind and rain. Rainfall following application can reduce the activity of the insecticide by simply washing it off the plant. Winds affect insecticide activity; if wind speeds are high the insecticide may drift off target leaving desired plants unprotected. Rainfall data collected in 1993 and 1994 at the West Tennessee Experiment Station provide no evidence that insecticide activity in these tests was influenced by rain.

These data can be used to monitor the development of resistance in TPB in West Tennessee. Comparisons between data collected in subsequent years can be made to determine if the response of TPB to common rates is changing.

If the efficacy of an insecticide changes, further studies can be conducted to determine the cause. Low mortalities could indicate that resistance to those insecticides has developed. The information obtained through this research can be used by chemical companies in labeling insecticides, and by the Agricultural Extension Service in making insecticide recommendations to producers.

CHAPTER III

IMPACT OF SELECTED INSECTICIDES ON BENEFICIAL ARTHROPOD POPULATIONS IN COTTON

i. INTRODUCTION

Public concern has focused recently on the impact of pesticides on the environment. This concern has been partially responsible for the increased emphasis on integrated pest management (IPM). Cultural, mechanical, and biological control techniques are supplemented by the judicious application of insecticides for control of insects in the production of agricultural crops.

In the crop ecosystem, beneficial arthropods (or natural enemies) are a naturally occurring means of biological control. Spiders, parasitoids, and predaceous insects aid in the management of crop pests. It has been theorized that natural enemies capable of killing pests over a range of pest densities and reproducing successfully over those densities can cause a substantial decrease in pest population numbers (Waage 1992). Reduced producer input (i.e., pesticides, labor, equipment etc.) can be achieved by encouraging beneficial arthropods.

Because synthetic chemical pesticides do not discriminate between pests and natural enemies, their application can be detrimental to populations of both.

Pesticides also may cause pest increases rather than controlling them, as well as making new pests of species that were not pests before treatment (DeBach and Rosen 1991). In California, the application of insecticides for control of *Lygus* spp. in cotton induced outbreaks of secondary pests because of the insecticidal effects on natural enemy populations (Huffaker et al. 1978). Beneficial organisms, as well as pests, are killed and show sublethal effects, including changes in fertility, fecundity, development, and survivorship, as a result of contact with insecticides (Croft 1990).

The elimination of natural enemies provides an opportunity for resurgence of key pests and/or outbreaks of secondary pests. In the San Joaquin Valley of California, organophosphate treatments for *Lygus* spp. had severe impacts on beneficial arthropod populations that aided in keeping *Heliothis* spp., beet armyworm, *Spodoptera exigua* (Hübner), and cabbage looper, *Trichoplusia ni* (Hübner), at acceptable levels. In eight weekly experiments, mortality of *Heliothis* spp., exposed for two days to native natural enemies, averaged 86.6% per day. Augmenting the number of predators reduced *Heliothis* spp. 90-99.5% (Sterling et al. 1989).

Utilization of selective insecticides may prove advantageous in controlling early-season pests, such as *Lygus lineolaris* Palisot de Beauvois, the tarnished plant bug (TPB), while still allowing increases in beneficial arthropod numbers. Studies concerning the impact of insecticides on beneficial arthropod populations are important in determining which insecticide treatments support the role of beneficial arthropods in pest management. The objective of this study was to determine the response of beneficial arthropod populations to early-season cotton insecticides, applied for management of *L. lineolaris*.

ii. MATERIALS AND METHODS

The impact of early-season insecticides on beneficial arthropod populations was studied at the Milan Experiment Station (MES), Milan, TN, in the summer of 1994. Prior to planting, nitrogen was applied to the field at 90.91 kg/ha. On May 9, 1994, the field was disked and treated with pendimethalin (2365 ml/ha) and fluometuron (2365 ml/ha) for weed control. Stoneville 453 cotton seed was then planted in the river bottom area of MES, in 101.6 cm rows at 17.05 kg/ha and a depth of 2.54 cm. Aldicarb (3.98 kg/ha) and metalaxyl (9.09 kg/ha) were applied in-furrow at planting for insect and disease control, respectively.

On June 13, 1994, dicrotophos (296 ml/ha) was applied as a foliar insecticide. Cyanazine (2365 ml/ha) and monosodium acid methanearsonate (MSMA) (2.27 kg/ha) herbicides were post-directed on June 21, 1994. Dimethoate was applied as a foliar insecticide at 236.8 ml/ha on June 29, 1994.

A randomized complete block design with four blocks and seven treatments was used. Treatments (insecticides and rates) are listed in Table 9.

Table 9. Insecticides and rates (kg AI/ha) evaluated for their impact on beneficial arthropods in cotton (Milan Experiment Station, Milan, TN, 1994).

Treatment	Rate (kg AI/ha)
Untreated	---
Acephate 90S	1.02
Azinphosmethyl 2EC	0.28
Dicrotophos 8EC	0.45
Malathion 5EC	1.42
Methyl parathion 4EC	0.28
Oxamyl C-LV	0.20

Plots were 16 rows and 30.5m long. On July 5, 1994, treatments were applied using an IH 660 Highboy with a 4 row boom at 5 km/hr. The boom was equipped with three hollowcone TXVS 4 nozzles per row with one nozzle over the row and two nozzles on drops, and delivered 14.29 liters/min at 276 kPa.

Beneficial arthropods were sampled using a sweep net. On each sampling date, 50 sweeps per 30.5 m were collected from each of two rows per treatment. Samples were collected immediately before treatment, and 1, 3, 7, and 14 days after treatment. Border rows were left between treatments, and on each collection date samples were taken from rows not previously sampled. Prior to treatment, samples were collected from rows 4 and 13; 1 day after treatment from rows 5 and 12; 3 days after treatment from rows 6 and 11; 7 days after treatment from rows 7 and 10; and, 14 days after treatment from rows 8 and 9.

Paper towels were placed in the bottom of cardboard containers (3.7-liter) and moistened with ethyl acetate. A label with collection information (i.e., test number, date, block, and treatment) also was placed into each container. The net was (quickly and carefully) inverted, and the sample was emptied into the appropriate cardboard container.

Samples were taken to the laboratory and processed. Each sample was emptied into a dissecting pan. Plant material was removed and the contents of the pan were transferred through a funnel into a 20-ml scintillation vial containing the appropriate label. The interior of the funnel was rinsed into the vial with 70% ethyl alcohol until the vial was filled. Each vial was later emptied into a petri dish and beneficial arthropods were counted. The interior of the vial was then rinsed with 70% ethyl alcohol to ensure that all beneficial arthropods were counted. Lady beetle and lacewing larvae and adults were counted. A list of the beneficial arthropods counted is provided in Table 10.

Data were log transformed and analyzed using General Linear Models (SAS 1989). Means were separated using least squares means pair-wise comparisons ($P \leq 0.05$).

iii. RESULTS AND DISCUSSION

Pre-treatment densities of arachnids were higher than those of most of the other beneficial arthropods. Methyl parathion- and oxamyl-treated plots had significantly greater pre-treatment densities than did the untreated plots (Figure 1, Table 11). No significant differences among treatments were found for any of the remaining sampling dates. Densities of arachnids in treated plots followed the same trend as those in untreated plots (Figure 1).

Overall numbers of big-eyed bugs collected were low throughout this study. Densities of big-eyed bugs, prior to treatment, were significantly different among treatments; densities in untreated plots were significantly lower than those in acephate- and azinphosmethyl-treated plots (Figure 2, Table 12).

Table 10. Groups of beneficial arthropods observed and counted from cotton samples (Milan Experiment Station, Milan, TN, 1994).

Order	Family	Groups Counted
Coleoptera	Coccinellidae	Convergent lady beetle
		Pink lady beetle
		Seven-spotted lady beetle
		Nine-spotted lady beetle
		Species A
		Species B
		Species C
		Lady beetle larvae
Hemiptera	Anthocoridae	Minute pirate bug
	Berytidae	Stilt bug
	Lygaeidae	Big-eyed bug
	Nabidae	Damsel bug
	Pentatomidae	Spined soldier bug
Hymenoptera		Various families
Neuroptera	Chrysopidae	Green lacewing
	Hemerobiidae	Brown lacewing
		Lacewing larvae
Arachnida		All

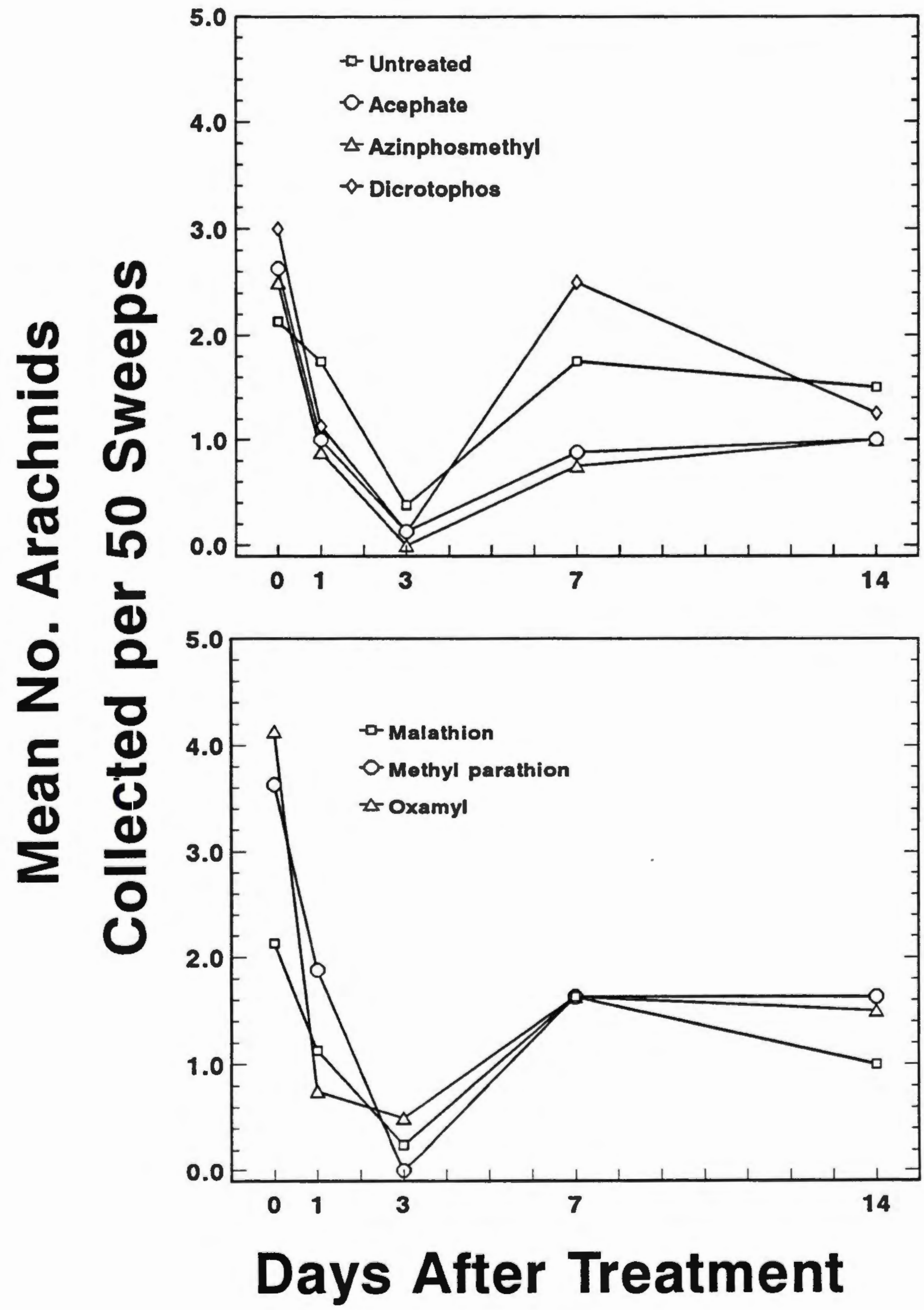


Figure 1. Impact of selected insecticides on densities of arachnids per 50 sweep-net samples (Milan Experiment Station, Milan, TN, 1994).

Table 11. Impact of selected insecticides on densities of arachnids per 50 sweep-net samples (Milan Experiment Station, Milan, TN, 1994).

TREATMENT	Sampling Date				
	Pre-treatment Jul 5	1 DAT[a] Jul 6	3 DAT Jul 8	7 DAT Jul 12	14 DAT Jul 19
Untreated	2.13 ± 0.8b[b]	1.75 ± 0.5a	0.38 ± 0.2a	1.75 ± 0.7a	1.50 ± 0.4a
Acephate	2.63 ± 0.9ab	1.00 ± 0.3a	0.13 ± 0.1a	0.88 ± 0.4a	1.00 ± 0.4a
Azinphosmethyl	2.50 ± 0.5ab	0.88 ± 0.3a	0.00 ± 0.0a	0.75 ± 0.3a	1.00 ± 0.3a
Dicrotophos	3.00 ± 0.9ab	1.13 ± 0.3a	0.13 ± 0.1a	2.50 ± 0.6a	1.25 ± 0.6a
Malathion	2.13 ± 0.3ab	1.13 ± 0.3a	0.25 ± 0.2a	1.63 ± 0.4a	1.00 ± 0.5a
Methyl Parathion	3.63 ± 0.7a	1.88 ± 0.9a	0.00 ± 0.0a	1.63 ± 0.5a	1.63 ± 0.5a
Oxamyl	4.13 ± 0.9a	0.75 ± 0.3a	0.50 ± 0.3a	1.63 ± 0.7a	1.50 ± 0.4a

a) DAT = days after treatment.

b) Means (± SE) within a column followed by the same letter are not significantly different (P>0.05). The letters following are from Least Square Means Pairwise Comparison Tests of the log transformed data.

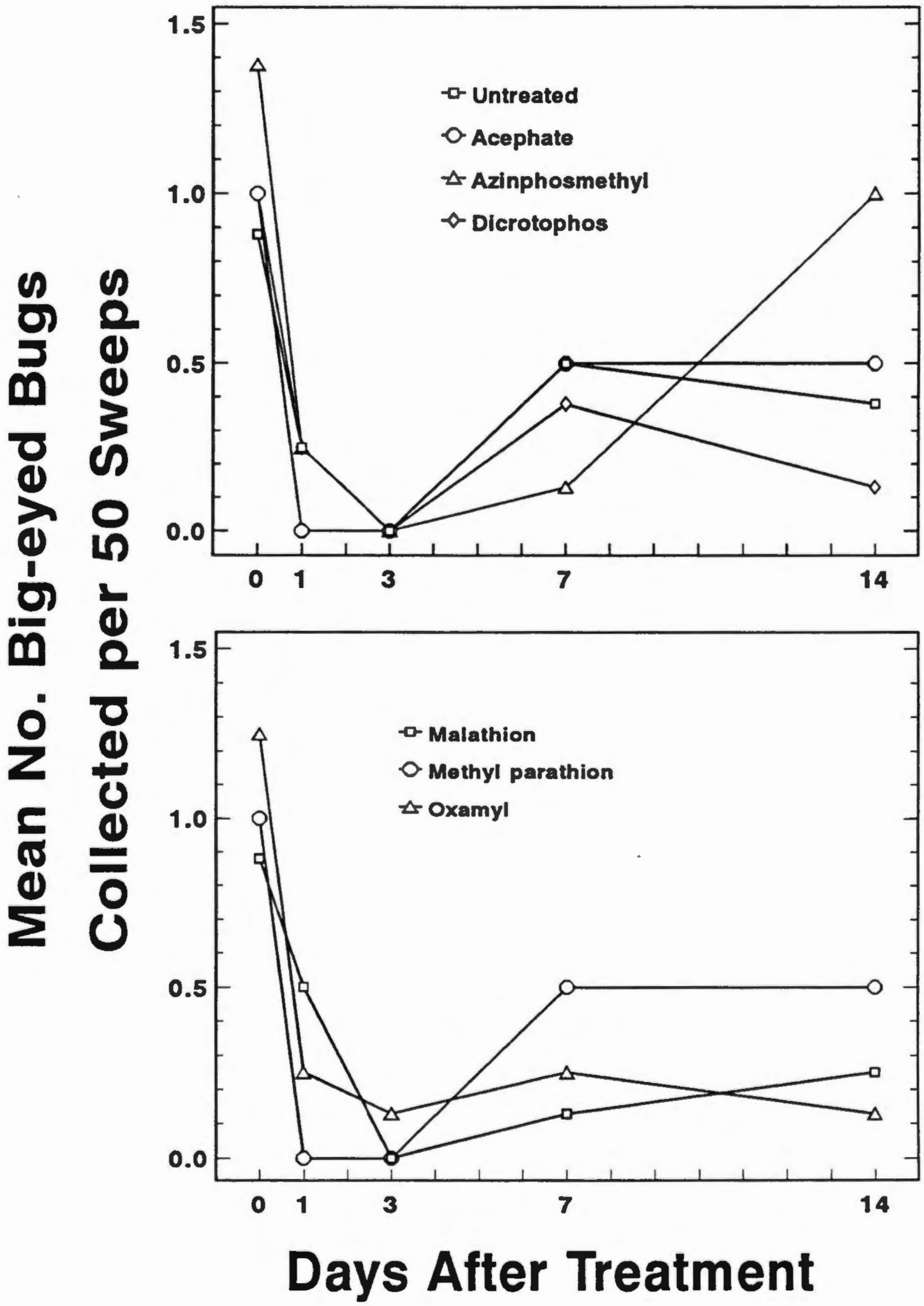


Figure 2. Impact of selected insecticides on densities of big-eyed bugs per 50 sweep-net samples (Milan Experiment Station, Milan, TN, 1994).

Table 12. Impact of selected insecticides on densities of big-eyed bugs per 50 sweep-net samples (Milan Experiment Station, Milan, TN, 1994).

	Sampling Date				
TREATMENT	Pre-treatment Jul 5	1 DAT[a] Jul 6	3 DAT Jul 8	7 DAT Jul 12	14 DAT Jul 19
Untreated	0.88 ± 0.3b[b]	0.25 ± 0.2a	0.00 ± 0.0a	0.50 ± 0.3a	0.38 ± 0.2ab
Acephate	1.13 ± 0.1a	0.25 ± 0.2a	0.00 ± 0.0a	0.13 ± 0.1a	0.75 ± 0.3ab
Azinphosmethyl	1.38 ± 0.4a	0.25 ± 0.2a	0.00 ± 0.0a	0.13 ± 0.1a	1.00 ± 0.3a
Dicrotophos	1.00 ± 0.3ab	0.25 ± 0.2a	0.00 ± 0.0a	0.38 ± 0.3a	0.13 ± 0.1b
Malathion	0.88 ± 0.5ab	0.50 ± 0.2a	0.00 ± 0.0a	0.13 ± 0.1a	0.25 ± 0.2b
Methyl Parathion	1.00 ± 0.5ab	0.00 ± 0.0a	0.00 ± 0.0a	0.50 ± 0.3a	0.50 ± 0.4ab
Oxamyl	1.25 ± 0.5ab	0.25 ± 0.2a	0.13 ± 0.1a	0.25 ± 0.2a	0.13 ± 0.1b

a) DAT = days after treatment.

b) Means (± SE) within a column followed by the same letter are not significantly different ($P>0.05$). The letters following are from Least Square Means Pairwise Comparison Tests of the log transformed data.

No significant differences among treatments were found 1, 3, and 7 days post-treatment. Fourteen days post-treatment, significant differences were found among densities of big-eyed bugs in treated plots; however, none of the treatments had densities significantly different from densities in untreated plots.

Densities of minute pirate bugs were similar to those of big-eyed bugs. Densities of minute pirate bugs in treated plots followed the same trend as in untreated plots. No significant differences were found among treatments for each sampling date until 14 days post-treatment (Figure 3, Table 13). On this date, acephate-, dicrotophos-, and oxamyl-treated plots had significantly lower densities of minute pirate bugs than did the untreated, malathion-, and methyl parathion-treated plots. A reduction in prey densities due to the systemic nature of acephate, dicrotophos, and oxamyl, as well as minute pirate bug feeding on the plant, may have caused the decrease in densities of minute pirate bugs within these plots.

Pre-treatment densities of hymenopterans, similar to those of big-eyed bugs, differed significantly between untreated and malathion-treated plots (Figure 4, Table 14). One day post-treatment, significant differences occurred among treatments; densities of hymenopterans were significantly greater in dicrotophos-, and methyl parathion-treated plots than in acephate- and oxamyl-treated plots. However, hymenopteran densities in treated plots were not significantly different from the untreated plots. No significant differences among treatments were found 3 or 7 days after treatment.

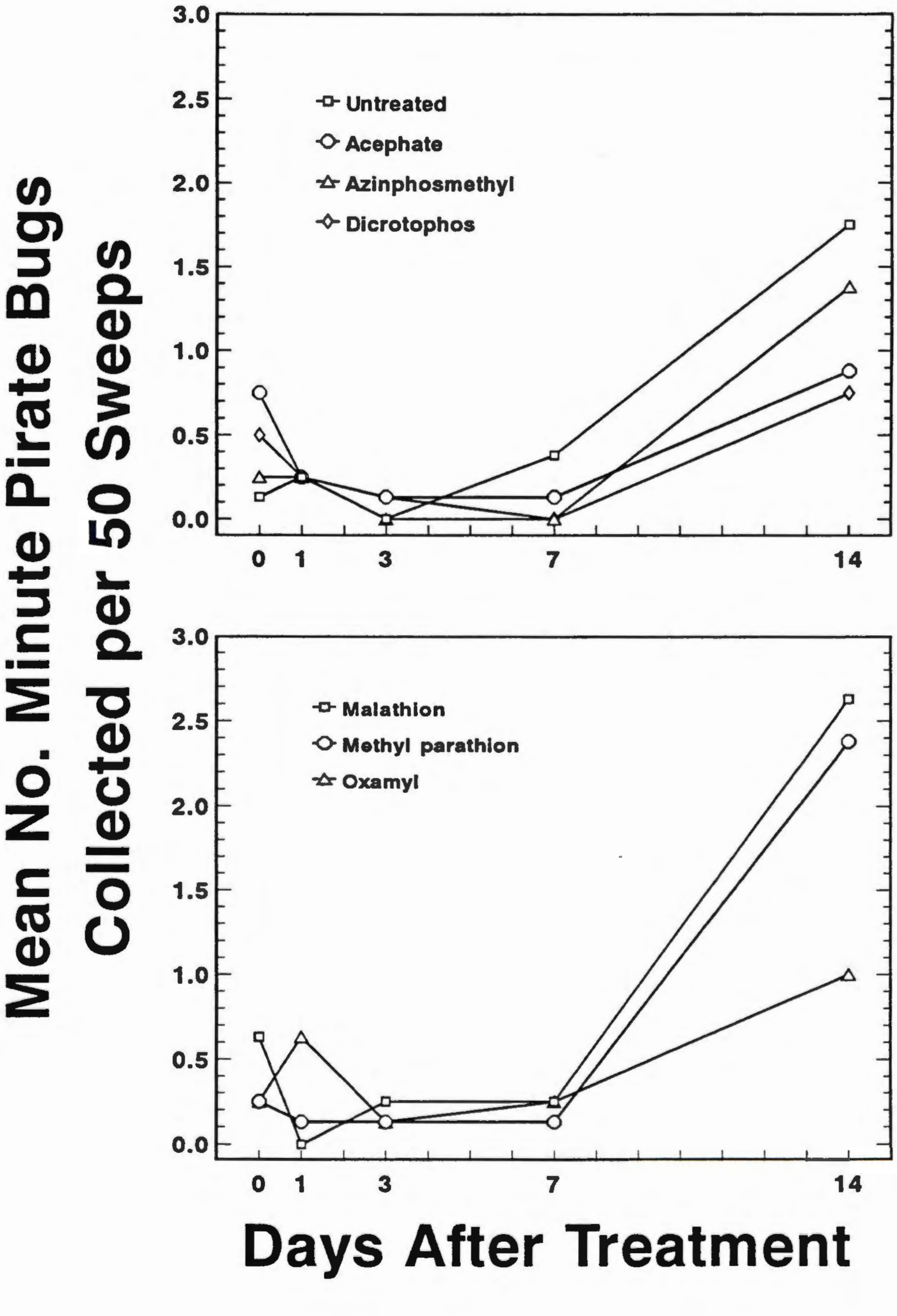


Figure 3. Impact of selected insecticides on densities of minute pirate bugs per 50 sweep-net samples (Milan Experiment Station, Milan, TN, 1994).

Table 13: Impact of selected insecticides on densities of minute pirate bugs per 50 sweep-net samples (Milan Experiment Station, Milan, TN, 1994).

	Sampling Date				
TREATMENT	Pre-treatment Jul 5	1 DAT[a] Jul 6	3 DAT Jul 8	7 DAT Jul 12	14 DAT Jul 19
Untreated	0.13 ± 0.1a[b]	0.25 ± 0.2a	0.00 ± 0.0a	0.38 ± 0.3a	1.75 ± 0.3a
Acephate	0.75 ± 0.4a	0.25 ± 0.2a	0.13 ± 0.1a	0.13 ± 0.1a	0.88 ± 0.3b
Azinphosmethyl	0.25 ± 0.2a	0.25 ± 0.2a	0.00 ± 0.0a	0.00 ± 0.0a	1.38 ± 0.5ab
Dicrotophos	0.50 ± 0.4a	0.25 ± 0.2a	0.13 ± 0.1a	0.00 ± 0.0a	0.75 ± 0.4b
Malathion	0.63 ± 0.4a	0.00 ± 0.0a	0.25 ± 0.3a	0.25 ± 0.2a	2.63 ± 0.8a
Methyl Parathion	0.25 ± 0.2a	0.13 ± 0.1a	0.13 ± 0.1a	0.13 ± 0.1a	2.38 ± 0.8a
Oxamyl	0.25 ± 0.3a	0.63 ± 0.4a	0.13 ± 0.1a	0.25 ± 0.3a	1.00 ± 0.5b

a) DAT = days after treatment.

b) Means (± SE) within a column followed by the same letter are not significantly different ($P>0.05$). The letters following are from Least Square Means Pairwise Comparison Tests of the log transformed data.

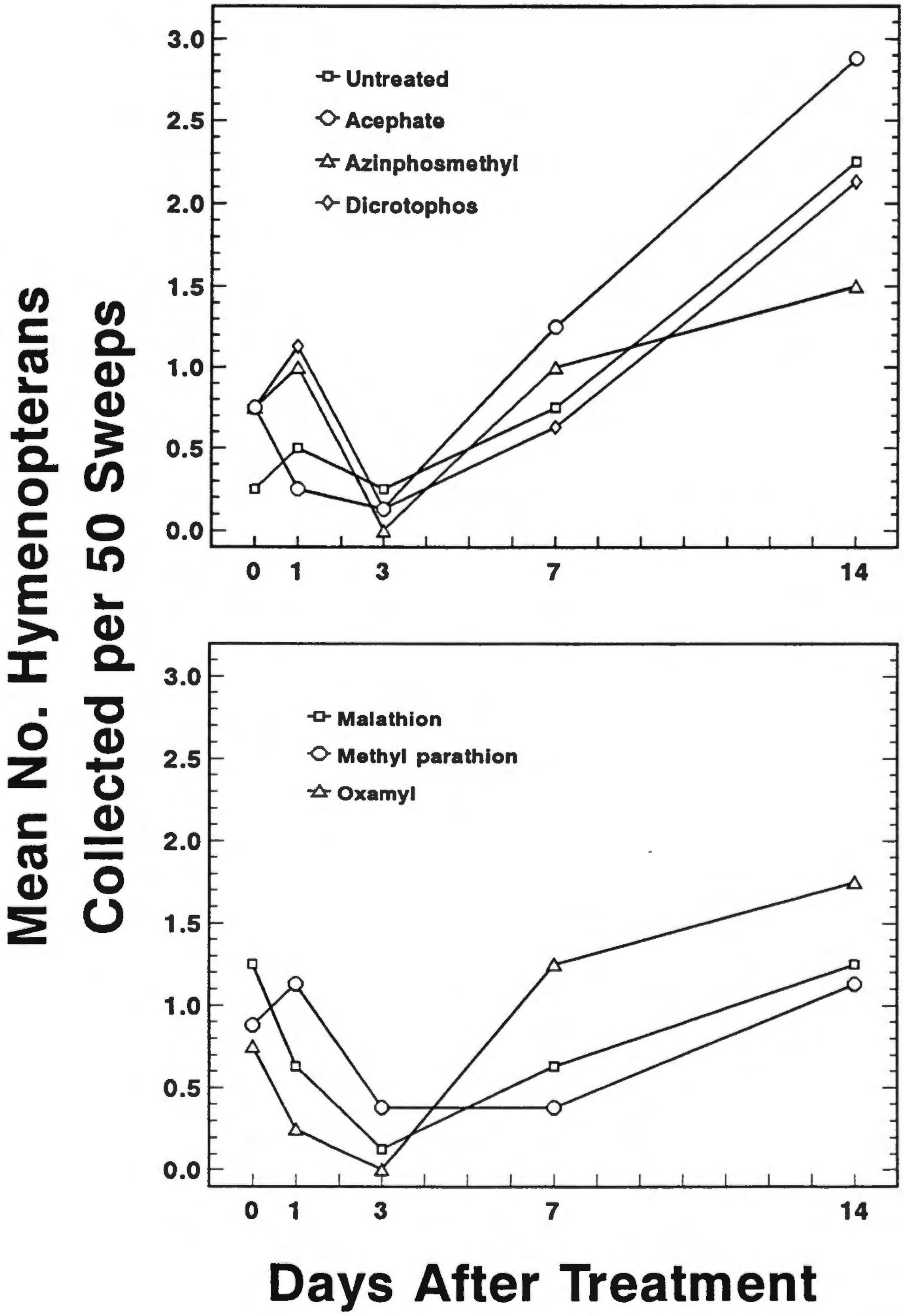


Figure 4. Impact of selected insecticides on densities of hymenopterans per 50 sweep-net samples (Milan Experiment Station, Milan, TN, 1994).

Table 14. Impact of selected insecticides on densities of hymenopterans per 50 sweep-net samples (Milan Experiment Station, Milan, TN, 1994).

	Sampling Date				
TREATMENT	Pre-treatment Jul 5	1 DAT[a] Jul 6	3 DAT Jul 8	7 DAT Jul 12	14 DAT Jul 19
Untreated	0.25 ± 0.2a[b]	0.50 ± 0.3ab	0.25 ± 0.2a	0.75 ± 0.4a	2.25 ± 0.3a
Acephate	0.75 ± 0.3ab	0.25 ± 0.2b	0.13 ± 0.1a	1.25 ± 0.6a	2.88 ± 1.2ab
Azinphosmethyl	0.75 ± 0.3ab	1.00 ± 0.4ab	0.00 ± 0.0a	1.00 ± 0.4a	1.50 ± 0.6abc
Dicrotophos	0.75 ± 0.4ab	1.13 ± 0.3a	0.13 ± 0.1a	0.63 ± 0.3a	2.13 ± 0.4ab
Malathion	1.25 ± 0.3b	0.63 ± 0.3ab	0.13 ± 0.1a	0.63 ± 0.4a	1.25 ± 0.5bc
Methyl Parathion	0.88 ± 0.3ab	1.13 ± 0.3a	0.38 ± 0.2a	0.38 ± 0.2a	1.13 ± 0.6c
Oxamyl	0.75 ± 0.4ab	0.25 ± 0.2b	0.00 ± 0.0a	1.25 ± 0.3a	1.75 ± 0.7abc

a) DAT = days after treatment.

b) Means (± SE) within a column followed by the same letter are not significantly different (P>0.05). The letters following are from Least Square Means Pairwise Comparison Tests of the log transformed data.

Densities of hymenopterans increased 14 days after treatment for all treatments. Fourteen days post-treatment, acephate- and dicrotophos-treated plots had significantly greater densities of hymenopterans than those found in methyl parathion-treated plots. Densities in malathion- and methyl parathion-treated plots differed significantly from the untreated plots. The lower densities in these two treatments may be an effect of the treatment in that fewer pests were present to be parasitized.

Densities of hymenopterans 14 days after treatment were greater in the systemic insecticide plots (acephate, dicrotophos, and oxamyl) while densities of minute pirate bugs were lowest in these treatment plots (Tables 13 and 14). Because minute pirate bugs may feed on plant juices, it is possible that systemic insecticides reduced their densities. However, densities of minute pirate bugs were greater in malathion- and methyl parathion-treated plots, whereas hymenopteran densities in those same plots were significantly lower than those in untreated plots.

Densities of lady beetles showed no significant differences among treatments pre-treatment, 1, or 3 days after treatment. Lady beetle densities collected 1 and 3 days after treatment decreased in densities collected and increased rapidly after 3 days post-treatment (Figure 5, Table 15).

An increase in densities of lady beetles occurred 7 days after treatment (Figure 5). Densities of lady beetles followed the trend of the untreated plots until 7 days after treatment. On this date, densities of lady beetles were

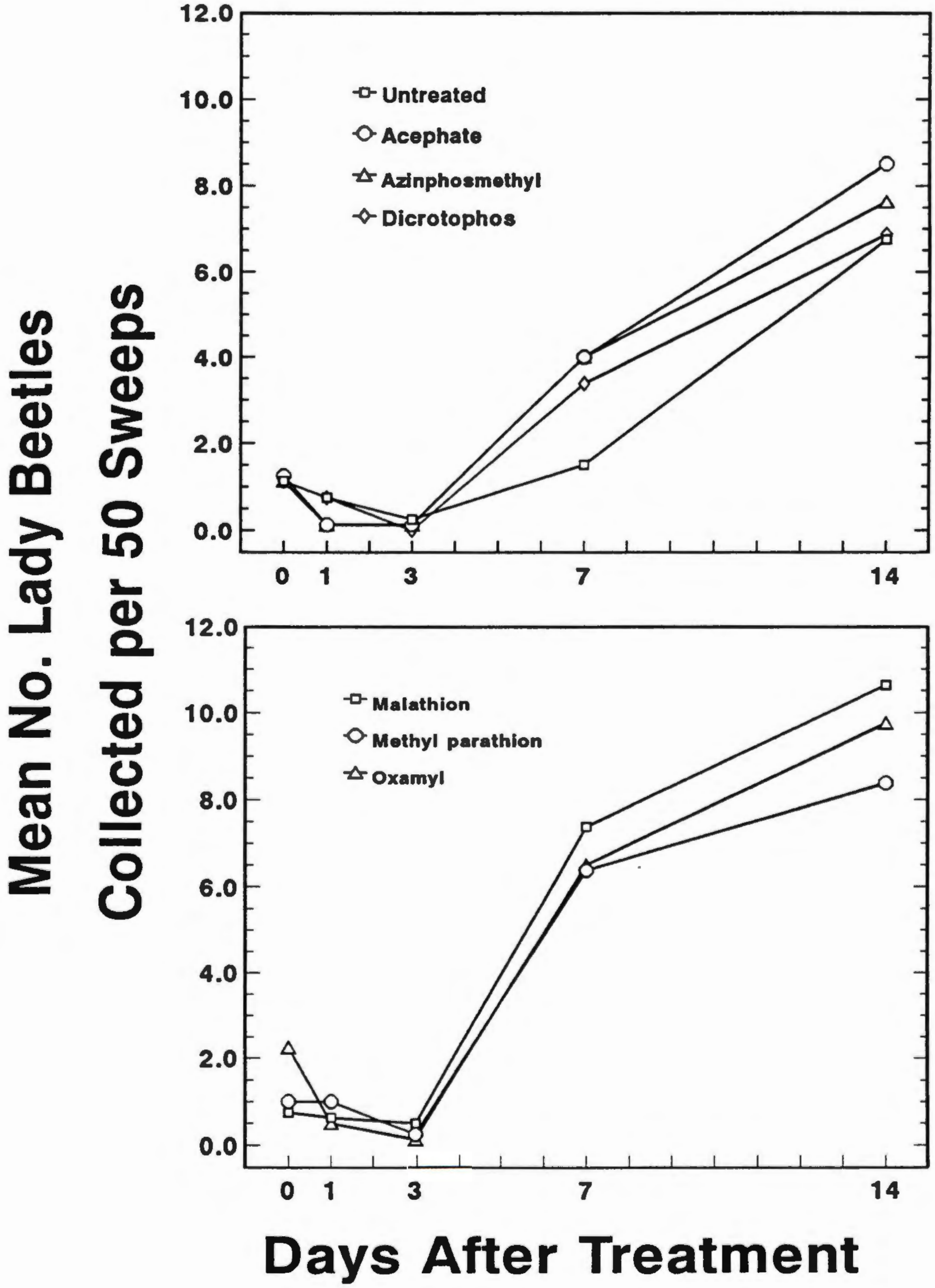


Figure 5. Impact of selected insecticides on densities of lady beetles per 50 sweep-net samples (Milan Experiment Station, Milan, TN, 1994).

Table 15. Impact of selected insecticides on densities of lady beetles per 50 sweep-net samples (Milan Experiment Station, Milan, TN, 1994).

	Sampling Date				
TREATMENT	Pre-treatment Jul 5	1 DAT[a] Jul 6	3 DAT Jul 8	7 DAT Jul 12	14 DAT Jul 19
Untreated	1.13 ± 0.5a[b]	0.75 ± 0.3a	0.25 ± 0.2a	1.50 ± 0.5c	6.75 ± 0.8c
Acephate	1.25 ± 0.4a	0.13 ± 0.1a	0.13 ± 0.1a	4.00 ± 1.2b	8.50 ± 0.9bc
Azinphosmethyl	1.13 ± 0.3a	0.13 ± 0.1a	0.13 ± 0.1a	4.00 ± 1.3b	7.63 ± 1.2c
Dicrotophos	1.13 ± 0.3a	0.75 ± 0.3a	0.00 ± 0.0a	3.38 ± 0.4b	6.88 ± 0.7c
Malathion	0.75 ± 0.2a	0.63 ± 0.3a	0.50 ± 0.3a	7.38 ± 0.9a	10.6 ± 1.5a
Methyl Parathion	1.00 ± 0.3a	1.00 ± 0.5a	0.25 ± 0.2a	6.38 ± 0.6a	8.38 ± 0.8bc
Oxamyl	2.25 ± 0.6a	0.50 ± 0.2a	0.13 ± 0.1a	6.50 ± 1.2a	9.75 ± 1.2ab

a) DAT = days after treatment.

b) Means (± SE) within a column followed by the same letter are not significantly different ($P>0.05$). The letters following are from Least Square Means Pairwise Comparison Tests of the log transformed data.

significantly greater in treated plots than in untreated plots, with malathion-, methyl parathion-, and oxamyl-treated plots supporting significantly greater densities than any other treatment (Table 15).

Densities of lady beetles in treated plots, as well as untreated plots, increased more by 14 days after treatment. On this date, only malathion- and oxamyl-treated plots had significantly more lady beetles than untreated plots. The increases in lady beetle densities may be related to the availability of prey (i.e., aphids) 14 days post-treatment.

Green lacewings, brown lacewings, and lacewing larvae were collected in low numbers during this study. No significant differences were found among treatments prior to treatment, 1 or 3 days after treatment; however, significant differences were found on 7 and 14 days after treatment (Figure 6, Table 16). Seven days after treatment, densities of lacewings were significantly greater in malathion-treated plots than in dicrotophos-treated plots, but these densities were not significantly different from those in untreated plots. Densities of lacewings in the acephate-treated plots increased from an average of 0.50 lacewing per 50 sweeps (7 days after treatment) to 2.25 lacewings per 50 sweeps (14 days after treatment). These densities 14 days after treatment were significantly greater than densities in the untreated plots and malathion-treated plots. No other treatments were significantly different from the untreated plots 14 days after treatment.

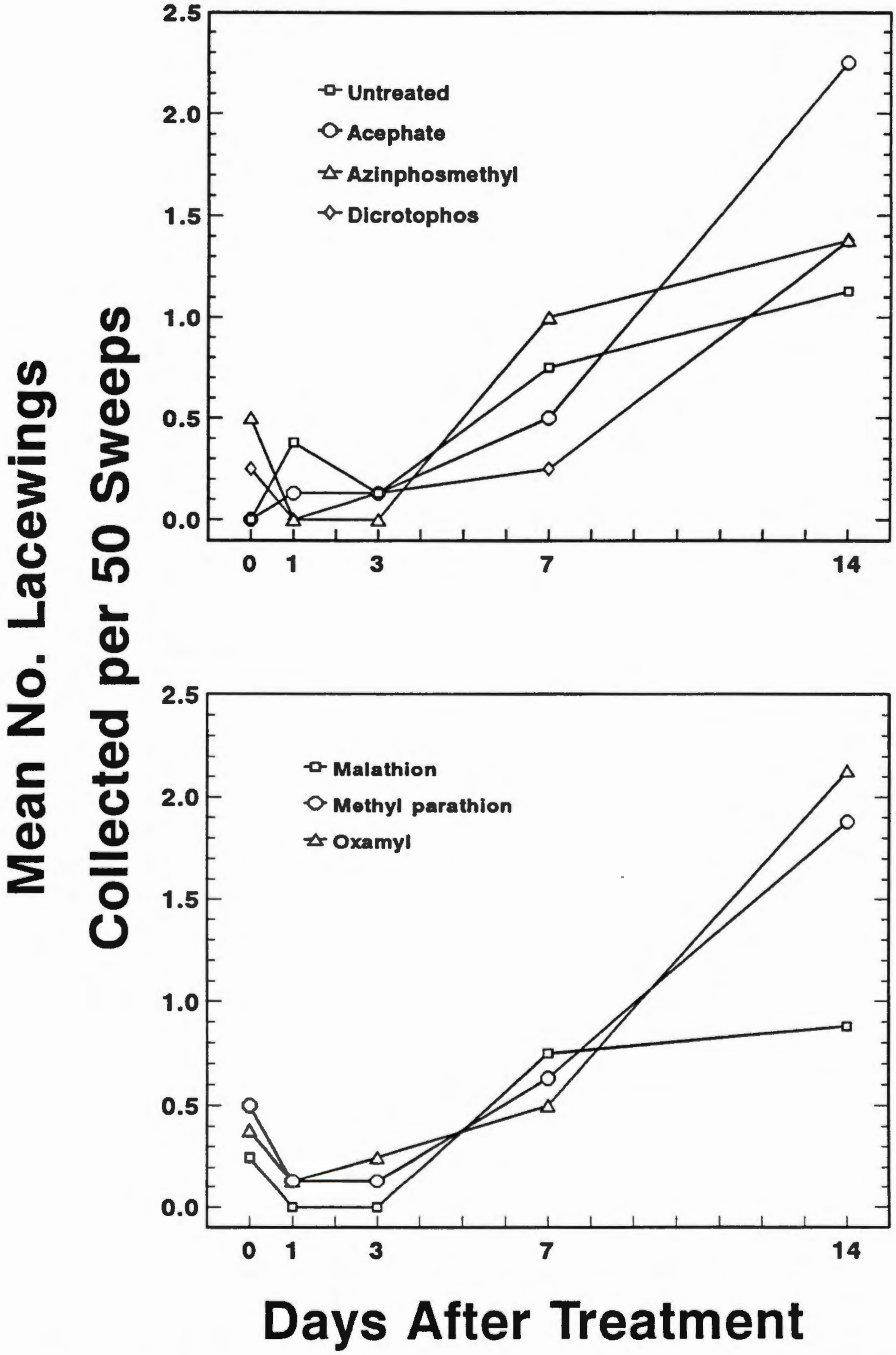


Figure 6. Impact of selected insecticides on densities of lacewings per 50 sweep-net samples (Milan Experiment Station, Milan, TN, 1994).

Table 16. Impact of selected insecticides on densities of lacewings per 50 sweep-net samples (Milan Experiment Station, Milan, TN, 1994).

	Sampling Date				
TREATMENT	Pre-treatment Jul 5	1 DAT[a] Jul 6	3 DAT Jul 8	7 DAT Jul 12	14 DAT Jul 19
Untreated	0.00 ± 0.0a[b]	0.38 ± 0.2a	0.13 ± 0.1a	0.75 ± 0.3ab	1.13 ± 0.4bc
Acephate	0.00 ± 0.0a	0.13 ± 0.1a	0.13 ± 0.1a	0.50 ± 0.2ab	2.25 ± 0.6a
Azinphosmethyl	0.50 ± 0.3a	0.00 ± 0.0a	0.00 ± 0.0a	1.00 ± 0.5ab	1.38 ± 0.4abc
Dicrotophos	0.25 ± 0.2a	0.00 ± 0.0a	0.13 ± 0.1a	0.25 ± 0.2b	1.38 ± 0.5abc
Malathion	0.25 ± 0.3a	0.00 ± 0.0a	0.00 ± 0.0a	1.00 ± 0.5a	0.88b ± 0.4c
Methyl Parathion	0.50 ± 0.2a	0.13 ± 0.1a	0.13 ± 0.1a	0.63 ± 0.3ab	1.88 ± 0.5ab
Oxamyl	0.38 ± 0.3a	0.13 ± 0.1a	0.25 ± 0.2a	0.50 ± 0.3ab	2.13 ± 0.7ab

a) DAT = days after treatment.

b) Means (± SE) within a column followed by the same letter are not significantly different (P>0.05). The letters following are from Least Square Means Pairwise Comparison Tests of the log transformed data.

Damsel bugs also were collected in low numbers during this study. Pre-treatment densities of damsel bugs in plots to be treated with methyl parathion were significantly greater than densities in untreated plots and plots to be treated with acephate (Figure 7, Table 17). One day after treatment, densities of damsel bugs were significantly greater in malathion-treated plots than in the untreated or any other treatment plots. Densities of damsel bugs were not significantly different among treatments 3 days after treatment. However, 7 days post-treatment, densities were significantly greater in the azinphosmethyl- and malathion-treated plots than in the untreated plots or any other treatment plots. Except for densities in azinphosmethyl- and malathion-treated plots, other treatments followed the trend as untreated plots. Fourteen days after treatment, no significant differences were detected among any treatments.

iv. SUMMARY

The impact of insecticide treatments on populations of beneficial arthropods in cotton was most evident among lady beetles, minute pirate bugs, big-eyed bugs, and hymenoptera. Densities in treated plots were compared with those in untreated plots to determine deviations from the fluctuations of the untreated plots.

Densities of beneficial arthropods began to decrease 1 day after treatment and continued to decrease for at least 3 days after treatment. This

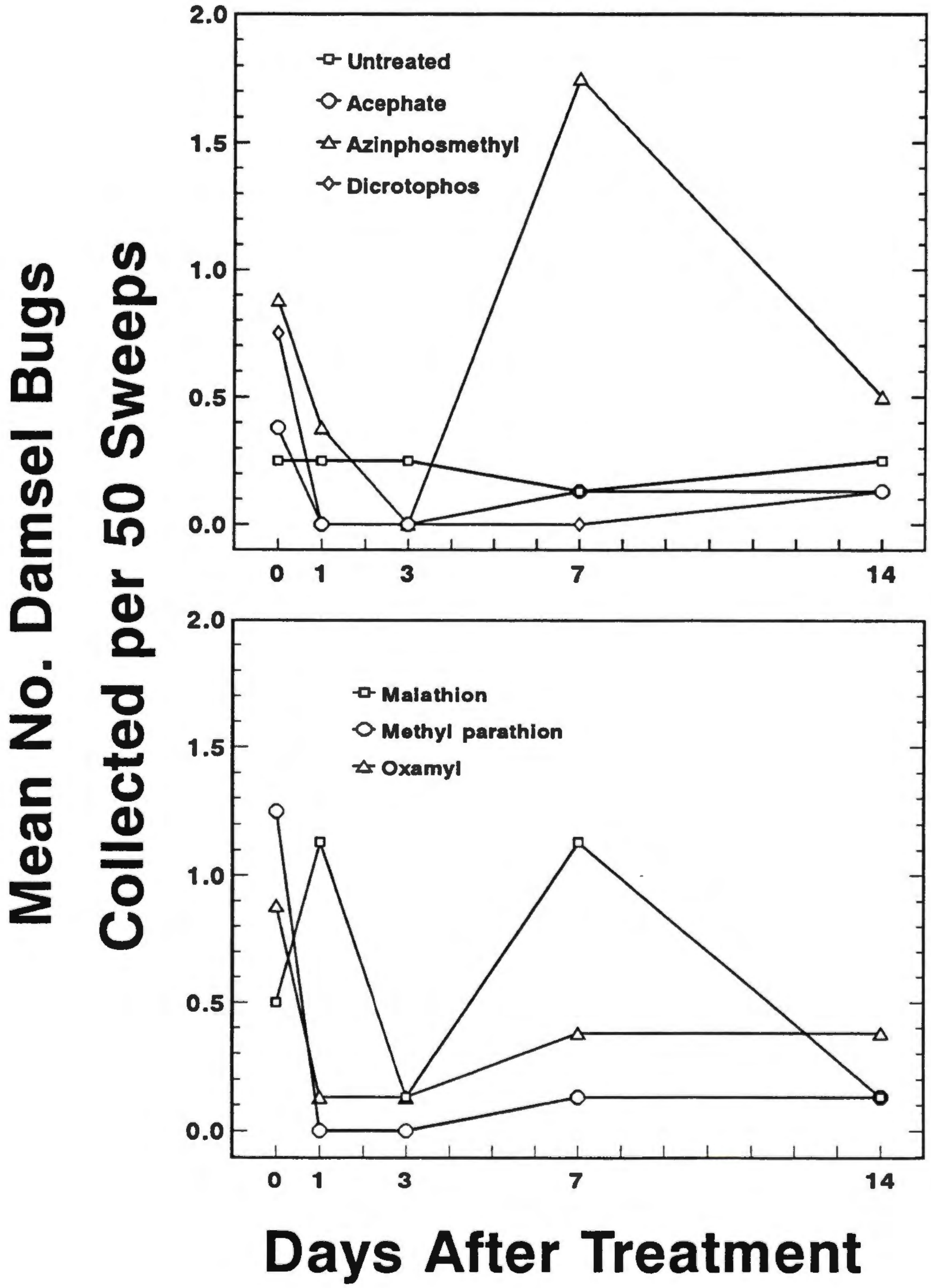


Figure 7. Impact of selected insecticides on densities of damsel bugs per 50 sweep-net samples (Milan Experiment Station, Milan, TN, 1994).

Table 17. Impact of selected insecticides on densities of damsel bugs per 50 sweep-net samples (Milan Experiment Station, Milan, TN, 1994).

	Sampling Date				
TREATMENT	Pre-treatment Jul 5	1 DAT[a] Jul 6	3 DAT Jul 8	7 DAT Jul 12	14 DAT Jul 19
Untreated	0.25 ± 0.2b[b]	0.25 ± 0.2a	0.25 ± 0.2a	0.13 ± 0.1b	0.25 ± 0.2a
Acephate	0.38 ± 0.2b	0.00 ± 0.0a	0.00 ± 0.0a	0.13 ± 0.1b	0.13 ± 0.1a
Azinphosmethyl	0.88 ± 0.4ab	0.38 ± 0.3a	0.00 ± 0.0a	1.75 ± 0.7a	0.50 ± 0.2a
Dicrotophos	0.75 ± 0.3ab	0.00 ± 0.0a	0.00 ± 0.0a	0.00 ± 0.0b	0.13 ± 0.1a
Malathion	0.50 ± 0.3ab	1.13 ± 0.4b	0.13 ± 0.1a	1.13 ± 0.4a	0.13 ± 0.1a
Methyl Parathion	1.25 ± 0.5a	0.00 ± 0.0a	0.00 ± 0.0a	0.13 ± 0.1b	0.13 ± 0.1a
Oxamyl	0.88 ± 0.5ab	0.13 ± 0.1a	0.13 ± 0.1a	0.38 ± 0.2b	0.38 ± 0.2a

a) DAT = days after treatment.

b) Means (± SE) within a column followed by the same letter are not significantly different ($P>0.05$). The letters following are from Least Square Means Pairwise Comparison Tests of the log transformed data.

decrease 3 days after treatment may be due to the loss of prey from surrounding plots and to 3.48 cm of rain the day before sampling (July 7). Seven and 14 days after treatment, densities may have increased as treatment residues were lost. Only lady beetles, hymenopterans, and minute pirate bugs re-populated the treated cotton plots to densities greater than the pre-treatment counts.

This study illustrates that the selectivity of the pesticide applied can have an effect on populations of natural enemies. Insecticides affect different arthropods in various ways. The method of application can affect natural enemy populations. Soil applications of aldicarb and stem applications of monocrotophos to cotton produced mortality of predators, such as *Nabis* spp. and *Geocoris* spp., which feed occasionally on the plant, as well as on prey. Parasitoids, spiders, and lacewing (*Chrysoperla*) larvae were affected to a lesser degree (Ridgway et al. 1967).

The effect a pesticide has on a beneficial arthropod depends on the characteristics of that arthropod (i.e., habitat, life cycle, feeding behavior, and mating behavior). As shown in this study, hymenopterans and minute pirate bugs responded to the same insecticide treatments in opposite ways. These responses may have been correlated to changes in prey densities resulting from treatment applications. Pesticides that are not harmful to generalist predators, such as lacewings, minute pirate bugs, big-eyed bugs, and damsel bugs, may eliminate prey from cotton fields and cause these predators to move to a more suitable location (Croft 1990). This emigration may encourage a resurgence of primary or secondary pests.

Biological and physical factors of the species affected, as well as environmental factors, determine the rate of recolonization of treated areas (Croft 1990). In this study, the application of Dimethoate on June 29, 1994, 6 days before experimental treatments were applied, could possibly have affected the recolonization rates of beneficial arthropods present in the samples collected. *Trichogramma*, coccinellids, and chrysopids required 40 days to return to the level found in the control plot after treatment with diflubenzuron, an insect growth regulator (Ables et al. 1977). However, since the pre-treatment count was taken, the effect of the treatments and comparisons among treatments over time can be made, with the untreated plots serving as a control.

Studies concerning the effects of insecticide treatments on beneficial arthropods are important in establishing IPM guidelines. Due to the selectivity of pesticides, a treatment that may be harmless to, or enhance beneficial populations, can be used. When determining the pesticides to be used, the biology of the natural enemy must be known as well as the effects of environmental conditions on the natural enemy, the available prey, and the treatment to be applied.

Early-season management of pests in cotton is dependent upon the use of insecticides. If the insecticides used in early season deplete beneficial arthropod populations and restrict repopulation by these arthropods, late-season pests, such as the bollworm, *Helicoverpa (=Heliothis) zea* Boddie, are given a greater potential to survive and cause damage and loss within cotton fields.

This study shows that some pesticides may not pose a great threat to populations of beneficial arthropods in a cotton agroecosystem; however, studies support that populations of beneficial arthropods are affected in numerous ways by pesticides. Reducing beneficial arthropod populations increases the potential for greater pest populations. It is important for researchers, extension personnel, and other agricultural workers to be familiar with the pests to be controlled. By knowing the pest situation and the natural enemies effective against that pest, the selection of appropriate pesticides can be made. By using selective insecticides, early-season insect control can be accomplished without affecting the densities of beneficial arthropods that aid in late-season pest control.

CHAPTER IV

EVALUATION OF RESISTANCE IN *Lygus lineolaris* TO SELECTED INSECTICIDES IN WEST TENNESSEE

i. INTRODUCTION

When the effectiveness of a chemical pesticide decreases, producers respond by applying more pesticides. Frequent applications of pesticides may lead to resistance in pest species. In Indonesia, the sole reliance on insecticides as a primary means of insect control in rice led to the development of widespread resistance in the brown planthopper, *Nilaparvata lugens* Stal., and threatened the economy of the country (Treakle and Sacko 1989). Because of the reliance on insecticides, resistance can develop in key cotton pests, such as the bollworm, *Helicoverpa zea* Boddie, and *Spodoptera* spp.

Increased pest resistance limits the effectiveness of many pesticides (Muir 1978). Resistance to organophosphate insecticides was reported 14 years after their introduction in 1944; resistance was reported 5 and 7 years after the introduction of carbamate insecticides and DDT (a chlorinated hydrocarbon), respectively (Brattsten 1990). Pyrethroid insecticides were introduced in 1978 for control of pests, primarily *Helicoverpa/Heliothis* spp., which were resistant to members of other classes of pesticides (Riley 1990).

In the United States, the tobacco budworm, *Heliothis virescens* F., was first reported to be resistant to pyrethroids in 1985 in western Texas (Clower 1987, Bull and Menn 1990).

Control of insect pests in agroecosystems is now focused on integrated pest management which utilizes several means of control, including the judicious application of insecticides. By observing economic thresholds and properly applying selective pesticides, resistance of pests can be managed, prolonging the effectiveness of pesticides. Strategies to limit pesticide resistance can be better implemented if information is available on resistance levels within a population. To monitor the resistance of pests in an area, efficacy tests and laboratory bioassays should be conducted regularly.

Lygus hesperus Knight, a pest of cotton in the western United States, has become resistant to DDT, cyclodienes, and organophosphates (Georghiou and Mellon 1983). Resistance of *L. hesperus* to organophosphate insecticides was first reported in the United States in California in 1977 (Zhu and Brindley 1990). In 1983, *Lygus lineolaris* Palisot de Beauvois, the tarnished plant bug (TPB), the eastern United States relative of *L. hesperus*, was reported to be resistant to organophosphates (Georghiou and Mellon 1983). TPB is most commonly controlled with early-season insecticides. Organophosphates are applied for management of early-season pests, such as TPB, to reduce the exposure and selection pressure on late-season pests, primarily *H. zea*, and *H. virescens*, which can be successfully controlled with pyrethroids.

The occurrence of organophosphate resistance in TPB populations in West Tennessee is not documented. Due to the use of organophosphates on many crops, and the wide host plant range of TPB, populations of this pest are frequently exposed to these insecticides throughout West Tennessee. Information concerning the resistance status of TPB in this region will help determine the proper management tactics for this pest. The objectives of this study were to:

1. evaluate the resistance of TPB populations in cotton with low, medium, and high levels of insecticide use in West Tennessee, and
2. establish LC_{50} values for selected insecticides on TPB.

ii. MATERIALS AND METHODS

A study was conducted in West Tennessee in the summer of 1994 to evaluate the resistance of TPB to selected insecticides (acephate, azinphosmethyl, chlorpyrifos, cyfluthrin, malathion, and methyl parathion). All insecticides except the pyrethroid, cyfluthrin, were organophosphates.

Technical grade material of each insecticide was obtained from Cheminova, Dow Elanco, Miles, and Valent. Each insecticide was serially diluted in 50 ml volumetric flasks using reagent grade acetone. Five μl of a dilution were pipetted into a small plastic zip-lock bag, 50 mm by 100 mm (Xu and Brindley 1993). Concentrations ranged from 0.1 - 50.0 μg per bag and were based on information obtained through personal communication with G.L. Snodgrass (USDA, Stoneville, Mississippi) (Table 18). The bag was closed, and the material was distributed throughout the bag by rubbing the sides together for 10 seconds. Each bag was then re-opened and a hair dryer was used to evaporate the acetone, leaving an insecticide residue of a known concentration on the interior of the bag. A kidney bean was placed into each bag so that the sides of the bag did not touch and the TPB were able to move freely within the bag. Control bags were treated with 5 μl of acetone alone.

Twenty-four bags were prepared for each concentration of each insecticide. Bags of the same concentration of an insecticide were kept together in larger plastic bags to reduce contamination through contact with bags of different concentrations. All bags were stored in a freezer until needed.

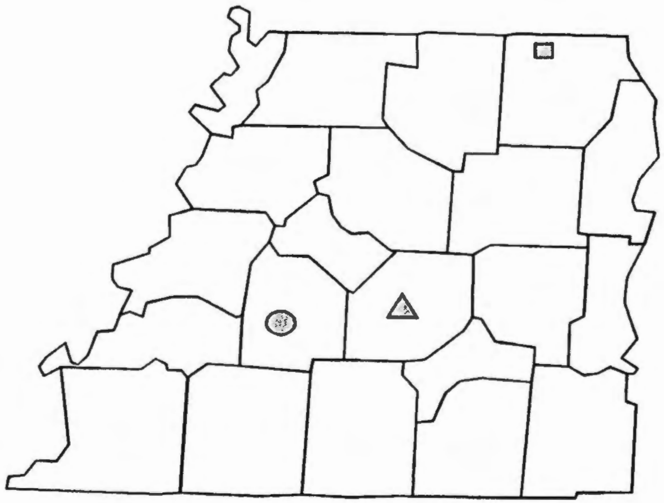
Three sites were chosen for collection of TPB adults based on the level of insecticide use in each area (Figure 8). Puryear, TN (Henry Co.), near the Tennessee-Kentucky border, was chosen as a low cotton-insecticide use site due to the low acreage of cotton produced in that area. The specific site chosen was located adjacent to a tobacco field. TPB were collected from a variety of weed hosts.

The West Tennessee Experiment Station, Jackson, TN (Madison Co.), was chosen as the medium cotton-insecticide use site. TPB were collected from alfalfa and various weed hosts.

Table 18. Concentrations of insecticides evaluated for tarnished plant bug resistance in West Tennessee.

Insecticide	Concentrations Tested (μg/bag)[a]
Acephate	25.00, 10.00, 5.00, 2.50, 1.00, 0.50, 0.25, 0.10
Azinphosmethyl	50.00, 25.00, 10.00, 5.00, 2.50, 1.00, 0.50, 0.25, 0.10
Chlorpyrifos	25.00, 10.00, 5.00, 2.50, 1.00, 0.50, 0.25, 0.10
Cyfluthrin	25.00, 10.00, 5.00, 2.50, 1.00, 0.50, 0.25, 0.10
Malathion	50.00, 25.00, 10.00, 5.00, 2.50, 1.00, 0.50, 0.25, 0.10
Methyl parathion	25.00, 10.00, 5.00, 2.50, 1.00, 0.50, 0.25, 0.10

a) The concentrations evaluated for each insecticide were based on information obtained from G.L. Snodgrass (USDA, Stoneville, Mississippi).



Puryear, TN
Low cotton-producing area

Jackson, TN
Medium cotton-producing area

Brownsville, TN
High cotton-producing area

Figure 8. Sites sampled in West Tennessee for resistance among tarnished plant bug populations.

A site in Brownsville, TN (Haywood Co.), was selected as the high cotton-insecticide use site because of the high cotton acreage in that area. The specific site chosen was located adjacent to a dirt road between two cotton fields. At this site, TPB were collected from horseweed, *Conyza canadensis* (L.) Cronq. Complete insecticide histories for each site were not obtained.

TPB were collected using a sweep-net in Jackson on August 5, 1994, in Puryear on August 11, 1994, and in Brownsville on August 12, 1994. Wild host plants were swept several times; five adult TPB were taken from the net via an aspirating tube and gently blown into a treated or untreated bag. The bags were closed, placed in a cooler and taken to the laboratory where they were held at room temperature. Eight hours after collection the number of dead TPB per bag was recorded (Xu and Brindley 1993). Death was defined as no movement or minimal twitching of the TPB. Data were analyzed using SAS Probit analysis (SAS 1989).

iii. RESULTS AND DISCUSSION

Not all chemicals were tested at the rates necessary to calculate LC_{50} values (Table 19). The resistance data collected shows that the rates evaluated for many of the chemicals were too low to achieve appropriate mortality levels.

Percent mortalities obtained from concentrations of acephate were high enough to obtain LC_{50} values for each site. LC_{50} values for acephate ranged

Table 19. Mean (± SE) mortality of tarnished plant bugs for insecticides evaluated for resistance development in West Tennessee, 1994.

Insecticide	Rate (µg/bag) (Low & High)	Percent Mortality		
		Puryear (Low Use)[a]	Jackson (Medium Use)	Brownsville (High Use)
Acephate	0.1	10.0 ± 7.6	10.3 ± 5.4	16.8 ± 6.3
	25.0	100.0 ± 0.0	100.0 ± 0.0	88.6 ± 10.7
Azinphos methyl	0.1	13.1 ± 5.6	22.7 ± 4.6	3.13 ± 3.1
	50.0	35.0 ± 15.5	48.5 ± 8.2	30.0 ± 13.6
Chlorpyrifos	0.1	10.0 ± 6.6	10.6 ± 5.5	11.7 ± 8.0
	25.0	28.1 ± 11.9	37.3 ± 10.2	24.0 ± 9.3
Cyfluthrin	0.1	7.50 ± 7.5	50.0 ± 15.6	5.00 ± 5.0
	25.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0
Malathion	0.1	20.0 ± 5.8	15.6 ± 7.4	18.1 ± 9.6
	50.0	79.2 ± 11.8	49.6 ± 12.3	45.0 ± 10.5
Methyl parathion	0.1	26.7 ± 14.3	34.4 ± 13.7	45.6 ± 16.7
	25.0	85.0 ± 6.3	80.0 ± 12.5	65.2 ± 12.3
Untreated	----	10.2 ± 4.4	10.2 ± 6.0	3.50 ± 2.7

a) Refers to level of insecticide use in each area.

from 0.95 - 2.40 μg/bag with the Brownsville site showing the most susceptibility (Table 20). Although the Brownsville area is a high cotton-producing area, acephate may not be the insecticide frequently used for insect control (G. Lentz, personal communication). The possibility of TPB populations from the Puryear site showing resistance to acephate was believed to be high because of the location of the site and the reliance on acephate for insect control in tobacco. However, the population of TPB at the Jackson site, in comparison with the other sites, was the most resistant.

Less than 50% mortality resulted at the highest concentration (50μg/bag) of azinphosmethyl. As a result, analysis did not provide LC_{50} values for the Puryear and Jackson sites. The LC_{50} value (1070.00 μg/bag; 95% CL = 62.80 -2.95 E21) calculated for the Brownsville site is outside the range of concentrations tested and cannot be considered an acceptable LC_{50}. This calculated value does support the need for testing at higher concentrations of azinphosmethyl.

The highest concentration (25 μg/bag) of chlorpyrifos tested also was too low to produce 50% mortality at any of the sites. Analysis of the data provided LC_{50} values for Puryear and Jackson (Table 20). However, the LC_{50} value for the Puryear site is out of the range of concentrations tested. The LC_{50} for the Jackson site is within the range of concentrations but has a large 95% confidence interval. Higher concentrations should be evaluated to reach the mortalities necessary to produce LC_{50} values with lower confidence levels.

Table 20. LC_{50} and 95% confidence levels of acephate and chlorpyrifos against the tarnished plant bug in West Tennessee, 1994.

Insecticide	**Site**	**LC_{50} (µg/bag)**	**95% CL**
Acephate	Puryear (low use)	1.35	1.00 - 1.80
	Jackson (medium use)	2.40	0.78 - 13.10
	Brownsville (high use)	0.95	0.37 - 2.24
Chlorpyrifos	Puryear (low use)	5812.00	113.00 - 4.83 E31
	Jackson (medium use)	35.90	6.30 - 4.85 E8
	Brownsville (high use)	----[a]	----

a) $P>0.05$. LC_{50} value cannot be determined from the range of mortalities observed.

The percent mortality found at the highest concentration of cyfluthrin was 100%. However, the data obtained were unable to provide LC_{50} values for the Puryear and Jackson sites. An LC_{50} value of 0.70 μg/bag (95% CL = 0.12 - 1.95) was determined for the Brownsville site. This site is in a high cotton-insecticide use area. Resistance to cyfluthrin, a pyrethroid, is less likely due to limited use of pyrethroids to control early-season cotton pests. TPB can be exposed to pyrethroids late in the season, as well as in previous growing seasons. Further dosages of cyfluthrin need to be evaluated in Puryear and Jackson to determine LC_{50} values in these areas.

Percent mortalities resulting from the malathion concentrations tested were great enough for LC_{50} calculations to be made (Table 21). The data for malathion were best explained by conducting probit analysis without a logarithmic model. Comparison of the ranges of percent mortalities follow the LC_{50} values calculated. The TPB population sampled at the Puryear site is more susceptible to malathion than populations at the other sites. The results demonstrate the potential for resistance of TPB to insecticides in higher cotton-producing areas, such as Jackson and Brownsville, which both had greater LC_{50} values than the Puryear site.

Greater than 50% mortality was achieved by the 25 μg/bag concentration of methyl parathion at the three sites studied. The data for methyl parathion also were best explained by probit analysis without a logarithmic model. LC_{50} values for the Puryear and Jackson sites were

Table 21. LC_{50} and 95% confidence levels of malathion against the tarnished plant bug in West Tennessee, 1994.

Site	LC_{50} (µg/bag)	95% CL
Puryear (low use)	24.9	11.7 - 107.6
Jackson (medium use)	51.8	36.9 - 94.4
Brownsville (high use)	50.2	31.9 - 147.2

determined from this analysis with the 95% confidence level for the Jackson site falling out of the range of the concentrations tested (Table 22). Analysis found that rate was not significant for this site; therefore, an LC_{50} value was not calculated. Additional concentrations of methyl parathion need to be evaluated at the Brownsville site.

iv. SUMMARY

Determining the status of selection pressure and resistance in pests is an important aspect in selecting pest management tactics. In 1994, TPB was responsible for the 2nd highest yield reduction in cotton in Tennessee (Williams 1995). Increased early-season treatments for TPB management may lead to the development of resistance among TPB populations. Because no published information on the status of TPB resistance in West Tennessee is available, the results presented are guidelines for future resistance studies.

Observation of the LC_{50} values calculated for acephate and malathion show that selection pressures do exist in West Tennessee. TPB populations at the Brownsville site, a high cotton-producing area, were found to be more susceptible to acephate than the populations tested from Puryear, the low cotton-producing area. However, TPB populations from the Puryear site were more susceptible to malathion than were the populations evaluated from the Brownsville site.

Table 22. LC_{50} and 95% confidence levels of methyl parathion against the tarnished plant bug in West Tennessee, 1994.

Site	LC_{50} (μg/bag)	95% CL
Puryear (low use)	11.0	6.2 - 24.2
Jackson (medium use)	14.0	6.4 - 271.4
Brownsville (high use)	----[a]	----

a) $P>0.05$. LC_{50} value cannot be determined from the range of mortalities observed.

LC_{50} values for many of the insecticides tested in this study were not able to be determined. The ranges of mortality and probit analysis have provided baseline information needed to study the concentrations required to establish LC_{50} values for West Tennessee.

TPB will feed on a variety of host plants. Therefore, the chance of resistance development is increased in this pest because of the exposure to chemical insecticides used on the many hosts of TPB. The higher dosages needed for LC_{50} determinations for azinphosmethyl and chlorpyrifos may be an indication of the development of TPB resistance in West Tennessee.

The boll weevil eradication program, now effective in parts of Tennessee, relies on the use of insecticides. This program may lead to an increase in resistance among TPB. Additional resistance studies will provide more indicative results which can be applied by extension personnel and farm managers to reduce resistance development and to implement appropriate control methods in the cotton-producing areas of West Tennessee.

CHAPTER V

CONCLUSIONS

Cotton is an important commodity in the United States. The 5.12 million hectares of cotton produced in the United States contributed $4,220,000,000 to the economy (Anon. 1994). Cotton production provides numerous jobs, as well as fiber, oil, and cottonseed meal for feed. In Tennessee, in 1994, 234,000 hectares of cotton were harvested at 1.50 bales per 2.5 hectares (Williams 1995). In 1993, cotton sold for $1.19 per kilogram; therefore, in 1994 the contribution of cotton to the economy of Tennessee was approximately $227,448,000 (Williams 1995, Anon. 1994).

Cotton was introduced into the United States during the colonial times. Pests of cotton have been imported on other plants, or have began using cotton as an alternate host. Key pests of cotton include the boll weevil, *Anthonomus grandis grandis* Boheman, which was introduced from Mexico, the bollworm, *Helicoverpa zea* (Boddie), and the tobacco budworm, *Heliothis virescens* (F.), which are pests of other crops, including corn and tobacco. *Lygus lineolaris* Palisot de Beauvois, the tarnished plant bug (TPB), is an example of a pest utilizing cotton as an alternate host. The boll weevil, bollworm/budworm complex and TPB are destructive to cotton bolls and can cause significant yield reductions.

The reliance on chemical methods to control pests of cotton has reduced the use of other control methods, such as biological and cultural control, and has resulted in the development of resistance. Knowledge of insecticides and their impact on the pest species and beneficial arthropods is essential to selecting and implementing pest management programs.

The University of Tennessee Agricultural Extension Service provides recommendations of insecticides for management of TPB. Factors, such as previous exposure to an insecticide, cause changes in the effectiveness of insecticides. Routine testing of recommended insecticides provides current information on the efficacy of an insecticide against a given pest. Efficacy tests conducted on experimental insecticides not yet labeled for a pest can determine if the insecticide is effective, and at what rates.

Beneficial arthropod populations can be adversely affected by chemical control methods. By reducing or eliminating beneficial populations, the resurgence of primary and secondary pests becomes a major concern. Selective insecticides which are less detrimental to beneficial populations should be chosen for pest management practices.

Another key problem facing pest management is the development of resistance to insecticides in pest populations. Frequent applications of insecticides lead to resistance, which limits the effectiveness of insecticides against pest populations. Resistance increases the control costs of producers as more treatment applications become necessary.

The objectives of this research were to: 1) determine the impact of recommended insecticides on *L. lineolaris* in field cage tests, 2) determine the effects of selected early-season insecticides on beneficial arthropod populations, and 3) evaluate the resistance of *L. lineolaris* to selected insecticides in West Tennessee.

Series of efficacy tests conducted at the West Tennessee Experiment Station, Jackson, TN, in 1993 and 1994, showed that acephate, malathion, and oxamyl consistently provided good initial and residual control of TPB. Combined analyses of Tests 3 and 4 in 1993 demonstrated that acephate and malathion can be applied at lower rates and achieve mortalities not significantly different from recommended rates. Although not statistically different, these differences in actual mortalities may be important in terms of crop damage.

The results of tests conducted in 1994 on insecticides recommended for TPB management were similar to those obtained in 1993, with acephate-, dicrotophos-, and malathion-treated plots yielding greater than 90% mortality. Azinphosmethyl and dimethoate, when used in combination, provided higher mortalities than when each was applied alone. The highest combined residual percent mortality was found in the cyfluthrin-treated plots; cyfluthrin was the only pyrethroid tested.

Of the insecticides evaluated in 1994 that are not currently labeled for TPB management, fipronil provided 91.0% initial and 57.5% residual control.

Imidacloprid and profenofos did not provide the control found in the fipronil-treated plots.

Insecticides that are commonly applied early-season for TPB management did cause reductions in beneficial arthropod densities at 1 and 3 days after treatment; however, overall densities showed an increase by 7 days after treatment. Minute pirate bugs, big-eyed bugs, and spiders are important in managing densities of the bollworm. The densities of these arthropods 14 days after treatment suggested that insecticide treatment did not affect repopulation. Densities of minute pirate bugs 14 days after treatment were significantly ($P<0.05$) lower in acephate-, dicrotophos-, and oxamyl-treated plots than densities in the untreated plots. These insecticides are systemic and reduced the ability of the plant to support prey for minute pirate bugs. Although not evaluated, these systemics may provide longer control of TPB. In the selection of an insecticide, the response of the desired beneficials to various insecticide types (i.e., contact, systemic, and high residual) should be considered.

Resistance studies performed in low, medium, and high cotton-insecticide use areas in West Tennessee provided information necessary for future determinations of LC_{50} values. The range of concentrations tested produced LC_{50} values for Acephate and Malathion. These values suggest that selection pressures may be present in West Tennessee however, further study will be needed.

TPB resistance to cotton insecticides is possible in low cotton-insecticide use areas due to the broad spectrum use of the insecticides applied, in combination with the large host range of TPB. Management of TPB resistance must consider other crops and insecticides used in cotton-producing areas. Based on the information obtained from this study, further tests can be conducted to provide LC_{50} values of insecticides commonly applied to cotton for TPB management.

Upon the completion of the boll weevil eradication program, efforts can be focused on utilizing integrated pest management strategies for control of cotton pests, including the bollworm and TPB. Efficacy tests and resistance studies will provide information needed to monitor the resistance selection pressures. If treatment is necessary, the appropriate insecticide can be applied. Utilization of selective insecticides for early-season TPB control will limit the reduction of beneficial arthropod populations that aid in management of late-season pests.

Insecticides are valuable tools in pest management. By monitoring the efficacy and resistance status of an insecticide, effective management practices can be employed. From this research, acephate and malathion can be used to achieve high levels of mortality; however, the possibility of resistance to these insecticides in areas of West Tennessee exists. This research suggests that early-season pests, such as TPB, can be managed using pesticides without harming beneficial arthropod populations that aid in late-season pest control.

This type of information regarding insecticides depended upon for pest management supports incorporation of chemical control methods into integrated management programs.

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