THE VERTICAL MIGRATION OF WHITE GRUBS AFTER PEAK ADULT FLIGHT IN WEST TEXAS[1,2]

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ABSTRACT

Research conducted in July and August, 1985-86 showed that white grubs, Phyllophaga crinita Burmeister and Cyclocephala pasadenae Casey, were randomly distributed in common bermudagrass, Cynodon dactylon (L.) Persoon. A random distribution of the number of larvae found per pit occurred in each sampling period revealing that circadian vertical migration did not occur. Significantly more larvae were found 0-7.6 cm deep in all trials. Only first- and second-instar larvae were present in July 1985-86, while second- and third-instar larvae predominated in August 1985-86. Numbers of larvae decreased with increasing depth. Soil temperature did not affect larvae counts, but soil moisture at sampled depths was linearly related to the number of larvae found. Grub populations in west Texas should be more vulnerable to insecticides in mid-summer because the smaller larval instars were found near the soil surface.

INTRODUCTION

White grubs, including Phyllophaga crinita Burmeister and Cyclocephala pasadenae Casey, are serious pests of turfgrass in the southwestern U. S. Larval feeding on roots of turf damage and may kill the grass if populations are sufficient (Hammond et al. 1985). Grub control is most effective when the highest proportion of the population is near the soil surface (Hartzell and Wilcoxon 1939) because little downward movement of the insecticides occurs (Sears and Chapman 1979). Therefore, research on the vertical migration of grub populations is essential. McColloch and Hayes (1923) and Travis (1939) reported that white grubs migrated in fall and spring in response to temperature.

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[1] Coleoptera: Scarabaeidae

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Grubs migrated towards the soil surface as temperature increased (spring and summer) when control measures were recommended. Hartzell and McKenna (1939) discovered that vertical migration of Japanese beetle larvae, Popilla japonica Newman, lagged 4 to 6 days behind air temperature fluctuations. Soil moisture may also affect vertical migration of white grub larvae. Gaylor and Frankie (1979) reported that the number of first instar P. crinita was equal in three intermediate moisture levels (10, 20, and 30%) but was significantly reduced in the two extreme moisture levels (0 and 37%). Also, different instar stages may have different vertical migration patterns. Huffman and Harding (1980) reported that first instar P. crinita moved downward while second instars moved upward toward the sugarcane; third instars remained around the cane.

Sears and Chapman (1979) reported that timing of insecticidal application is extremely important for adequate control of turf insect pests. Crocker (1981, 1983) reported that control of white grubs is most effective soon after egg hatch, which occurs 2-4 wk after adult flight activity. Insecticides are more effective then because the grubs are small and near the soil surface. Earlier treatments lost their effectiveness before the pest appeared, and later treatments were applied after the grubs had grown larger and had become harder to control.

The objectives of this research were to: 1) determine vertical distribution of white grubs in the soil after peak adult flight, 2) determine if significant vertical migration occurred during short 24 hr intervals or if migration was long term, and 3) examine the effects of temperature and moisture on distribution of white grub larvae.

MATERIALS and METHODS

The research site was a city park in the eastern part of El Paso, Texas, known to be infested with white grubs. The park turf was well-established Bermudagrass, Cynodon dactylon (L.) Pers., grown on a basic pH, sandy-loam soil. The park was irrigated weekly at a rate of 205 m^3.

A plot, 7.3 x 0.6 m, was established in each sampling period in July and August, 1985 and 1986. Each plot was divided into twelve sub-plots, 0.6 x 0.6 m, which were randomly assigned to be dug at a specific time. Pits measuring 0.6 x 0.6 x 0.3 m were dug and sampled for grub populations every 2 hr commencing at 1200 hr and terminating at 1000 hr the following morning. Soil was removed in 7.6 cm increments to a level of 30.6 cm. Illumination during night sampling was by Coleman® lantern.

Grub samples were counted, and the number and stage of white grubs at each increment in each pit were recorded. Larval stage was determined by head capsule size. It was not feasible to identify each of the larvae, but all the adults collected from this location were either P. crinita or C. pasadenae, as were all identified larvae. Grubs were stored in Ziploc® bags and taken to the laboratory. They were

transferred to labeled vials of 70% ethanol. Soil temperature was monitored at each depth of the pit with a Pak-Tronics Model 1720-201 soil temperature recorder. Soil was sampled for moisture content at each depth gravimetrically.

Data were analyzed by analysis of variance in the GLM procedure of SAS (SAS Institute 1985). The analysis indicated non-normality of the larva counts; therefore, the analysis was repeated on ranked-transformed data. Means were separated by least significant difference tests where appropriate.

RESULTS AND DISCUSSION

Differences in larval numbers among pits in each sampling date were random, i.e. the time of day did not have any affect on larvae distribution (Table 1).

TABLE 1. Mean Number of Larvae Found in Sample Pits During Each 24-hr Sampling Period.

	Mean Number of Larvae[a,b]			
	1985		1986	
Pit No.(hr)	July	Aug	July	Aug
1(1200)	5.3a	15.2 b	1.3a	5.2ab
2(1400)	16.8ab	5.0ab	1.8ab	8.4ab
3(1600)	22.3ab	8.8ab	2.0ab	10.8 b
4(1800)	3.5a	11.9ab	1.6ab	11.0 b
5(2000)	8.8a	6.1ab	1.3a	2.2a
6(2200)	24.4ab	4.2ab	2.5ab	7.3ab
7(2400)	2.9a	12.0ab	5.3ab	7.8ab
8(0200)	21.4ab	5.0ab	4.5ab	11.2 b
9(0400)	16.9ab	8.0ab	1.6ab	11.2 b
10(0600)	25.0ab	9.3ab	5.9ab	8.0ab
11(0800)	42.3 b	2.8a	6.6 b	7.2ab
12(1000)	4.5a	4.3ab	1.8ab	9.1ab

[a]Values shown are the number of larvae/pit(12)/depth(4)/no. instar stages found. First- and second-instar larvae were present in July and third instar larva was also present in August.

[b]Values followed by the same letter within a column are not significantly different ($p<0.05$, LSD).

Significantly more larvae were found at the 0-7.6 cm depth in mid-summer of both years (Table 2) and numbers of larvae decreased with increasing depth. First- and second-instar larvae were found exclusively in July. Second- and third-

TABLE 2. Mean Number of Larvae Found at Different Depths from 12 Sample Pits During Each 24 hr Sampling Period.

Depth(cm)	Mean Number of Larvae[a,b] 1985 July	1985 Aug	1986 July	1986 Aug
0-7.6	59.3a	26.3a	10.3a	24.7a
7.6-15.2	4.6 b	3.9 b	2.1 b	6.2 b
15.2-22.9	0.5 b	0.4 b	0.2 b	1.9 bc
22.9-30.5	0.2 b	0.2 b	0.1 b	0.4 c

[a]Values shown are number of larvae/pit/no. instar stages found in each depth. First- and second-instar larvae were present in July and third instar larva was also present in August.
[b]Values followed by the same letter within a column are not significantly different ($p<0.05$; LSD).

instar larvae predominated in August. There was a significant interaction between mean counts of larval instars (1st, 2nd, and 3rd) and soil depth (depth 1=0-7.6, 2=7.6-15.2, 3=15.2-22.9, and 4=22.9-30.5cm) in July-August 1985 and July-August 1986, (Figs. 1a, 1b, 2a, and 2b). The trend in each year-month combination revealed that the number of larvae decreased with depth.

There was no correlation between soil temperature and total numbers of all larval instars or between temperature and the counts of each larval instar. Total larval counts were linearly related to soil moisture in 1985-86 (Figs. 3a, 3b, 4a, and 4b). Each larval instar was affected by moisture. There was a significant ($P<0.05$) linear relationship between moisture and number of first instar larvae in July 1986. Number of second- and third-instar larvae were linearly related to moisture in most of the trials. All regression coefficients, relating white grub counts to moisture, were positive indicating that an increase in moisture at sample depths was associated with an increase in larvae numbers.

The data showed that circadian vertical migration did not occur during the periods when samples were taken. Grubs were found near the surface in both July and August. However, because the less developed and more susceptible forms (first- and second- instar larvae) were prevalent in July, insecticides would probably be more effective at that time. Third instar larvae predominated in August, at which time they would be more difficult to control. Larval instar and location are major factors influencing effective control of grubs.

Larval numbers and soil moisture level were positively and linearly related. Moisture content was highest near the

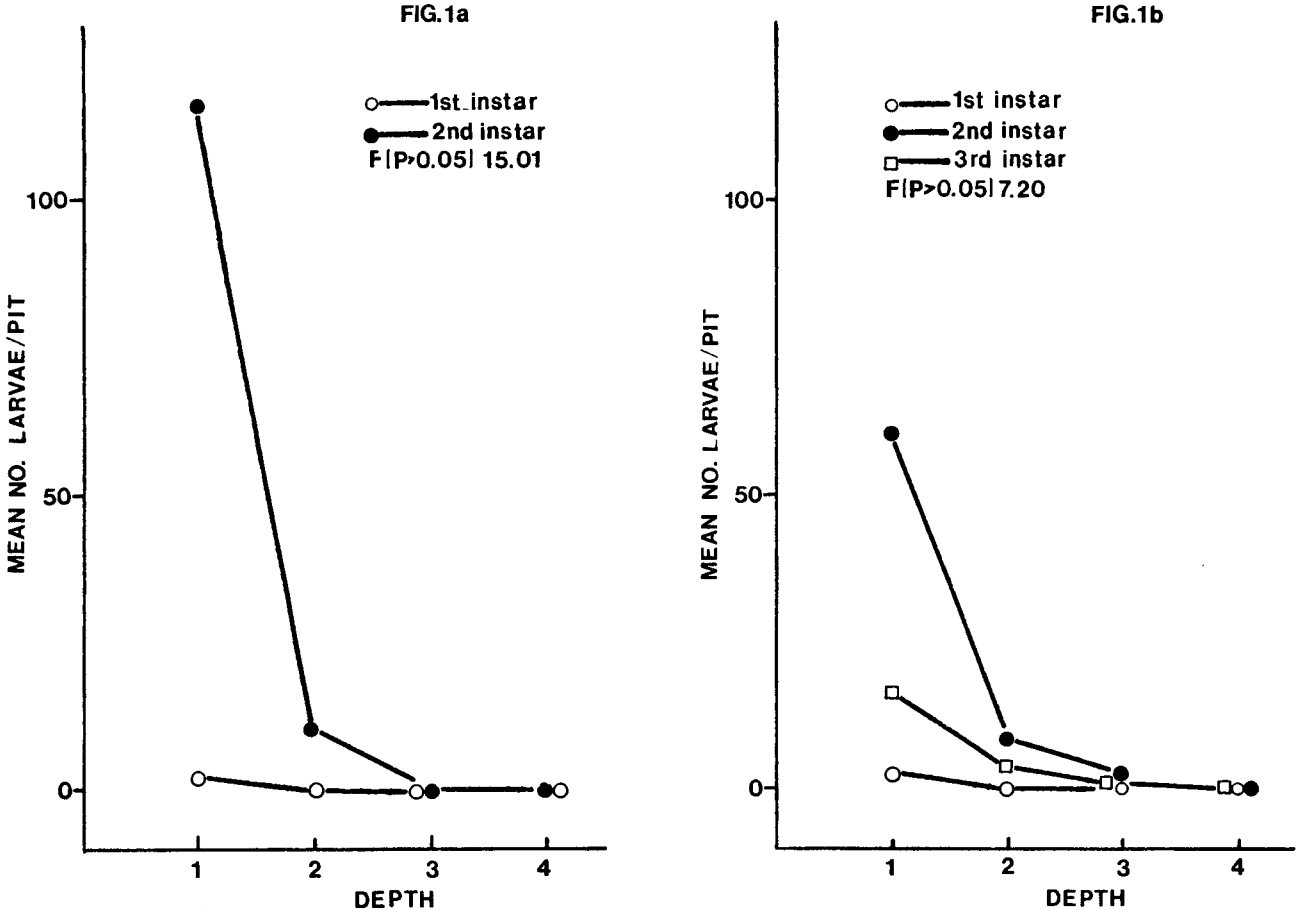
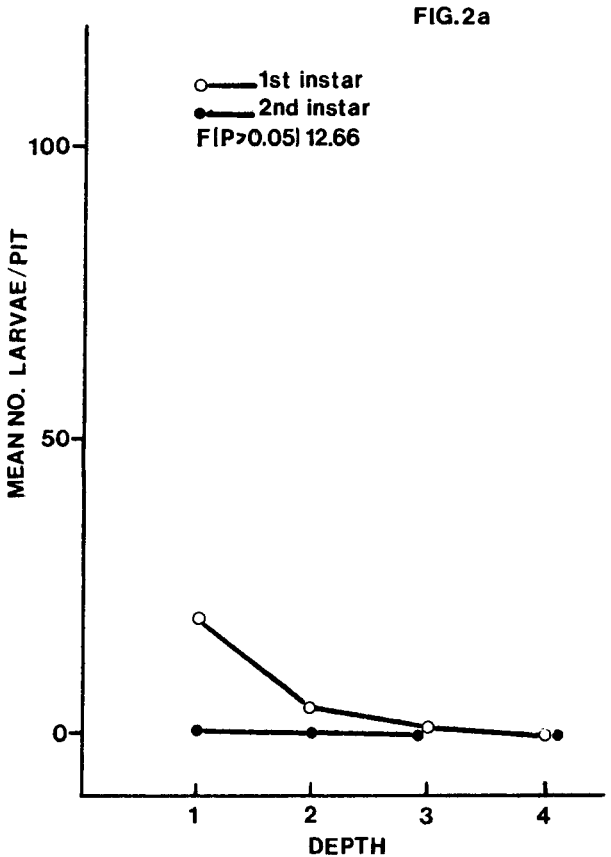


FIG. 1. (A) The location of different instars of white grubs at various depths in July 1985. (B) The location of different instars of white grubs at various depths in August 1985.



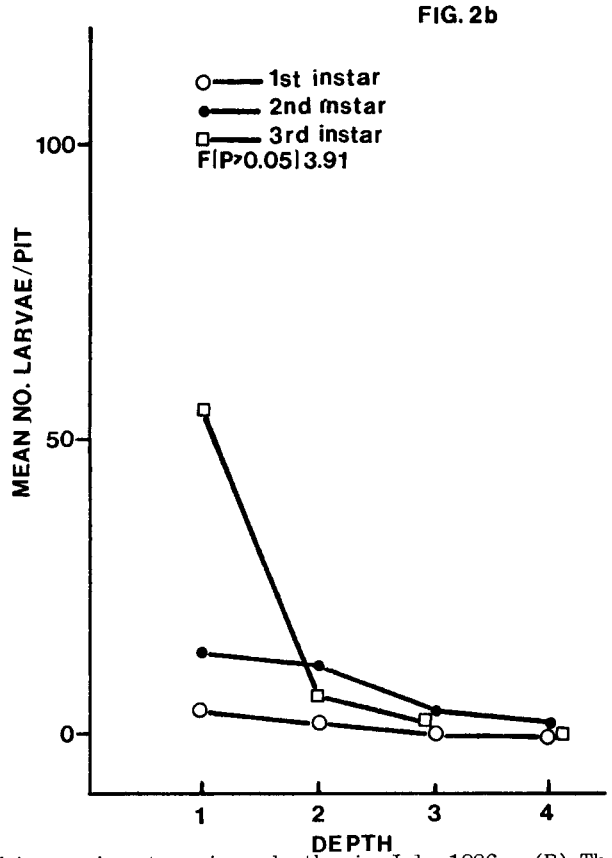


FIG. 2. (A) The location of different instars of white grubs at various depths in July 1986. (B) The location of different instars of white grubs at various depths in August 1986.

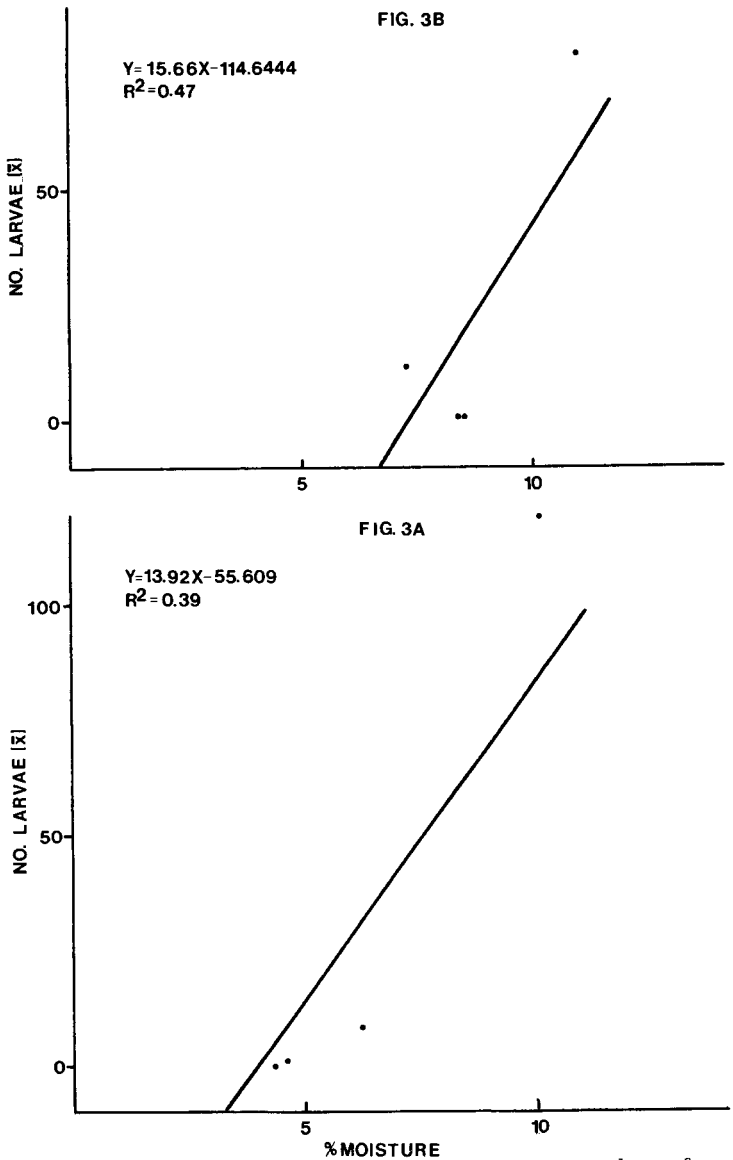
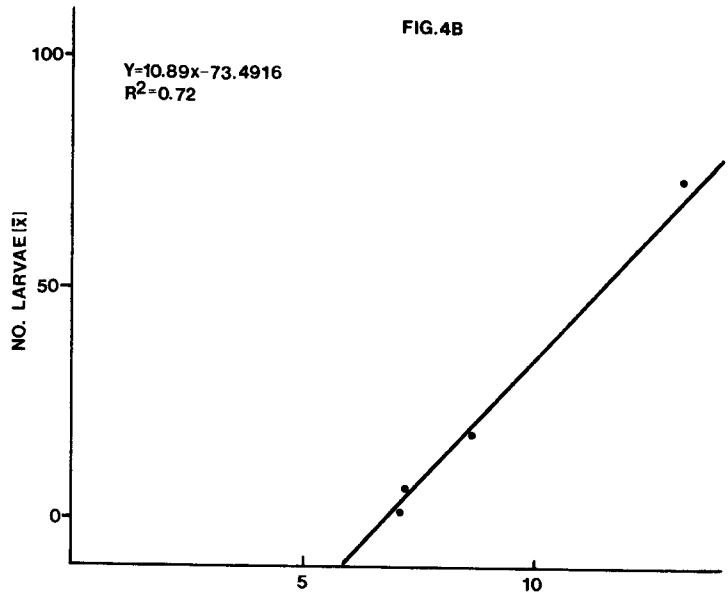


FIG. 3. (A) Regression line of the average number of larvae found in the soil at different moisture levels in July 1985. (B) Regression line of the average number of larvae found in the soil at different moisture levels in August 1985.



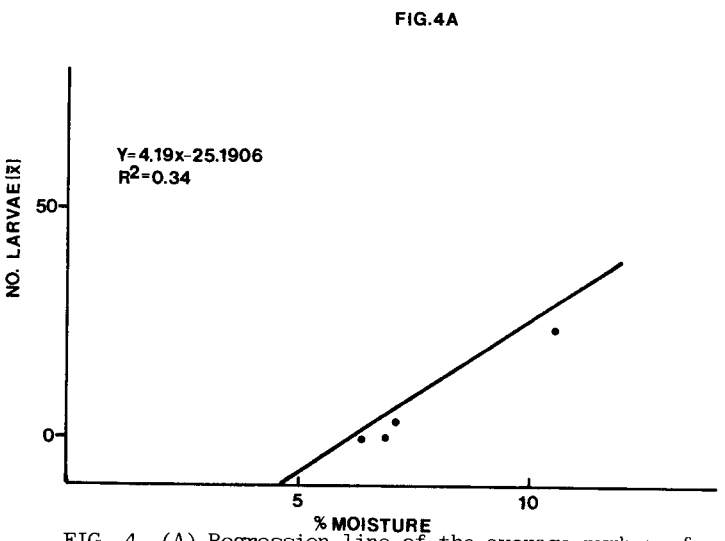


FIG. 4. (A) Regression line of the average number of larvae found in the soil at different moisture levels in July 1986. (B) Regression line of the average number of larvae found in the soil at different moisture levels in August 1986.

surface where most of the grubs were found. During summers of low rainfall, grubs may migrate deeper into the soil making insecticides less effective. Moisture content may aid in determining the time of insecticide application. The data reveal the time when white grub populations are more vulnerable to insecticide applications.

LITERATURE CITED

Crocker, R. L. 1981. White grub management in Texas turfgrass. Tex. Agric. Exp. Sta. Prog. Rep. 3846, pp.69-77, In: Texas Turfgrass Research-1979-80. Tex. Agric. Exp. Sta. Consol. Prog. Rep. 3831-3851.

Crocker, R. L. 1983. Active ingredient and application date influence on efficacy of treatments for control of white grubs in Texas turfgrass. Tex. Agric. Exp. Sta. Prog. Rep. 4162, pp.94-98, In: Texas Turfgrass Research. Tex. Agric. Exp. Sta. Consol. Prog. Rep. 4147-4170.

Gaylor, M. J., and G. W. Frankie. 1979. The relationship of rainfall to adult flight activity; and of soil moisture to oviposition behavior and egg and first instar survival in Phyllophaga crinita. Environ. Entomol. 8: 591-594.

Hammond, P. J., B. S. Brewer, J. D. Stone, and R. L. Crocker. 1985. White grubs in turfgrass. Tex. Agric. Ext. Serv. Leaf.1131.

Hartzell, A., and G. F. McKenna. 1939. Vertical migration of Japanese beetle larvae. Boyce Thompson Institute Contrib. 11: 87-91.

Hartzell, A., and F. Wilcoxon. 1939. Experiments on control of Japanese beetle larvae with B,B-dichloroethyl ether. Boyce Thompson Institute Contrib. 10: 509-513.

Huffman, F. R., and J. A. Harding. 1980. Biology of Phyllophaga crinita (Burmeister) in Lower Rio Grande Valley sugarcane. Southwest. Entomol. 5: 59-64.

McColloch, J. W., and W. P. Hayes. 1923. Soil temperature and its influence on white grub activities. Ecol. 4: 29-36.

SAS Institute. 1985. SAS User's Guide: Statistics. SAS Institute, Cary, N.C.

Sears, M. K., and R. A. Chapman. 1979. Persistance and movement of four insecticides applied to turfgrass. J. Econ. Entomol. 72: 272-274.

Travis, B. V. 1939. Migration and bionomics of white grubs in Iowa, 1930-1935. J. Econ. Entomol. 32: 693-697.

RESIDUES ON HONEY BEES[1], HIVE PRODUCTS, AND FOLIAGE FOLLOWING APPLICATIONS OF THE EMULSIFIABLE CONCENTRATE OF ETHYL PARATHION TO BLOOMING SUNFLOWERS[2]

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ABSTRACT

Two aerial applications of EC ethyl parathion onto blooming sunflower, Helianthus annuus L., in northern Texas caused a serious loss of adult honey bees, Apis mellifera L., in colonies adjacent to the sprayed field. The number of dead bees collected from the dead-bee traps was more than 50 times larger in exposed colonies than in comparable unexposed check colonies during the first 2 days following the insecticide applications. However, adult mortality decreased to the pretreatment level 4 days after the first spray, although the mortality rate decreased more slowly after the second application. Nevertheless, when the colonies were moved to northern Colorado in late July into an area of low insecticide usage, they recovered sufficiently to winter well.

Parathion residues in dead bees the first day after each spray averaged 3.6 ppm and 1.5 ppm, respectively, but residue levels dropped rapidly. Only 0.1 ppm was found by the fifth day. Pollen collected from pollen traps contained up to 3.7 ppm of parathion, but averaged between 0.5 and 0.9 for 7 of the 10 days that samples were taken. Residues of parathion were several times greater on sunflower leaves than on the floral heads, but this may reflect the difference in the tissue surface area to mass ratio.

The first and second sprays caused a 99 and 96% reduction in the collection of sunflower pollen and a 73 and 96% reduction in the collection of other pollens, respectively, on the first complete pollen-collecting day after treatment. Parathion residues were not detected in newly stored honey, recently capped honey, beeswax, live bees or in air samples taken above the sunflower plants.

1/ Hymenoptera: Apidae.

2/ This paper reports the results of research only. Mention of a pesticide or proprietary product does not constitute a recommendation or an endorsement for its use by the USDA, nor does it imply registration under FIFRA as amended.

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INTRODUCTION

Both ethyl and methyl parathion are broad-spectrum insecticides that are widely used in agriculture (McEwen and Stephenson 1979). Several studies have shown that these materials are highly toxic to honey bees, Apis mellifera L. (Moffett and Stith 1972, Atkins et al. 1978, Johansen and Kious 1978, Barker et al. 1979, Rhodes et al. 1979, Waller et al. 1984). Their use has often caused serious economic losses to beekeepers (Wilson et al. 1980). Therefore, field testing of insecticides which have proven toxic to honey bees in the laboratory is essential (Smart and Stevenson 1982, Stevenson 1983).

This study was undertaken to determine the amount of parathion residue in bees, bee products, and sunflower foliage resulting from aerial applications of ethyl parathion to blooming sunflowers.

MATERIALS AND METHODS

Six colonies of honey bees were moved to within 30 m of each of two sunflower fields about 20 km NE of Lubbock, TX, in early July 1982. Each colony consisted of about 10 frames of brood and 18 frames of adults and occupied two Langstroth deep hive bodies and one shallow super. A Todd dead-bee trap was attached to the entrance of each hive. Modified OAC (Ontario Agricultural College) pollen traps (Smith and Adie 1963) were placed under three of the six hives at each location.

All types of field samples were placed in Ziploc® plastic sandwich bags, immediately stored in chests containing dry ice, and then kept frozen (in a laboratory freezer at -20°C) until they were analyzed for parathion residue. All residue samples were analyzed by a modification of the Ross and Harvey (1981) method. Analysis of variance was used to analyze the data and means were separated by Duncan's New Multiple Range Test.

Dead bees in the dead-bee traps were counted daily between 11 and 24 July. Then, subsamples of these dead bees were collected for residue tests.

The actual numbers of frames covered by adult bees and those containing brood were counted (nearest 1/4 frame) in each colony. In parathion-exposed colonies, measurements were made 2 days before and 4 days after first spray and 2 days after second spray. Counts in untreated colonies were made on 12 and 23 July. On 2 and 9 September, brood and adult counts were made on all colonies.

Pollen from each trap was collected and weighed daily and a subsample taken for residue analysis.

Three frames of empty comb were placed in each shallow super 3 days before the 1st spray was applied. One combined sample (20 ml) of newly stored honey was collected with a clean wooden tongue depressor from three frames in each colony every 2nd day. Residue analysis was performed on the honey.

Six beeswax-coated silanized glass microscope slides (2.5 x 7.5 cm) were suspended between two frames in the center of each shallow super 3 days before the first treatment was applied. One slide was collected to test for parathion residue every other day.

Live bees were collected from the super above the brood nest the day after the second spray was applied and then again 7 to 8 wk later to determine if the bees were receiving sublethal amounts of parathion. The bees were killed by freezing.

The following data and samples were collected daily between 11 and 24 July in three predetermined blocks distributed diagonally across each sunflower field. Populations in the fields were estimated by recording

the number of worker honey foraging bees visiting 100 sunflower heads as the observer walked slowly down a row. The number of blooming sunflower heads per 100 heads were counted. The flowers were considered open when the yellow ray flower petals had unfolded. A leaf was collected at random for residue analysis from each of 20 sunflower plants. A portion of a sunflower head ca. 7 x 10 cm in size was collected for residue analysis from each field block. Air samples were taken 1.8 m above the ground. About 250 ml of air was drawn through a 0.6 x 7.6 cm silanized glass column packed with Porapak-Q® with Accuhaler® personal air sampling pump.

The percentage of sunflower pollen was calculated by examining 250 pollen pellets (ca. 0.6 g) from each sample, and both the number of sunflower pollen pellets and the number of pollen pellets from other plant species were recorded. Floral origin was determined by a combination of unaided visual examination for color and texture and then microscopic examination for further refinement and confirmation with reference slides.

At 2:30 p.m. on 12 July and again at 9:00 a.m. on 20 July 1982, the sunflower field of ca. 40 ha was sprayed aerially with EC ethyl parathion at a rate of ca. 1.1 kg A.I. in 28 L of water per ha. This application rate controlled the sunflower moth, Homoeosoma electellum (Hulst.), in earlier studies by Archer et al. (1983). The check field of ca. 0.8 ha was left untreated.

RESULTS AND DISCUSSION

Aerial applications of an emulsifiable concentrate of ethyl parathion produced a rapid and severe kill of adult bees when the spray was applied to sunflowers with 30% of the flower heads in bloom (Table 1). Eight days later, another similar bee loss occurred when the second spray was applied with the field in 100% bloom. No correlation could be found between bee-visitation counts in the field (few bees seen) and the heavy adult bee mortality after exposure.

TABLE 1. Mean Number of and Residues in Dead Honey Bees Collected from Traps on Colonies Located Adjacent to Sunflowers in Bloom. Lubbock, TX. 1982.

Date	No. dead bees from traps near		Parathion (ppm) in dead bees from traps near	
	check field	sprayed field	sprayed field	check field
11 July	46	133	0.0	0.0
		..1st spray (2:30 p.m., 12 July)..		
12 July	19	611[a]	3.6	0.0
13 July	13	2680[a]	1.3	0.0
14 July	22	200	0.5	0.0
15 July	15	75	0.2	0.0
16 July	45	46	0.1	0.0
		..2nd spray (9:00 a.m., 20 July)..		
20 July	60	1229[a]	1.5	0.1
21 July	42	2017[a]	0.7	0.0
22 July	23	230	0.9	0.0
23 July	25	417[a]	0.1	0.0
24 July	15	362[a]	0.1	0.0

[a]/Sprayed field data was significantly different from check field data at the 0.05 level of probability.

During the first 2 days following each spraying, more than 50 times as many dead bees (3,269 vs. 67) were collected per colony from the dead-bee traps near the treated field as were collected from traps on colonies near the unsprayed field (Table 1). Less than 1 h after both applications, large numbers of dead and dying bees were seen in the dead-bee traps, at the entrance to the hives, and inside each of the six colonies adjacent to the sprayed field. Bee mortality after the first spraying, as measured by the data from the dead-bee traps, dropped to the level of the check colonies by the fourth day. However, 4 days after the second treatment, there were still significantly more dead bees in traps on colonies exposed to the parathion than in the traps on the check colonies (362/colony vs. 15/colony). Although the colonies were uniform in population size at the beginning of the study, the number of frames of brood and the adult bee populations were both greatly lower in the parathion-exposed colonies following each application. However, the populations in the colonies recovered ca. 6 weeks after they were moved, in late July, to a rural area of northeastern Colorado where few or no field applications of insecticides have been made in recent years.

Parathion residues were high on the dead bees collected from the traps the first day after the sprays were applied (3.6 and 1.5 ppm, respectively). However, the residue dropped rapidly and was only 0.1 ppm after 4 days (Table 1).

Residues were much higher on the sunflower leaves than on the flower heads (107.1 vs. 16.7 and 40.9 vs. 1.8 ppm) after the first and the second treatments respectively, (Table 2). The residues were higher in the leaf samples than in the head samples because the surface area of a leaf exposed to the spray was larger than the surface area of a head sample. Although residues dropped at a steady rate, they still remained high on the leaves 4 days after the sprays were applied (20.3 and 12.4 ppm). There was a significant positive correlation between both residues on leaves (r^2 = .6616, df = 8) and on sunflower heads (r^2 = .9172, df = 8) and the residues on dead adult bees. Following the first parathion application, when residues were greater than about 30 ppm on leaves and 6 ppm on heads high adult-bee mortality occurred (Table 1 and 2). There were no parathion residues on the foliage from the untreated field.

TABLE 2. Mean Residues of Parathion on Sunflower Head and Leaf Tissue and in Pollen Collected by Bee Colonies Located near the Field Sprayed Twice Aerially with Ethyl Parathion. Lubbock, TX. 1982.

	Parathion residue (ppm):[a]		
Date	Sunflower heads	Sunflower leaves	Bee-collected pollen
11 July	ND[b]	0.0	2.7
.....1st spray (2:30 p.m., 12 July).....			
12 July	16.7	107.1	0.8
13 July	8.5	50.9	0.9
14 July	6.9	39.4	3.7
15 July	3.5	29.1	0.9
16 July	1.3	20.3	0.5
.....2nd spray (9:00 a.m., 20 July).....			
20 July	1.8	40.9	0.5
21 July	8.6	33.3	0.3
22 July	2.9	26.6	0.5
23 July	2.8	10.8	0.9
24 July	1.3	12.4	0.1

[a] No parathion residue on foliage from untreated field.
[b] ND = no data.

TABLE 3. Effect of Aerial Spraying of Blooming Sunflowers with Ethyl Parathion on the Quantity of Pollen Collected by Honey Bees. Lubbock, TX. 1982.

Date	Grams of pollen collected per colony located near check field			Grams of pollen collected per colony located near sprayed field			Pollen collected from sprayed field as % of pollen collected from check field
	sunflower	other[a]	total	sunflower	other[a]	total	
11 July	0.2	47.8	48.0	2.9	13.2	16.1	34
				.....1st spray (2:30 p.m., 12 July)....			
12 July	0.0	48.3	48.3	11.6	40.9	52.5	109
13 July	7.2	85.4	92.6	0.1	11.0	11.1	12
14 July	23.0	83.6	106.6	1.1	7.9	9.0	8
15 July	13.8	73.6	87.4	7.0	11.0	18.0	21
16 July	45.5	106.0	151.5	37.8	45.2	83.0	55
				.....2nd spray (9:00 a.m., 20 July)....			
20 July	47.4	177.8	225.2	51.2	81.4	132.6	59
21 July	58.9	238.7	297.6	2.0	2.9	4.9	2
22 July	55.0	181.2	236.2	12.8	20.2	33.0	14
23 July	36.1	185.6	221.7	25.8	31.9	57.7	26
24 July	19.3	90.0	109.3	21.8	45.5	67.3	62

[a] Pollen from other than sunflower plants.

The pollen samples collected from the pollen traps contained varying amounts of parathion residue ranging from 0.1 to 3.7 ppm (Table 2). Residue levels could easily be correlated with adult bee mortality. Pollen collected the day before the first experimental spray application contained 2.7 ppm parathion. This pretreatment residue probably came from pollen collected from nearby fields that had been sprayed earlier. Parathion residues in pollen on 7 of the 10 days analyzed after the spray applications averaged between 0.5 and 0.9 ppm. These data were similar to the residues on pollen and dead bees as reported by Atkins et al. (1978), Ross and Harvey (1981), Hanny et al. (1983), and Waller et al. (1984). The contaminated pollen recovered from the traps was destined for storage inside the hive. Storage of this pollen would have been detrimental to a colony since honey-bee larvae die from eating contaminated pollen (Johansen and Kious, 1978, and Rhodes et al. 1979). Boelter and Wilson (1984) demonstrated that adult bees die and beeswax comb is contaminated by fumes emitting from methyl-parathion-contaminated pollen.

The sprays caused a 99% (11.6 reduced to 0.1 grams) and 96% (51.2 to 2.0g) reduction in the amount of sunflower pollen collected the first complete collection day after each spray was applied, and a 73% (40.9 to 11.0g) and 96% (81.4 to 2.9g) reduction in the collection of other pollens (Table 3). Such reductions in the amount of pollen collected resulted from the loss of the adult foraging bee population caused by insecticide exposure. After 2 days the amount of pollen collected increased slowly, but pollen from the treated field remained less than from the control field for several days. Large reductions in pollen collection can be important since colony brood development is often hampered and crop pollination is reduced.

No parathion residues were found in newly stored honey in any of the hives. Although Nazarov (1969) demonstrated that foraging bees can carry sugar syrup contaminated with various organic insecticides back to the hive, this did not occur at detectable levels with ethyl parathion in this study. Moffett et al. (1983) reported similar results in Oklahoma studies,

as no parathion residues were detected in honey from the brood nest of colonies damaged by spraying alfalfa with either EC methyl parathion or Penncap-M®.

None of the beeswax on the glass slides that had been placed between the frames in the super had any detectable parathion residues. This is consistent with most other studies which have recovered either no or minute quantities of methyl parathion from beeswax taken from combs from colonies in the field (Rhodes et al. 1979, Ross and Harvey 1981, Moffett et al. 1983, Waller et al. 1984). In contrast, Boelter and Wilson (1984) found that beeswax absorbed volatile methyl parathion from contaminated pollen that had been placed in the hive. No parathion was detected in the air samples or in the live-bee samples.

Since aerial applications of ethyl parathion killed foraging bees and other insect pollinators, it becomes important to understand the economics of sunflower pest control. Krause (1983) pointed out the need to consider the value of pollinators in maximizing sunflower seed yields compared to the damage that might be caused by the pest insect. He explained that in some cases protecting pollinators may be more advantageous economically than controlling the pest species.

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LITERATURE CITED

Archer, T. L., C. S. Manthe, C. R. Rogers, and E. D. Bynum, Jr. 1983. Evaluation of several insecticides for control of the sunflower moth. Southwest. Entomol. 8: 54-56.

Atkins, E. L., D. Kellum, and K. W. Atkins. 1978. Encapsulated methyl parathion formulation is highly hazardous to honey bees. Am. Bee J. 118: 483-485.

Barker, R. J., Y. Lehner, and M. R. Kunzmann. 1979. Pesticides and honey bees. The danger of microencapsulated formulations. Z. Naturforsch. 34C: 153-156.

Boelter, A. M., and W. T. Wilson. 1984. Effect of methyl parathion vapors from contaminated pollen on honey bees (Hymenoptera: Apidae) within a hive. Environ. Entomol. 13: 1233-1236.

Hanny, B., G. Loper, and J. Harvey. 1983. Chemical detection of Penncap-M capsules in pollen, and methyl parathion residues in honey bees (Apis mellifera L.) and bee products from colonies near Arizona cotton fields treated with Penncap-M-1980. Am. Bee J. 123:526-529.

Johansen, C. A., and C. W. Kious. 1978. Bee poisoning characteristics of microencapsulated methyl parathion. Glean. Bee Cult. 106:382-385.

Krause, L. 1983. Economic considerations in sunflower pollination and insecticide appplication for control of the sunflower moth (Homoeosoma electellum). Am. Bee J. 123: 211-214.

McEwen, F. L., and G. R. Stephenson. 1979. The Use and Significance of Pesticides in the Environment. John Wiley & Sons, New York. 538 pp.

Moffett, J. O., J. Harvey, and A. Stoner. 1983. Toxicity to honey bees of two formulations of methyl parathion sprayed on flowering alfalfa. Southwest Entomol. 8: 113-117.

Moffett, J. O., and L. S. Stith. 1972. Bee losses from parathion decreased as distance from sprayed field increased. Am. Bee J. 112: 174-175.

Nazarov, S. S. 1969. On the possibility of foraging bees transferring high concentrations of organic insecticides into the brood nest. Proc. Int. Beekeeping Congr. XXII, Munich, Germany. Apic. Abstr. 629/70.

Rhodes, H. A., W. T. Wilson, P. E. Sonnet, and A. Stoner. 1979. Exposure of Apis mellifera to bee-collected pollen containing residues of microencapsulated methyl parathion. Environ. Entomol. 8: 944-948.

Ross, B., and J. Harvey. 1981. A rapid, inexpensive, quantitative procedure for the extraction and analyses of Penncap-M (methyl parathion) from honeybees (Apis mellifera L.), beeswax, and pollen. J. Agric. Food Chem. 29: 1096-1098.

Smart, L. E., and J. H. Stevenson. 1982. Laboratory estimating of toxicity of pyrethroid insecticides to honey bees: Relevance to hazard in the field. Bee World. 63: 150-152.

Smith, M. V., and A. Adie. 1963. A new design in pollen traps. Can. Bee J. 74: 4-5, 8

Stevenson, J. H. 1983. Factors affecting the hazard of pesticides to honey bees. Bee World. 64: 117-121.

Waller, G. D., B. J. Erickson, J. Harvey, and T. L. Archer. 1984. Comparison of honey bee (Hymenoptera: Apidae) losses from two formulations of methyl parathion applied to sunflowers. J. Econ. Entomol. 77: 230-233.

Wilson, W. T., P. E. Sonnet, and A. Stoner. 1980. Pesticides and honey bee mortality, pp. 129-140. In Beekeeping in the United States. U.S. Dept. Agric. Handb. 335.

BIOLOGY AND PHENOLOGY OF THE BLACKMARGINED APHID, [1/][2/] MONELLIA CARYELLA (FITCH), A NEW PEST OF PECAN IN ISRAEL

F. Mansour [3/] and M. K. Harris [4/]

ABSTRACT

The foliar feeding aphids of pecan were studied to determine the species present, their life cycle, biology, physical development, reproduction and population dynamics. The blackmargined aphid, Monellia caryella (Fitch) was the only species found, and it is a new pest of pecan trees in Israel.

Alate fundatrices of this aphid appeared in the spring. They reproduced parthenogenetically, and apterous oviparae and males were found from mid-October until early December. The overwintering eggs were laid by oviparous females. The alate viviparae required 7 days to develop from birth to adulthood. There were four instars, and the stadia were about equal in duration. Adults produced an average of 57 nymphs each, and reproduction lasted an average 16.6 days. There were two population peaks observed each year.

INTRODUCTION

The aphids, M. caryella and Monelliopsis nigropunctata (Granovsky), are economically important pests in pecan orchards in the U.S.A. and are frequently targets of control measures (Harris 1983, Payne et al. 1979). They are considered together as a complex in sampling procedures, and they have been studied as such due to the difficulty in differentiating between species in the field (McVay et al. 1982, Tedders 1978). These aphids excrete a sticky honeydew that collects on the upper surface of leaves and supports a superficial growth of sooty mold that interferes with photosynthesis (Tedders and Smith 1976). Their feeding activity greatly reduces the growth and vigor of pecan trees (Tedders et al. 1982).

The pecan, Carya illinoensis (Wang) K. Koch, is a commercially important plant in Israel. The blackmargined aphid, Monellia caryella (Fitch), appeared for the first time in the northern region of Israel in the spring of 1976. By late autumn of that year, most of the pecan trees throughout the country were heavily infested with the aphid. Intensive chemical treatments were applied to eradicate the new pest; but all attempts failed, and it has become a serious pecan pest (Golan et al. 1977, Plaut and Mansour 1977).

[1/] Homoptera: Aphididae.

[2/] Approved as TA 23092 by the Director of the Texas Agricultural Experiment Station.

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Identifying the aphid species that had infiltrated into Israel and determining their population fluctuations and biology were prerequisites for understanding their population dynamics and control. The present study was made to examine blackmargined aphid under Israeli climate conditions.

MATERIALS AND METHODS

The study of population fluctuations and species composition were conducted in a commercial orchard in the Hulla Valley in the north, where the aphid appeared for the first time in Israel, and in an unsprayed orchard at Newe Ya'ar Experiment Station in the interior part of Israel. Seasonal aphid population phenology was examined by observing hatch from overwintered eggs. Four compound leaves were randomly collected once every 14 days from each of five trees in each orchard to study nymphs and adults. All aphid stages were counted. Alate forms were fixed in alcohol and submitted to an aphid taxonomist for species identification.

The life cycle of the parthenogenetic forms was studied in the laboratory on pecan seedlings during 1983 and 1984. A colony of M. caryella was started from field-collected alate viviparae. The aphids were reared at 26°C ± 1°C and 50-60% R.H. on pecan seedlings that were propagated in plastic pots (Tedders et al. 1970). Fluorescent tubes provided 16 h of light per day with an intensity ranging from 2800 - 3000 lux on plants. The aphids were maintained under these conditions all year round. Five groups of five alate viviparae each, from the respective stock colony, were placed on five different pecan leaflets on five different pecan seedlings. Twenty-four h later the viviparae were removed, and the nymphs that had been deposited were caged in containers (3 cm diam, 10 cm length) covered at one end with 40 mesh/cm^2 nylon organdy. The other end of the cage was plugged by a sponge wrapped around the leaflet blade. Nymphs were examined daily, and their development was recorded until they reached adulthood. Each of these alate aphids was caged individually on a single pecan leaflet. All aphids were examined, and the numbers of progeny were recorded every-other-day for each aphid until its death. All the young were removed at each counting.

RESULTS AND DISCUSSION

Species Determination and Damage. Samples of aphid populations that were taken throughout the study period from different regions in Israel indicated that M. caryella was the only species presently on pecan, in contrast to the situation in U.S.A. This aphid feeds on the primary and secondary veins of leaflets. Adults and older nymphs preferred the large primary vein, and younger nymphs preferred the secondary vein. Most of the aphids were found on the lower leaf surfaces. Damage to veins appeared first as discoloration beneath the epidermis of the vein. Discolored spots subsequently turned brownish or black.

Life Cycle, Development and Reproduction. After the alate fundatrices of M. caryella appeared in the spring, alate viviparae were found for the rest of the growing season until mid-November. They reproduced parthenogenetically throughout spring, summer and early autumn. Apterous oviparae were found mating with males and depositing eggs from mid-October until early December (Fig. 1). Eggs were yellow to orange when laid and turned dark to black within a few days. Eggs were scattered in small groups on buds and branches and beneath the loose bark on the tree trunk. The nymphs hatched during the first two weeks in April (Fig. 2).

Laboratory studies on alate viviparae showed that this aphid required 7 days to develop from birth to adulthood. There were four

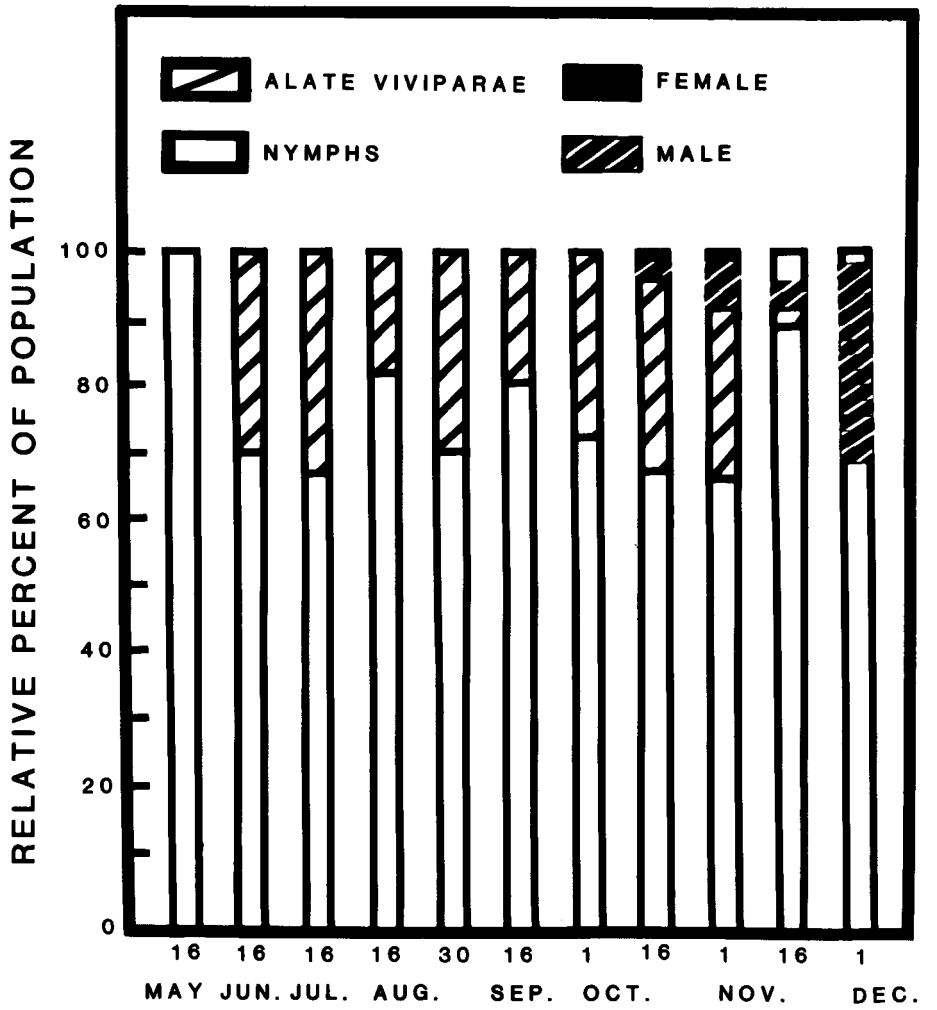

FIG. 1. Lifestage composition of Monellia caryella on pecan trees at Newe Ya'ar during the period May - December 1979.

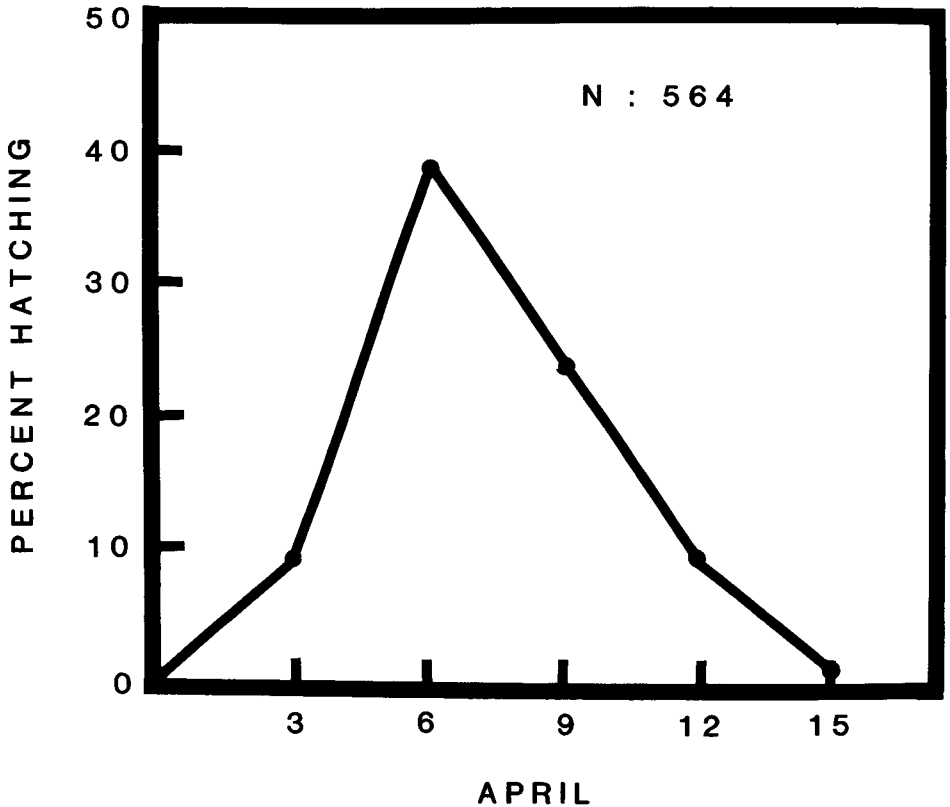

FIG. 2. Hatching percentage of Monellia caryella eggs on Mahan pecan trees, Newe Ya'ar, Israel.

instars, and the stadia were about equal in duration. Adults matured and began reproducing one day after the last molt. Maximum reproduction occurred on the sixth day of adulthood, and a range of 1.5 - 3.0 aphids were born every day from day 2-16 of adulthood (Fig. 3). Reproduction lasted an average of 16.6 days, with each adult living an average of 23.6 days and producing an average of 57 nymphs. Some adults reproduced for 33 days, and they produced 121 - 135 nymphs. In general, our findings and observations are similar to those of Tedders (1978), except that adults in the latter study produced an average of 125 nymphs each. These differences could be the result of differences in the rearing conditions.

Population Dynamics of M. Caryella. First instars of M. caryella were collected in some years at the beginning of April and in other years from late April to early May. High temperatures early in the season were associated with an earlier appearance of the aphid.

There were two population peaks in the Hulla Valley. The first occurred between 15 - 30 May, and the second at the end of October. Very few aphids were present from June to August (Fig. 4). At this site the first peak was the highest.

There were two population peaks observed each year at Newe Ya'ar (Figs. 5 & 6). The number of aphids generally increased as the season progressed and reached a peak between 14 - 30 May. Very few aphids were found during June and July. A second peak occurred in mid-September.

No significant differences in the appearance and population of the aphids was noticed throughout the years 1977, 1978, 1984, 1985 (Fig. 4 - 6).

Various authors have described the seasonal abundance pattern of the yellow aphid complex (two species grouped) as bimodal, with peaks of abundance early and late in the season (Alverson 1982, Gentry et al. 1975, Polles and Mullinex 1977). Tedders (1978) separated adults and nymphs species and described their seasonal abundance.

Leser (1981) indicated that pecan seedling leaves, after being exposed to heavy feeding by M. caryella, became a poor substrate for further development of populations of this aphid. Edelson (1982) and Leser (1981) proposed that this conditioning effect was a major factor regulating the population dynamics of M. caryella. Field studies by Liao et al. (1985) demonstrated that numbers of the blackmargined aphid, when held in closed cages, reached maximum levels of 30 - 100 aphids per compound leaf, and then numbers rapidly declined, presumably caused by a conditioning effect. Efforts to re-establish infestations on the green, conditioned foliage by re-inoculating each cage with 20 alates failed, even though the adults persisted for 3 - 4 wk which allowed a 4 - 6 wk period for foliage recovery following earlier feeding. Findings in the present study indicated the bimodal population fluctuations of blackmargined aphids were not always caused by conditioning. When early season populations were high enough to induce conditioning, pecan foliage 12 wk later was able to support aphids again. For example, early season peak populations found at Newe Ya'ar in 1977 were $\leq$ 3 aphids per compound leaf (no conditioning); while in 1978 populations exceeded 30 aphids per leaf, and late season outbreaks occurred in both years (Fig. 5). The same relationships occurred in the Hulla Valley (Fig. 4). The Newe Ya'ar data from 1984 and 1985 (Fig. 6) show no early season conditioning levels occurred in 1984 and probably 1985, but the same bimodal pattern persisted.

Possible factors affecting fluctuations in pecan aphid populations are temperature, wind, natural enemies, host phenology, interspecific competition, development rates, natality and fecundity. According to Sluss (1967), temperature and host phenology are of great importance and are interrelated. Temperature changes affect development rates; the rate

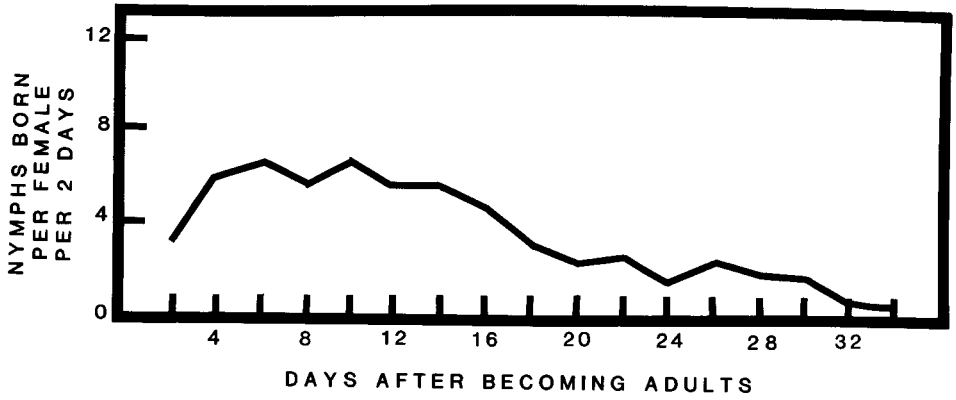

FIG. 3. Mean production of nymphs by 33 alate viviparae of M. caryella.

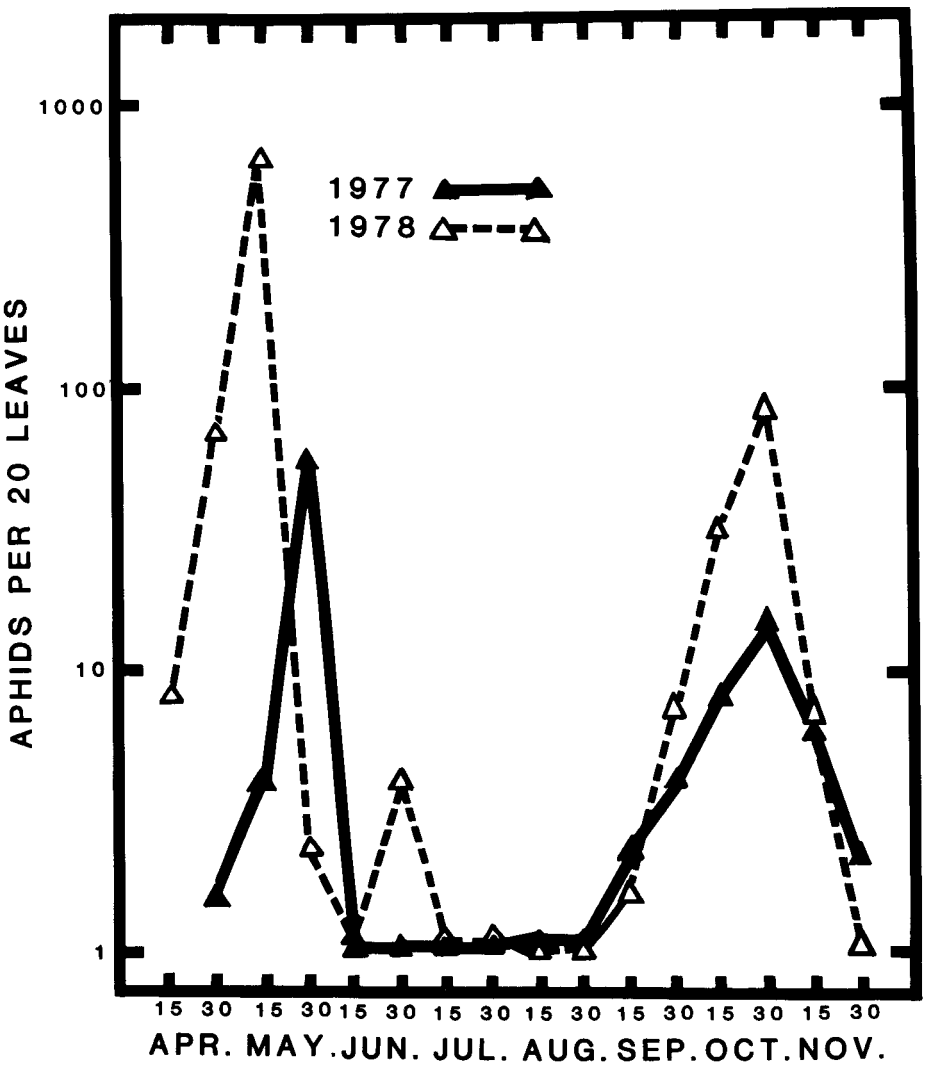

FIG. 4. Number and seasonal distribution of M. caryella collected from unsprayed pecan trees at Hulla valley.

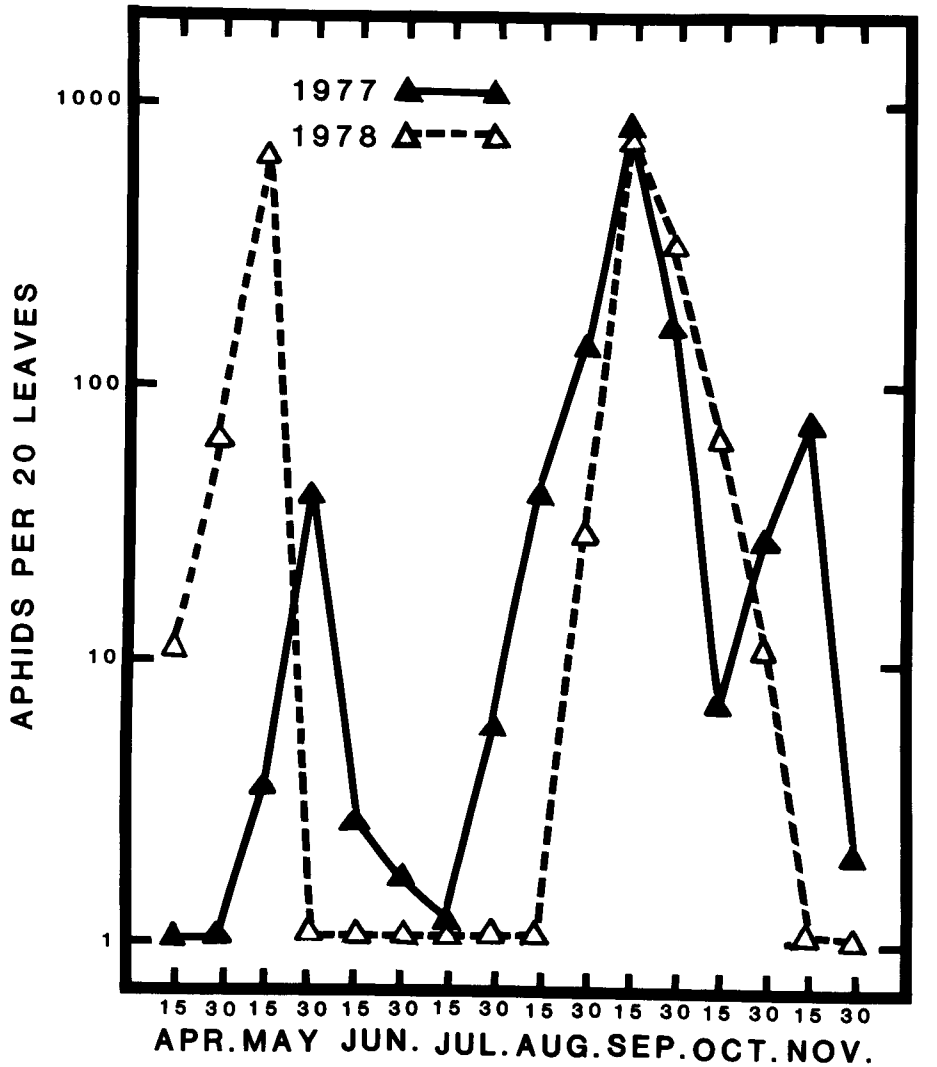

FIG. 5. Number and seasonal distribution of M. caryella collected from unsprayed pecan trees at Newe Ya'ar.

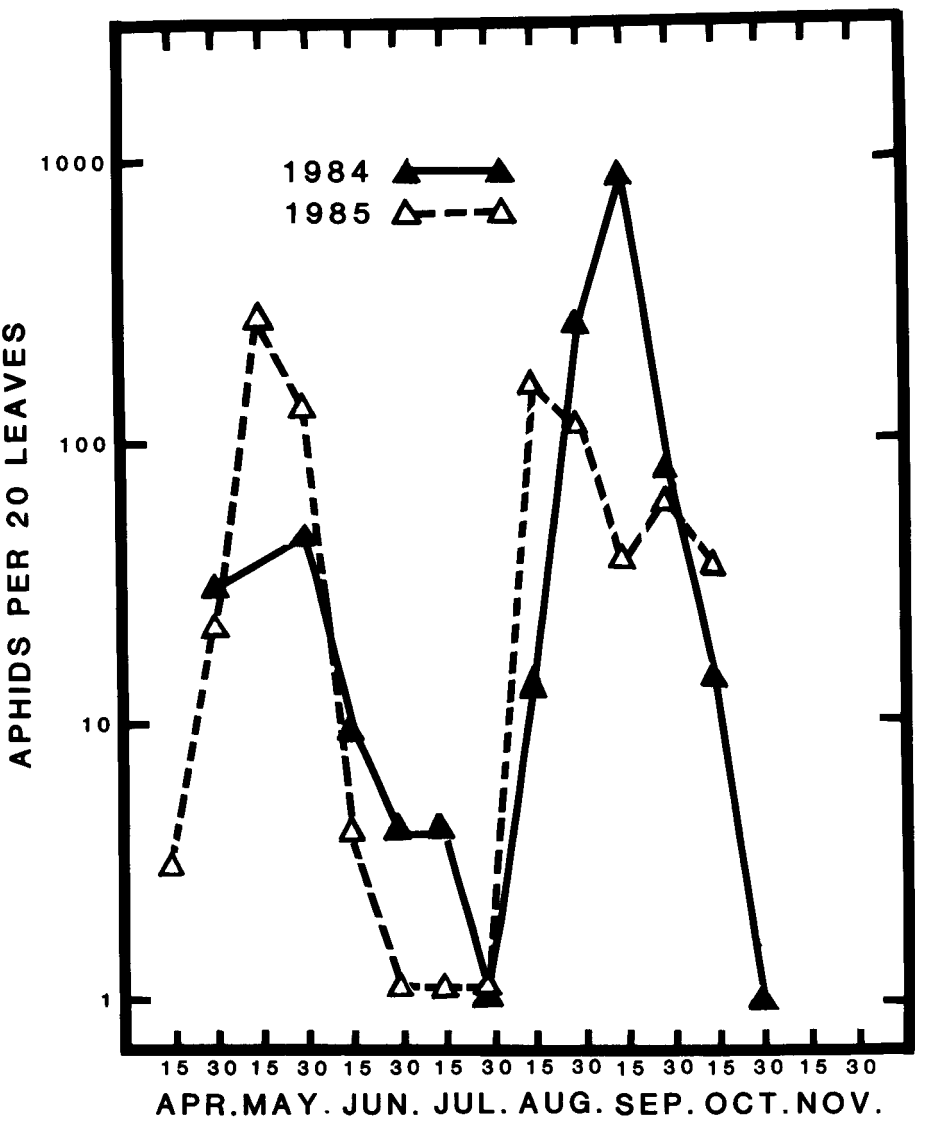

FIG. 6. Number and seasonal distribution of M. caryella collected from unsprayed Pecan trees at Newe Ya'ar.

increases as temperature increases to an upper threshold, after which the rate declines (Tamaki et al. 1980). Natural enemies, particularly predators, maintain M. caryella populations at low levels in the field (Liao et al. 1984, 1985). This exotic aphid presently has few natural enemies in Israel and no interspecific pest competitors; therefore, we conclude the bimodal pattern was probably caused by weather directly or was indirectly mediated by the pecan tree.

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LITERATURE CITED

Alverson, D. R. 1982. Yellow pecan aphids in South Carolina orchards: leaflet infestation indices of population density. J. Georgia Entomol. Soc. 17: 229-236.

Edelson, J. V. 1982. Seasonal abundance, distribution and factors affecting population dynamics of yellow pecan aphids (Monellia caryella and Monelliopsis nigropunctata). Ph.D. Dissertation, Auburn University, Auburn, AL.

Gentry, C. R., H. L. Malstrom, and J. L. Blythe. 1975. Georgia tests show aphid preferences. Pecan Quart. 9: 20-21.

Golan, Y., M. Chen, M. Cohen, I. Zachs, I. Izhar, E. Koter, and A. Tadmor. 1977. [The yellow leaf aphid of pecan, a new pest in Israel.] Alon haNote'a, 31: 457-467 (in Hebrew).

Harris, M. K., 1983. Integrated pest management of pecans. Ann. Rev. Entomol. 28: 291-318.

Leser, J. F., 1981. Effects of temperature and host-insect interaction on the population dynamics of the blackmargined aphid, Monellia caryella (Fitch). (Homoptera: Aphididae). Ph.D. Dissertation. Univ. Arizona, Tucson, AZ.

Liao, H. T., M. K. Harris, F. E. Gilstrap, D. A. Dean, C. W. Agnew, G. J. Michels, and F. Mansour. 1984. Natural enemies and other factors affecting seasonal abundance of the blackmargined aphid on pecan. Southwest. Entomol. 9: 404-420.

Liao, H. T., M. K. Harris, F. E. Gilstrap, and F. Mansour. 1985. Impact of natural enemies on the blackmargined pecan aphid, Monellia caryella (Homoptera: Aphididae). Environ. Entomol. 14: 122-126.

McVay, J., B. Gazway, B. Hagler, P. Estes, and A. Latham. 1982. Commercial Pecan Insect and Disease Control Guide. Ala. Coop. Ext. Serv. Circ. ANR-27. 8 pp.

Payne, J. A., H. L. Malstrom, and G. E. KenKnight. 1979. Insect Pests and Diseases of the Pecan. USDA-SEA, Agric. Rev. Man. AEMS-S 5: 43 pp.

Plaut, H. N., and F. Mansour. 1977. The blackmargined yellow aphid, Monellia costalis (Fitch) (Homoptera: Aphididae), a new pest in Israel. Hassadeh, 57: 1816-1822 (Hebrew, with English summary).

Polles, S. G., and B. Mullinex. 1977. Distribution of yellow pecan aphids within pecan trees. Environ. Entomol. 6: 429-434.

Sluss, R. R. 1967. Population dynamics of the walnut aphid Chromaphis juglandicola (Kalt.) in northern California. Ecol. 48: 41-58.

Tamaki, G., M. A. Weiss, and G. E. Long. 1980. Impact of high temperatures on the population dynamics of the green peach aphid in field cages. Environ. Entomol. 9: 333-337.

Tedders, W. L. 1978. Important biological and morphological characteristics of the foliar-feeding aphids of pecans. Tech. Bull. U.S. Dep. Agric. 1579. 22 pp.

Tedders, W. L., V. R. Calcote, and J. A. Payne. 1970. A method for rapid germination of pecan seed. Pecan Quart., 4: 11.

Tedders, W. L., and J. S. Smith. 1976. Shading effect on pecan by sooty mold growth. J. Econ. Entomol. 69: 551-553.

Tedders, W. L., B. W. Wood, and J. W. Snow. 1982. Effects of feeding by Monelliopsis nigropunctata, Monellia caryella, and Melanocallis caryaefoliae on growth of pecan seedlings in the greenhouse. J. Econ. Entomol. 75: 287-291.

SEXUAL ATTRACTION OF LYGUS HESPERUS KNIGHT[1/]

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ABSTRACT

A study was conducted to provide details on sexual attraction in Lygus hesperus Knight. Males of L. hesperus are attracted by an airborne sex pheromone produced by the females. Removal of antennal flagella of males or isolating them from airborne female odors eliminated their response to females. The area near the ovipositor was found to be important in attraction of males.

INTRODUCTION

The attraction of Lygus lineolaris (Palisot) males to virgin female-baited traps was demonstrated in the field by Scales (1968), Blumenthal (1978), and Slaymaker and Tugwell (1984). A similar attraction of L. hesperus Knight in the field was shown by Strong et al. (1970), who also presented some detailed laboratory studies on the reproductive systems and mating behavior. Results of the latter field study suggested a windborne sex pheromone was involved.

In a very limited laboratory experiment, Strong et al. (1970) found that L. hesperus males or females from which antennal flagella were removed mated with intact insects, although the precopulatory periods were lengthened from those intact insects. Since antennae of insects usually bear the receptors for sex pheromones (Jacobson 1972), these results suggest another form of attraction, such as visual or acoustic, might be involved.

The source and nature of a sex pheromone in L. hesperus, if there is one, is unknown. Strong et al. (1970) were unsuccessful in extracting a pheromone from females. They attributed this to lack of a good bioassay. Sexual dimorphism was found in L. lineolaris for ratios of hexenyl butyrate to hexyl butyrate (Geldner and Parrott 1978). These compounds were concentrated in the thorax, site of the metathoracic scent glands, but Blumenthal (1978) found the content of the reservoir of these glands in both sexes was almost entirely hexyl butyrate. The latter is the case in L. hesperus, also (L.M. McDonough and H.G. Davis, ARS, Yakima, WA; personal communication). Hexyl butyrate is repellant to both species of Lygus (Blumenthal 1978; McDonough and Davis, personal communication).

Development of an olfactometer that determined sexual attraction in L. desertinus Knight and L. elisus Van Duzee (Graham 1987) provided a tool for further study of this attraction in L. hesperus.

The laboratory study reported here was undertaken to confirm the results of previous field studies and to provide additional information on sexual attraction and responses as they affect mating in L. hesperus.

[1/]Heteroptera: Miridae

METHODS AND MATERIALS

General Procedures. The L. hesperus used in these studies had been reared in our laboratory for about 7 yr using the artificial diet and techniques of Patana and Debolt (1985). To obtain virgin males and females, last instar nymphs from the colony were held for development to the adult stage. Adults were collected daily, anesthetized by CO_2, and sexed. Adults were held separately by sex in cages made from 1.9 L cylindrical cardboard cartons and fed green beans, broccoli, and coddled beet armyworms, Spodoptera exigua (Hübner). The adults were held at 27 ± 2°C with a 14L:10D photoperiod for at least 6 days after eclosion so that they would be sexually mature when used in the following experiments.

Mating studies were conducted with single pairs of virgin insects in a 0.47 L cylindrical cardboard container with a nylon organdy lid. A green bean and coddled beet armyworm were provided as food. For each replication, up to ten pairs were held about 24 h, then the females were dissected to determine if they had mated (Graham and Debolt 1986). The percentage mated was calculated for each replicate, and values were transformed to arcsin $\sqrt{\%}$ for analysis of variance. The means were separated at the 0.05 level of probability by Duncan's Multiple Range Test (Duncan 1955). The means and standard deviations (SD) of the untransformed data are shown in this manuscript.

Olfactometer studies were conducted as described by Graham (1987), who used an olfactometer consisting of a center chamber, 17.0 x 31.8 x 8.9 cm, made from a plastic shoe box, with a tube at each end divided into two sections by a screen. The distal ends of the tubes were covered by a cap with screen center. The candidate attractant (five insects of one sex with a segment of green bean when they were tested) was contained in the distal end of both tubes. Twenty test insects were released into the center chamber, which contained two green beans; and air was drawn over the attractant and through the center chamber by a vacuum pump. Test insects responding to the attractant were trapped in the proximal ends of the tubes by an inverted cone at the entrance to the tubes. The distance of attraction in this device was between 10.5 and 43.0 cm. The olfactometer was operated between 0730 and 1530 h in a room at 24 ± 2°C, 55 ± 5% RH, and constant fluorescent light. Each exposure lasted 1.5 h. A single replicate was completed during a day, and the sequence of treatments in the replicates was randomized. The percentages of insects responding to the attractants were calculated and analyzed as in the mating study. The total numbers observed excluded those resting on the cone that had not passed through the tip into the collection chamber.

Nonolfactory Attraction. Two experiments were conducted in the olfactometer to determine if male L. hesperus were attracted by females by nonolfactory means, as reported for the pentatomid, Nezara viridula (L), by Cokl and Bogataj (1982). In the first experiment, the screen separating the attractant chamber from the collection chamber in the olfactometer was replaced by a tightly stretched piece of plastic wrapping material (Saranwrap®[2/]). The vacuum pump was not used with this modification. This allowed males to receive visual and some auditory stimuli from females, but olfactory stimuli were eliminated. Movement of males toward females and toward green bean segments with no females was compared to movement toward females exposed in the usual manner. There were three replications of each treatment, with means of 16.3 to 18.7 males observed per treatment per replicate.

[2/]Mention of a trademark or proprietary product does not constitute endorsement by the USDA-ARS for its use over any other product.

In the second experiment, the airflow in the olfactometer was reversed, with the vacuum lines attached to the distal ends of the attractant chambers. The screen lid on the distal end of each tube was replaced by a solid lid with a tube in the center for attaching the vacuum line. The holes in the sides of the release chamber, usually fitted with rubber stoppers for attaching the vacuum lines, were enlarged to a diameter of about 4.0 cm and covered by screen to allow free airflow into the chamber. This device prevented any olfactory stimuli from the attractants from reaching the males, but would have had little effect on visual or auditory stimuli. Responses of males to females and to segments of green beans without females in this modified olfactometer were compared to responses to females in the unmodified model. There were three replications of each treatment, with means of 17.0 to 18.3 males observed per treatment per replicate.

Effects of Antennae on Sexual Attraction and Mating. In a mating study, the distal three segments (flagellum) were removed from the antennae of anesthetized adult L. hesperus males and females about 4 days after they reached adulthood. Another group of males and females were anesthetized, but antennae were not removed. Crosses were made between and among insects with and without antennae 6-8 days after they reached adulthood. There were six replications, with six to ten pairs per treatment per replicate.

A second experiment compared mating of males with their flagella removed to that of normal males and to those with the antennae severed at the base of the pedicel with the remnants sealed with nail polish. There were three replications with seven to ten pairs per treatment per replicate.

The impact of antennectomy on sexual attraction was studied in the olfactometer. The insects were treated as in the mating study, and the attraction of males with and without antennae by both types of females was determined. The initial experiment utilized insects with the entire flagellum removed. In addition, attraction of normal males by a segment of green bean with no females was measured as a control.

A second experiment measured the attraction of intact males and of males with one to three antennal segments removed to intact females. Attraction of normal males to a segment of green bean with no females was used as a control. There were four replications of each treatment in both of these olfactometer tests.

Importance of Female Wings in Attraction of Males. An experiment was conducted in the olfactometer to compare the attractiveness of wingless and intact L. hesperus females to males. Mature virgin females were anesthetized, and the wings were severed at the bases. Two to four days later, the responses of males to the wingless and winged females and to segments of green beans were determined in the olfactometer. There were four replications, with means of 17.5 to 18.8 males observed per treatment per replicate.

Source of Pheromone. Experiments were conducted to locate the source of the sex pheromone in L. hesperus females. The first tests were to determine if the metathoracic glands were sites of the attractant in L. hesperus females, as was found in Dysdercus spp. (Hebbalkar and Sharma 1982, Siddigui and Kahn 1982). In the first experiment females were anesthetized three days after eclosion, and their mesothoracic legs were amputated at the bases of the coxae to provide better access to the peritremes of the metathoracic glands. Then the peritremes were sealed with a coat of nail polish. Another group of females was treated similarly, but the peritremes were not sealed. A third group was anesthetized, but otherwise untreated. Three to six days later, the movement of L. hesperus males toward these three groups of females was measured in the olfactometer. There were four replications of each

treatment, with means of 17.0 to 18.8 males observed per treatment per replicate.

In the second experiment, three groups of females were treated as in the first experiment. Four days after treatment they were paired with male L. hesperus for a day, and the percentage mated was determined. There were three replications of each treatment, with seven to nine pairs per treatment per replicate.

When the results of the first series of experiments eliminated the metathoracic glands as the sources of pheromone, a second series was undertaken to determine from what other areas the pheromone might be emitted. The first experiment determined whether the pheromone was emitted from the thoracic or abdominal region. The mesothoracic legs and wings were removed from a group of anesthetized females. The thorax of some females and the abdomen of others were coated with nail polish. A third group was not coated with nail polish and served as a control. The movement of males toward the three types of females and toward segments of green beans was compared in the olfactometer. There were three replications with means of 16.0 to 17.7 males observed per treatment per replicate.

The results of the first experiment of this series indicated the abdominal region of the female was the area eliciting the greatest response from males, so another experiment was done to determine if the ovipositor was the primary source of the stimulant. Mature virgin female L. hesperus were anesthetized and their wings removed. The entire abdomen of a portion of these was coated with nail polish to seal the ovipositors. The abdomens of a second group were coated, except for the region around the ovipositor, and a third group was left uncoated as a control. The movement of males toward these three groups of females and towards a segment of green bean was tested in the olfactometer from 1 to 4 days after painting. There were six replications, with means of 16.7 to 18.8 males observed per treatment per replicate.

RESULTS

Nonolfactory Attraction. A significantly greater percentage of L. hesperus males were collected in the olfactometer tubes when the airstream was drawn over females (69.8 ± 7.0%) than when the females (12.4 ± 16.6) or green beans (21.2 ± 10.7) were separated from the males by a plastic barrier, which prevented airflow from reaching the males. The percentages of males collected using females or green beans was similar when the barrier was in place. A significantly greater percentage of males (76.6 ± 7.1%) was collected when the airstream was drawn over females than when it was drawn from them towards females (25.7 ± 7.9) or green beans (19.2 ± 12.2). Males responded similarly to females or green beans when the air was drawn toward the candidate attractant.

Effects of Antennae on Sexual Attraction and Mating. Males with the entire flagellum removed mated significantly less than those with intact antennae (Table 1). Removal of antennae from females had no effect on their mating. Severing of the males' antennae at the bases of the pedicels and sealing the remainder did not reduce their mating as compared to those with only the flagella removed. When male antennae were severed and the bases sealed, 16.7 ± 20.8% mated. This was similar to the response when the base was not sealed (10.8 ± 10.1% mated). The control group of intact males mated well (66.0 ± 5.7% mated).

The experiments in the olfactometer supported the results of the mating experiment, with response to intact males by females with flagella removed similar to that by intact females (Table 2). Collections of males with only one or two antennal segments removed were similar to those of males with intact antennae, while removal of the entire flagellum significantly reduced the collection (Table 3).

TABLE 1. Mating Lygus hesperus with and without antennal flagella. Six replications of each cross.

Cross[a] (♀ X ♂)	Number pairs observed (SD)	Percentage females mated (SD)[b]
I X I	8.3 (1.0)	71.8 (12.8)B
A X A	9.5 (0.8)	10.0 (8.9)A
I X A	8.7 (1.4)	14.6 (15.2)A
A X I	9.2 (0.8)	50.9 (19.9)B

[a] I=intact, A=those with flagella removed.

[b] Means followed by the same letter were not significantly different (P > .05), Duncan's (1955) multiple range test.

TABLE 2. Responses of Male Lygus hesperus with and without Antennal Flagella to the Females in Olfactometer. Four Replications of Each Combination.

	Males			
	Mean number observed/rep. (SD)		Percentage responding/rep. (SD)[b]	
Attractant[a]	I	A	I	A
Females				
I	17.8 (1.7)	18.5 (1.7)	61.0 (13.5)B	16.2 (8.2)A
A	18.5 (1.0)	18.3 (1.0)	57.2 (22.8)B	15.2 (7.1)A
Green Bean Only	17.8 (1.9)	-	15.4 (7.3)A	-

[a] I=intact, A=those with flagella removed.

[b] Means followed by the same letter were not significantly different (P > .05), Duncan's (1955) multiple range test.

TABLE 3. Responses of Lygus hesperus Males with None to Three Segments Removed from Antennal Flagella to Intact Females in Olfactometer. Four Replications of Each Combination.

	Mean/replication	
Number segments removed from male antennae	Number observed/rep. (SD)	Percentage responding (SD)[a]
0	18.3 (1.0)	78.0 (13.0)B
0 (Control)[b]	17.8 (1.0)	47.7 (10.6)A
1	17.5 (1.9)	86.4 (15.9)B
2	18.0 (2.3)	76.0 (14.3)B
3	16.5 (1.7)	34.4 (14.2)A

[a] Means followed by the same letter were not significantly different (P > .05), Duncan's (1955) multiple range test.

[b] Response to green bean segment without females.

Importance of Female Wings in Attraction of Males. The absence of wings of females did not significantly affect the collections of males in the olfactometer tubes, with 74.3 ± 9.6% collected when intact females were used and 61.2 ± 12.3% with wingless females. Significantly fewer males (35.5 ± 14.1%) were collected when green beans were used.

Source of Pheromone. When females with their mesothoracic legs removed and metathoracic gland peritremes sealed were used as the attractant, 69.2 ± 18.6% of the males were collected in the tubes. The percentage collected when only the females' legs were removed (68.9 ± 15.9%) or when females were intact (62.6 ± 13.2%) were similar to this. Also, mating was unaffected by the treatments, with 53.2 ± 12.2, 42.8 ± 24.7 and 48.2 ± 9.9% of the females mated in the respective treatments. Examination of females with sealed glands under 15-X magnification showed all remained well-coated with nail polish at the end of the experiment.

Sealing the females' thorax had no effect on the percentage of males captured (58.8 ± 13.2%) compared to unsealed females (58.3 ± 5.2%). However, the percentage of males captured when females' abdomen was sealed (24.4 ± 9.7%) was significantly lower than these and was similar to the capture when green beans were used alone (24.8 ± 4.2%).

A significantly lower percentage of males was attracted to females with completely sealed abdomens (26.8 ± 4.5%) than to those in which the area of the ovipositor was unsealed (42.9 ± 7.2%). The latter was not significantly different from attraction by untreated females (51.9 ± 16.5%), while the former was similar to that by green beans alone (14.3 ± 11.3%).

DISCUSSION

Sexual attraction in L. hesperus appears to be an olfactory response of males to an airborne sex pheromone produced by the females, at least at distances beyond 10.5 cm, which confirms results of earlier field studies. However, comparison of my results to those of Strong et al. (1970) suggests stimuli other than olfactory may be effective at very short distances. In the study by Strong et al. (1970), who used 12.9-ml cages, five of eight males without antennae mated with normal females; while in my study, using 4.7 L cages, fewer than ten percent mated. The close confinement in the former study brought stimuli other than olfaction into play for the location of mates, while the males in the present study relied primarily on olfaction.

Absence of the entire antennal flagellum significantly reduced the percentage of males collected, while absence of the distal two segments had little effect. This suggests the basal, or third segment is important in their response to females.

Sealing of the ovipositor of L. hesperus females was the only area that reduced the percentages of males collected as compared to unsealed females. The ovipositor seems important in stimulating males.

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LITERATURE CITED

Blumenthal, M. A. 1978. The metathoracic gland system of Lygus lineolaris (Heteroptera: Miridae). MS Thesis, Cornell University, Ithica, NY.

Cokl, A., and E. Bogataj. 1982. Factors affecting vibrational communication in Nezara viridula. Biol. Vestn. 30: 1-20.

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

Graham, H. M. 1987. Attraction of Lygus spp. males by conspecific and congeneric females. Southwest. Entomol. 12: 147-155.

Graham, H. M., and J. W. Debolt. 1986. Reproductive isolation between colonies of Lygus lineolaris. Southwest. Entomol. 11: 125-130.

Gueldner, R. C., and W. L. Parrott. 1978. Volatile constituents of the tarnished plant bug. Insect Biochem. 8: 389-391.

Hebbalker, D. S., and R. N. Sharma. 1982. An experimental analysis of mating behaviour of the bug Dysdercus koenigii F. (Hemiptera: Pyrrhocoridae). Indian J. Exp. Biol. 20: 399-405.

Jacobson, M. Insect Sex Pheromones. Academic Press, New York. 383 pp.

Patana, R., and J. W. Debolt. 1985. Rearing Lygus hesperus in the laboratory. USDA, ARS-45. 5 pp.

Scales, A. L. 1968. Female tarnished plant bugs attract males. J. Econ. Entomol. 61: 1466-1467.

Siddiqi, J. I., and M. A. Khan. 1982. Location of sex pheromone of Dysdercus cingulatus Fabr. (Hemiptera: Pyrrhocoridae). J. Entomol. Res. 6: 182-186.

Slaymaker, P. H., and N. P. Tugwell. 1984. Inexpensive female-baited trap for the tarnished plant bug. J. Econ. Entomol. 77: 1062-1063.

Strong, F. E., J. A. Sheldahl, P. R. Hughes, and E. M. K. Hussein. 1970. Reproductive biology of Lygus hesperus Knight. Hilgardia 40: 105-147.

FLIGHT PATTERNS OF CLEARWING BORERS[1/] IN COLORADO BASED ON PHEROMONE TRAP CAPTURES

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ABSTRACT

For two years a pheromone monitoring program for clearwing borer moths (Lepidoptera: Sesiidae) utilizing Z,Z-3,13-octadecadienyl acetate has been conducted in Colorado. In 1985 trapping was conducted in only a few localities. An intensive study was initiated in 1986 in eight Colorado counties representing a wide diversity of climates and habitats. Onset and duration of flight periods of Podosesia syringae (Harris), the lilac/ash borer, and Synanthedon exitiosa (Say), the peachtree borer, were studied in detail for these locations. For P. syringae emergence occurred approximately 2 wk earlier in the southern portions of the state; for S. exitiosa first emergence was approximately the same time in all locations. Other sesiid species were captured including two species not previously recorded in Colorado, S. scitula Harris, the dogwood borer, and S. viburni (Englehart), the viburnum borer.

INTRODUCTION

Larvae of the family Sesiidae are borers primarily of roots and stems. Some species of sesiids are potentially damaging to horticultural crops and ornamental plantings of particular importance in Colorado. The lilac/ash borer, Podosesia syringae (Harris), feeds on ash (Fraxinus spp.), and the peachtree borer, Synanthedon exitiosa (Say), damages commercial and ornamental plantings of Prunus spp., particularly peach, cherry and plum. The identification of the female sex pheromones of S. exitiosa and S. pictipes (Grote and Robinson) (Tumlinson et al. 1974) allowed pheromone monitoring and was quickly exploited for these pest species. Nielson and Balderston (1973) reported pheromone cross-attractivity between adults of various species, and this phenomenon also was true for the pheromone component Z,Z-3,13-octadecadienyl acetate (ZZ-ODDA) (Nielsen et al., 1975). Many studies have utilized this sex attractant to monitor for these species, and often new records have been reported and even new species described (Underhill et al. 1978, Solomon et al. 1982, Adler 1983, Nielsen and Purrington 1978, Brown et al. 1985a). Here, we report the results of pheromone trapping studies with ZZ-ODDA, which document the species captured and the variation in emergence patterns throughout Colorado.

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MATERIALS AND METHODS

Traps in 1986 were located in the Colorado counties shown in Fig. 1. This represents a geographic area of 430 km north to south and 600 km east to west. The elevation varied from 1050 m in Wray, Yuma Co. to approximately 2400 m in Pinos Creek, Rio Grande Co. In 1985 traps were located in Boulder, Denver, and Larimer counties. Pherocon® 1C traps were used, and the bottoms were changed approximately once a week. There was one trap at each location except in 1986; four traps were in Larimer Co. and two in Denver Co.. Cooperators sent the traps to our laboratory at regular intervals, and identifications were based on apparent morphospecies. The trap bottoms were stored in a freezer until final determinations were made. Species identity was assigned by T. D. Eichlin. The pheromone source was commercially available Scentry® clearwing borer fiber-strip lures that were replaced monthly. Trapping commenced in April in most locations and was terminated in September.

TABLE 1. Sesiid Species Captured In Pheromone Traps In Colorado, 1986

County	Species	Major Hosts	Total Trapped	Trapping Period
Denver	Podesesia syringae	Lilac, Ash	210	29 Apr-3 Jun
	Synanthedon exitiosa	Peach, Cherry	121	3 Jun-29 Jul
	Sesia tibialis	Cottonwood	64	26 Jun-29 Jul
	Synanthedon scitula	Many Hardwoods	1	15 Jul-31 Jul
Larimer	P. syringae		705	20 Apr-21 Jul
	S. exitiosa		365	2 Jun-4 Sep
	S. tibialis		2	23 Jun-6 Jul
	Albuna fraxini	Virginia creeper	10	7 Jul-28 Jul
	Carmenta mimuli	Chamaesaracha coronopus	6	2 Jun-4 Aug
Jefferson	P. syringae		286	24 Apr-9 Jul
	S. exitiosa		222	2 Jun-2 Sep
	S. tibialis		148	2 Jun-13 Aug
	C. mimuli		2	27 Aug-2 Sep
	Synanthedon culiciformes	Alder	1	17 May-24 May
Pueblo	P. syringae		432	4 Apr-11 Jul
	S. exitiosa		508	10 May-5 Sep
	S. tibialis		1	9 Aug-15 Aug
Rio Grande	S. tibialis		10	19 Jun-13 Aug
	S. culiciformes		10	28 May-19 Jun
	Penstemonia edwardsii	Penstemon	2	12 Jun-26 Jun
Weld	P. syringae		60	28 Apr-16 Jun
	S. exitiosa		83	9 Jun-2 Sep
Yuma	S. exitiosa		224	1 Jul-18 Aug
	C. mimuli		6	1 Jul-18 Aug

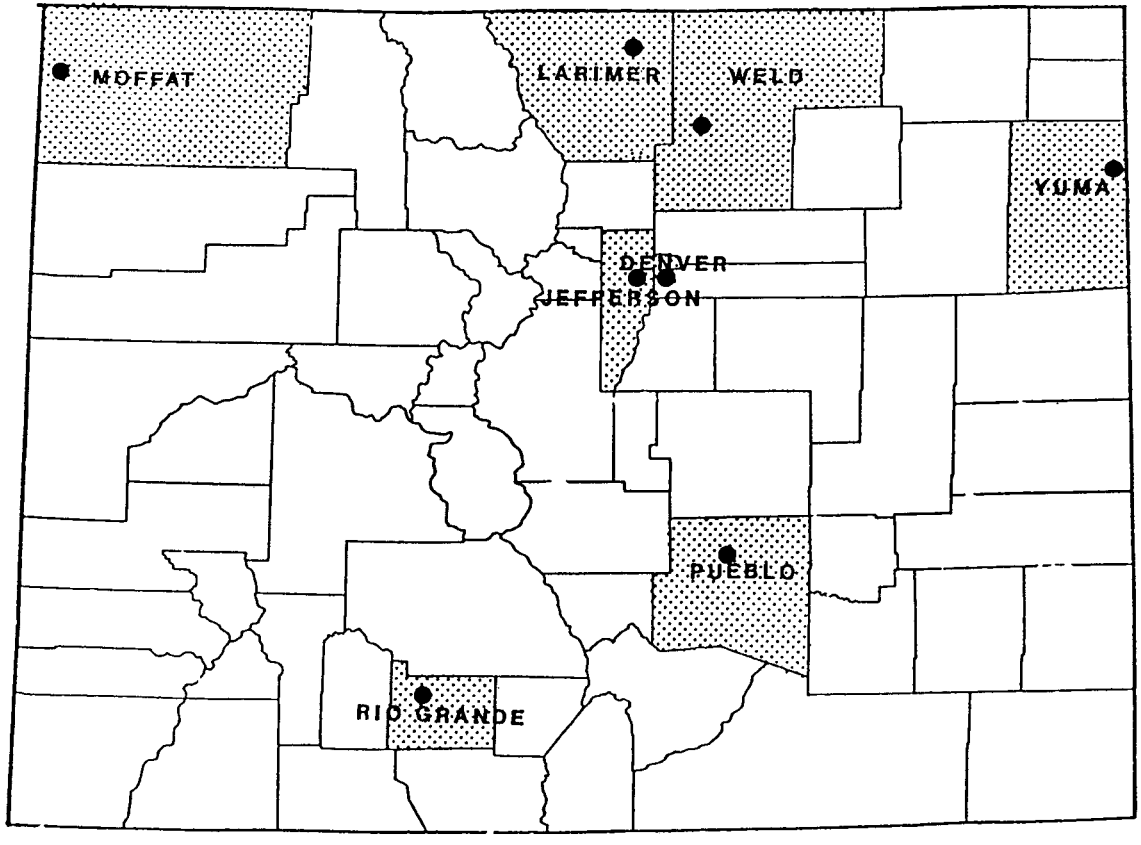

FIG. 1. Colorado Counties (shaded) where pheromone traps were located in 1986; dots indicate trap locations.

RESULTS AND DISCUSSION

Table 1 shows the species captured in each location in 1986, the major host plant(s) for each species, the total number trapped, and the duration of capture for that location. Sesiid moths were captured at all locations except for Moffat Co. (Dinosaur, CO).

The most abundant species at Denver, Larimer and Jefferson county locations was P. syringae. At Weld and Pueblo more S. exitiosa were trapped. Trapping did not begin in Yuma Co. until 1 July 1986, which was near the end of P. syringae flight periods. The only location where moths were trapped but neither of these two pest species was captured was in Rio Grande County, a high mountain location.

Additional species caught in 1985 in a trapping study over a more limited area included S. viburni, trapped in Fort Collins, and S. scitula, trapped in Denver. Both are new records for Colorado. These species have been attracted to ZZ-ODDA in other locations (Nielsen et al. 1975, Adler 1983, Reidl et al. 1985). Some of those studies (Adler 1983, Riedl et al. 1985) reported captures of S. scitula much larger than ours. In our studies we captured one male in 1985 and one in 1986, both in Denver County. Low indigent populations, an inappropriate chemical signal, or a limited number of host plants in the area could have caused the small catches. The latter is unlikely since S. scitula has one of the broadest host ranges of any North American sesiid (Englehardt 1946).

New locality records and new species of sesiids have been reported using ZZ-ODDA as bait alone and in combination with other isomers and the alcohol derivatives of this compound (Nielsen et al. 1979). The compound E,Z-2,13-octadecadienyl acetate has been identified as a sex pheromone component for other sesiids, including the currant borer moth, Synanthedon tipuliformis (Clerck), (Szocs et al. 1985, Voerman et al. 1984), the grape root borer, Vitacea polistiformes (Harris), and the squash vine borer, Melittia curcurbitae (Harris) (Schwarz et al. 1983). Many other new locality and possibly species records will likely be reported when this compound is incorporated in a pheromone attractant blend (Brown et al. 1985b).

We were interested in learning if there was a difference in the onset of emergence for the species of most economic importance, P. syringae and S. exitosa, in different areas of the state. Knowledge of emergence periods is important for timing of control materials, since most effective control is achieved before neonate larvae enter the wood of the tree hosts. Fig. 2 shows the flight pattern for P. syringae in three trapping locations in 1986. Pueblo Co. is the southernmost locality, and the onset of flight was approximately 2 wk earlier than in Larimer Co. locations. Table 2 shows the mean monthly temperatures for the trapping locations.

TABLE 2. Mean Monthly Temperatures ^{o}C (Jan-July, 1986) In Different Colorado Counties.

County	Jan	Feb	Mar	Apr	May	Jun	Jul
Denver	4.61	2.28	8.36	9.75	13.72	21.28	23.06
Larimer	2.33	2.06	8.03	9.47	13.50	20.19	21.69
Jefferson	4.64	2.11	8.97	9.00	12.75	19.00	22.02
Pueblo	4.14	3.81	8.78	11.78	15.50	21.69	24.39
Weld	-0.22	1.42	8.39	10.03	14.22	21.19	22.88

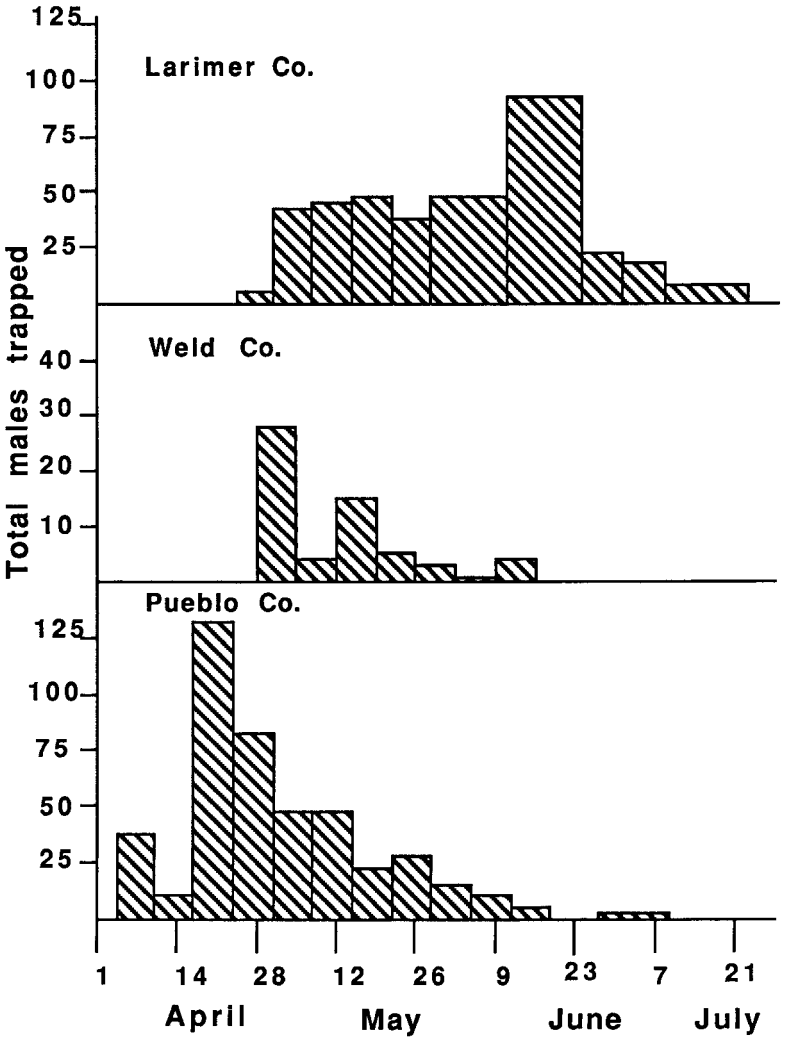

FIG. 2. Flight patterns of Podosesia syringae in three Colorado counties in 1986.

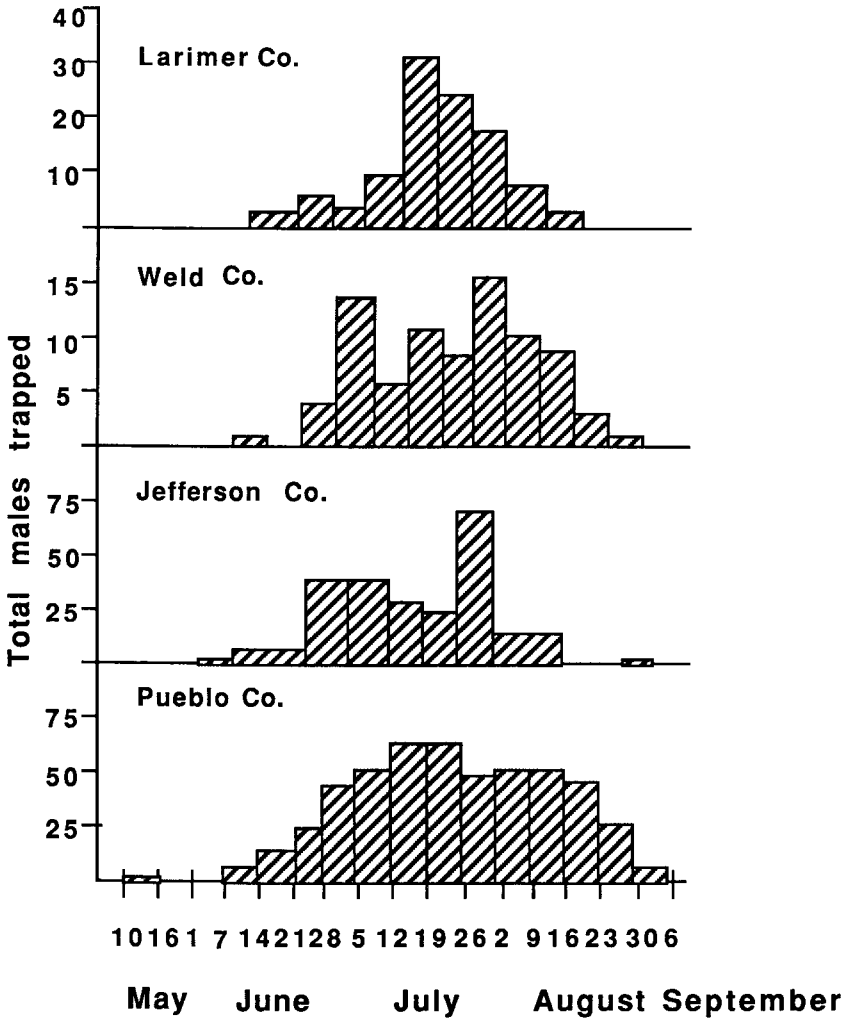

FIG. 3. Flight patterns of Synanthedon exitiosa in four Colorado counties in 1986.

The temperatures in Pueblo Co. were higher than in Larimer Co. during the months preceeding flight initiation for P. syringae. For S. exitiosa, the major portion of the flight period was somewhat earlier in Pueblo Co. than in Larimer Co. (Fig. 3), but flight activity could not be correlated with a south to north cline as for P. syringae. However, a single male was captured on 10 May in Pueblo. This male may represent an isolated emergence incidence or perhaps was indicative of the true onset of emergence. Since there was only one trap at this location, low levels of flight activity may not have been adequately detected.

The lack of variation in flight activity periods over our geographical area for S. exitiosa could be caused by less variation in the mean monthly temperatures during S. exitiosa flight periods (Fig. 3, Table 2). Mean monthly temperatures from April and later are near or above developmental thresholds as calculated for the sesiid species. For P. syringae and S. exitiosa a base temperature of 10^{o} has been used as a developmental threshold. Differences in mean monthly temperatures may have less of an effect on S. exitiosa than on earlier emerging species such as P. syringae. Another possible explanation for the differences in emergence periods is the large fluctuation in daily temperatures seen throughout the year in Colorado. It is not uncommon for the difference between the high and low temperatures to be over 10^{o}. For the months of this study the maximum daily difference in temperatures ranged from 13.3^{o} (Feb) in Pueblo County and 8.3^{o} (May) in Larimer County. With successive trapping we hope to develop a predictive model, such as degree-day, which will function for these species under our conditions. This has been useful for other sesiids in other areas (Potter and Timmons, 1983a,b; Barry, 1978; see also Riedl et al., 1985).

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LITERATURE CITED

Adler, V. E. 1983. Adult Sesiidae of Maryland collected in traps baited with isomers of 3,13-octadecadien-1-ol acetate. Environ. Sci. Health A. 18: 611-619.

Barry, M. W. 1978. Sex pheromone mediated behavior and biology of the peachtree borer, Synanthedon exitiosa (Say). Ph. D. thesis. Ohio State University, Columbus.

Brown, L. N., T. D. Eichlin, and J. W. Snow. 1985a. A new species of clearwing moth, Carmenta laurelae (Sesiidae) from Florida. J. Lepid. Soc. 39: 262-265.

Brown, L. N., T. D. Eichlin, and J. W. Snow. 1985b. Ecological notes on Synanthedon dominicki Duckworth and Eichlin (Sesiidae) in Florida and first description of the female. J. Lepid. Soc. 39: 196-200.

Englehardt, G. P. 1946. The North American clear-wing of the family Aegeriidae. US Nat. Mus. Bull. 190.

Nielsen, D. G., and C. P. Balderston. 1973. Evidence for intergeneric sex attraction among aegeriids. Ann. Entomol. Soc. Am. 66: 227-228.

Nielsen, D. G., F. F. Purrington, J. H. Tumlinson, R. E. Doolittle, and C. E. Yonce. 1975. Response of male clearwing moths to caged virgin females, female extracts and synthetic sex attractants. Environ. Entomol. 4: 451-454.

Nielsen, D. G., and F. F. Purrington. 1978. Field attraction of male Podesesia syringae and P. aureocincta to blends of synthetic compounds. Environ. Entomol. 7: 708-709.

Nielsen, D. G., F. F. Purrington, and G. F. Shambaugh. 1979. EAG and field responses of sesiid males to sex pheromones and related compounds. pp. 11-26. In: Pheromones of the Sesiidae (formerly Aegeriidae). USDA-ARS. ARR NE-6.

Potter, D. A., and G. M. Timmons. 1983a. Forcasting emergence and flight of the lilac borer (Lepidoptera: Sesiidae) based on pheromone trapping and degree-day accumulations. Environ. Entomol. 12: 400-403.

Potter, D. A., and G. M. Timmons. 1983b. Flight phenology of the dogwood borer (Lepidoptera: Sesiidae) and implications for control in Cornus florida L. J. Econ. Entomol. 76: 1069-1074.

Riedl, H., R. W. Weires, A. Seaman, and S. A. Hoying. 1985. Seasonal biology and control of the dogwood borer, Synanthedon scitula (Lepidopera: Sesiidae) on clonal apple rootstocks in New York. Can. Entomol. 117: 1367-1327.

Schwarz, M., J. A. Klun, B. A. Leonhardt, and D. T. Johnson. 1983. (E,Z)-2,13-octadecyldien-1-ol acetate, a new pheromone structure for sesiid moths. Tetrahedron Letters. 24: 1007-1010.

Solomon, J. D., F. L. Olivera, J. H. Tumlinson, and R. E. Doolittle. 1982. Occurrence of clearwing borers (Sesiidae) in West Central Mississippi. J. Ga. Entomol. Soc. 17: 4-12.

Szocs, G., M. Schwarz, G. Sziraki, M. Toth, J. A. Klun, and B. A. Leonhardt. 1985. Sex pheromone of the female currant borer, Synanthedon tipuliformes: identification and field evaluation. Entomol. Exp. Appl. 39: 131-133.

Tumlinson, J. H., C. E. Yonce, R. E. Doolittle, R. R. Heath, C. R. Gentry, and E. R. Mitchell. 1974. Sex pheromones and reproductive isolation of the lesser peachtree borer and the peachtree borer. Science. 185: 614-616.

Underhill, E. W., W. Steck, M. D. Chisholm, H. A. Worden, and J. A. G. Howe. 1978. A sex attractant for the cottonwood crown borer, Aegeria tibialis (Lepidoptera: Sesiidae). Can. Entomol. 110: 495-498.

Voerman, S., C. J. Persoons and E. Priesner. 1984. Sex attractant for the currant clearwing moth, Synanthedon tipuliformis (Clerck) (Lepidoptera: Sesiidae). J. Chem. Ecol. 10: 1371-1376.

THE FORAGING ACTIVITY OF AGAPOSTEMON ANGELICUS COCKERELL[1] RELATIVE TO HYBRID COTTONSEED PRODUCTION IN TEXAS[2]

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ABSTRACT

Agapostemon angelicus Cockerell, a solitary ground nesting native bee species, provides a potential economic alternative to using honey bees, Apis mellifera L., for pollination of male-sterile cotton. The relative abundance and foraging behavior of A. angelicus was examined to determine its role in the production of hybrid cottonseed in the Texas High Plains. A. angelicus was the most abundant native bee species visiting cotton flowers, comprising over 30% of the floral visits. Significantly greater numbers of A. angelicus and other native bees were found foraging in cotton adjacent to alternate host plants as compared to foraging activity in cotton lacking a nearby alternate host reservoir. In hybrid cotton production blocks, A. angelicus spent a significant proportion of its foraging time (87.5% of all visits) on the pollen-bearing male-fertile lines and was most active during the morning (0900-1200 h CDT) hours.

INTRODUCTION

One of the main obstacles to the commercial production of hybrid cottonseed is the difficulty in obtaining adequate and economical transfer of pollen from male-fertile (MF) flowers to the stigmas of male-sterile (MS) flowers (Niles and Feaster 1984). Because no viable pollen is made available by MS lines, pollen must be provided by blooms on the adjacently planted MF lines. Pollen transfer between these lines is necessary for fertilization and seed set to take place.

Bees are the principal agents for cotton pollen transfer, although a few beetles, flies, and butterflies have been observed to carry cotton pollen (Moffett 1974, Moffett et al. 1980). Currently, honey bees Apis mellifera L. are the only manageable pollinator readily available for large scale pollination efforts. The number of hives required to pollinate large production fields, however, is highly variable and depends upon variety, row ratios, irrigation practices, and other factors affecting honey bee behavior (Moffett. 1974, Moffett et al. 1976, and Vassiere et al. 1984). In addition, the cost of providing honey bees may prove prohibitive (Moffett et al. 1978).

Several authors have suggested the use of native bees to pollinate MS cotton because they are attracted to the plant, have potentially high pollination efficiency, and show potential to reduce seed production costs in comparison to using honey bees (Butler et al. 1960, Moffett et al. 1980, and Vaissiere et al. 1985). In spite of these benefits, there is a lack of quantitative data necessary to establish the role of native bee species either as principal agents of pollen transfer or to supplement the pollination provided by honey bees.The present studies were conducted to obtain quantitative information on the foraging activity of Agapostemon angelicus Cockerell, a species reported to be a major component

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1/ Hymenoptera: Halictidae

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of the native bee species complex on the High Plains (Moffett et al. 1980, and Berger 1982). Prior to these studies, only general investigations on the activity of native bees had been conducted in cotton (Moffett et al. 1976, 1978, and 1980), and no information was available on any particular native species regarding its potential use in pollination efforts. Our objectives were to examine some aspects of the foraging activity of A. angelicus in cotton relative to hybrid seed production in the Texas High Plains.

MATERIALS AND METHODS

The study area was located in the Texas High Plains, a region devoted to intensive row crop agriculture with relatively little acreage composed of native or improved rangeland. The High Plains consists of a high level plateau separated from the Rolling Plains by the Caprock Escarpment. Elevation is from 900 to 1400 m, gently sloping towards the southeast. The region is considered to be semi-arid with average annual rainfall ranging between 380 and 540 mm.

Bee visitation to cotton was monitored by an observer walking slowly along a row and counting the number of bee visitations per 100 flowers as described by McGregor (1959). Records were taken on the number of A. angelicus, honey bees, and miscellaneous native bees visiting the cotton blooms. Because the females of A. angelicus are indistinguishable from those of the closely related species Agapostemon texanus Cresson, regional determination of the species composition was based on males (Roberts 1973). Surveys taken in the study area indicated the predominant Agapostemon species (98.8%) was A. angelicus (Berger 1982). During this study, bees recorded as Agapostemon were considered to be A. angelicus.

The first portion of the study was conducted in commercial (self-fertile) cotton. Fields (dryland and irrigated) were chosen which conformed to standard production practices in the region. Comparisons were made between fields which were near an alternate host plant reservoir and fields lacking adjacent alternate hosts. The term "alternate host" refers to any type of flowering plant which provided forage for native bees (e.g. sunflowers, alfalfa, bindweed, or pastureland with a variety of native plant species) and which was within 100 m of the selected cotton field. The size of the alternate host areas varied from a 0.5 - 10 ha. These floral hosts were in bloom prior to and during the cotton blooming season.

From 20 July until 20 August 1981, records of native bee visitation were taken in eight fields of each of the two location types. Counts were started at 0900 h (CDT) and taken hourly until closure of the blooms later in the day (approximately 1800 h). All visitation counts were taken on warm, sunny days with temperatures ranging from 29 - 35° C. An unpaired *t*-test was used to compare visitation levels in fields with and without alternate hosts.

An irrigated hybrid production block located near Lamesa (Dawson County, Tex.) was used in a second series of experiments. Observations were made in an 8 ha field of irrigated MF and MS cotton (2:4 row ratio, utilizing Dekalb-Pfizer varieties 949MS x R964, respectively, planted in a skip-row pattern). Native pasture was located north of the study area, and commericial cotton bordered the southern and eastern sides. Ten rows of sorghum were on the western border of the field, and a dryland field of commercial cotton was west of the sorghum. In addition to native pollinators, 94 colonies of honey bees (11.6 colonies/ha) were placed on the western edge of the field just after blooming had commenced (12 July). Adjacent MF and MS rows in the middle of this production field (located approximately 75 m from the honey bee hives) were used to observe bee visitation. Counts were made on each row between 1000-1200, 1200-1400, and 1400-1600 h CDT on warm, sunny days. Data were collected weekly for five consecutive weeks (25 July - 25 August 1981).

Analysis of variance and Duncan's (1955) multiple range test were performed to determine differences in bee visitation throughout the day. A paired comparison *t*-test was used to determine preferences for MS or MF lines by the visiting bee species.

RESULTS AND DISCUSSION

Over 30% of the total native bee visits to commercial cotton were made by A. angelicus females (Table 1). The percentage of the total number of bees observed indicates the importance of Agapostemon in the study area, although the observed numbers of bees were low at several sites. Ultimately, the successful pollination of MS cotton depends on the number of active foragers in a given area; however, native species which exhibit attraction to cotton are the most likely to be included in pollination strategies. Our findings confirmed that A. angelicus is a very important species in the Texas High Plains across a wide variety of natural factors (eg. soil types, vegetation) as well as different cultural practices (eg. irrigated vs. dryland). The presence of this bee species across varied conditions should be considered a benefit in terms of potential utilization of A. angelicus in pollination efforts in the High Plains.

TABLE 1. Native Bee Visitation to 16 Commercial Cotton Fields, Texas High Plains, 1981.

	Category		
Field No.	Total native bee visits	No. A. angelicus visits	% A. angelicus
1	31	7	22.6
2	18	6	33.3
3	20	0	0.0
4	74	51	68.9
5	8	2	25.0
6	16	1	6.3
7	0	0	0.0
8	16	1	6.3
9	6	4	66.7
10	6	0	0.0
11	4	2	50.0
12	3	1	33.3
13	29	4	14.8
14	10	3	30.0
15	3	2	66.6
16	8	4	50.0
Total	260	90	___

Significantly greater densities of A. angelicus and other native bees were observed in cotton fields near alternate hosts (Table 2). The relative abundance of native bees in these fields is probably due to the richness of the varied flora at these sites, which provide a foraging resource in spring and early summer prior to cotton availability in July. When planning the pollination of MS cotton, consideration should be given to diversification in host plant availability to increase the abundance of the local bee fauna. Jany and Bush (1980) showed that in the Rolling Plains region MS cotton was efficiently pollinated by native species alone (i.e. no honey bees were provided), and they indicated that the availability and diversity of the surrounding flora was a major factor contributing to the abundance of native pollinators.

At the study sites, native sunflower species, Helianthus spp., sweet clover, Mellilotus spp., and alfalfa, Medicago sativa L., were the most common alternate host plants. All of these plant species are commercially available and could be produced to supplement floral resources provided by cotton. Strip cropping techniques , which have

been shown to be effective in the management of native alfalfa pollinators (Bohart 1971), could be employed in a similar manner in hybrid cotton production fields to provide a variety of forage availability. In addition to potentially increasing pollinator densities, alternate forage could serve as habitat to conserve and augment beneficial insect populations (Robinson et al. 1972, and Laster 1974) and could lessen the need for pesticides which are detrimental to bees.

TABLE 2. Comparison of Native Bee Visits to Cotton Blooms in Commercial Fields With and Without Alternate Hosts[a/], Texas High Plains, 1981.

Alternate host	No. blooms observed	Total native visits	Bees /100 blooms
present	69,416	193	0.34 a
absent	82,721	67	0.09 b

[a/] Means in the same column followed by the same letter are not significantly different ($t<0.05$, paired comparisons t-test).

Significant differences were observed in the foraging times of A. angelicus and honey bees (Table 3). The period of greatest foraging activity for A. angelicus occurred in the morning hours in commercial, MS, and MF cotton, after blooms were open wide enough to permit visitation (Fig. 1). Significantly fewer visits by this species were observed after 1000 h, and foraging activity generally decreased towards the end of the day. Conversely, honey bees were most active after 1200 h on MS and MF lines. The differential activity of A. angelicus and honey bees may indicate that competetive exclusion of A. angelicus in the afternoon hours occurs, or simply that pollen and nectar are most available at different times during the day, and foraging activity is targeted towards only one of these resources by each of these pollinating species.

TABLE 3. Number of Visits to Cotton Blooms by A. angelicus and Honey Bees Throughout the Day[a/], Texas High Plains, 1981.

	Species	
Time	A. angelicus	Honey bees
1000	4.7 a	6.3 b
1200	1.5 b	21.9 a
1400	1.4 b	24.2 a
1600	0.2 b	17.1 a

[a/] Means in the same column followed by the same letter are not significantly different ($p<0.05$, Duncan's (1955) multiple range test).

The morning foraging habit of A. angelicus was observed at all study areas, and may be due to pollen availability or physical characteristics of the pollen at this time of day on commercial and MF lines. Pollen becomes available around 0900 h and is rather viscid or sticky compared to the powdery texture of the pollen found on the anthers in the afernoon. This condition may facilitate the collection and transport of pollen on the body hairs of the individual bees, especially in rather arid areas such as the High Plains.

Honey bees foraged later in the day in comparison to A. angelicus (Fig. 2). While A. angelicus had a distinct time of day at which its foraging was most apparent, visitation by honey bees was relatively low at 1000 h and significantly higher at 1200, 1400, and 1600 h.

Time of foraging may be an important factor in pollination effectiveness because pollen viability and stigma receptivity may be greatest in the earlier part of the day (McGregor 1976). Accordingly, A. angelicus may be more efficient than honey bees for cotton pollination due to its morning foraging habit. This aspect of the relative efficiency of pollinating species warrants further investigation. It is likely that a self-fertile and self-pollinated plant species such as G. hirsutum would dehisce its pollen at the time of optimal stigma receptivity.

Almost 900 visits to 47,805 cotton flowers were observed during the study in the hybrid production block. Honey bees were the dominant bee species (Table 4), accounting for over 77% of all visits. A. angelicus and other native bees were recorded in much smaller numbers, at 7.7 and 14.3 per cent of all visits, respectively. Over one third of the 197 observed native bee visits were by A. angelicus, which is consistent with the relative abundance of this species previously reported in this study (Table 1).

TABLE 4. Number of Bees Observed per 100 Flowers[a/] on MS and MF Cotton Lines[b/], Texas High Plains, 1981.

Species	MS line	MF line
honey bees	1.73 a	1.20 a
A. angelicus	0.03 c	0.25 b
other native bees	0.22 b	0.30 b

a/ As observed in 23,875 MS and 23,930 MF blooms.

b/ Means in the same column followed by the same letter are not significantly different ($p<0.05$, Duncan's (1955) multiple range test).

Visitation to MS and MF lines by all bee species was 1.99 and 1.76 individual foragers observed per 100 flowers, respectively. According to studies by Moffett et al. (1978), one honey bee per 100 flowers is adequate to obtain satisfactory yields on MS lines. In this sudy, visitation was very high and the number of honey bee colonies brought into the production area was probably in excess of what was needed for good pollen transfer to the MS line. Visitation by native bees and A. angelicus at 0.25 and 0.30 visits per 100 blooms, respectively, was low relative to the standard set forth by Moffett et al. (1978) for honey bees. Pollen transfer capabilities, however, vary according to pollinator species (Primack and Silander 1975), and this value may not be indicative of pollination efficiency levels of by non-Apis species on MS lines.

Agapostemon spent significantly more foraging time on the pollen bearing MF line (Table 5). Over 87% of all visits made by A. angelicus were to these rows and this behavior was consistent throughout the five-week study period. Selective foraging on fertile rows has also been observed in other studies related to hybrid production (Parker 1981). A preference for the MF line by A. angelicus as observed could be a serious problem to the overall amount of pollen transfer if bee densities were insufficient to provide enough visitation and pollen transfer to the MS rows.

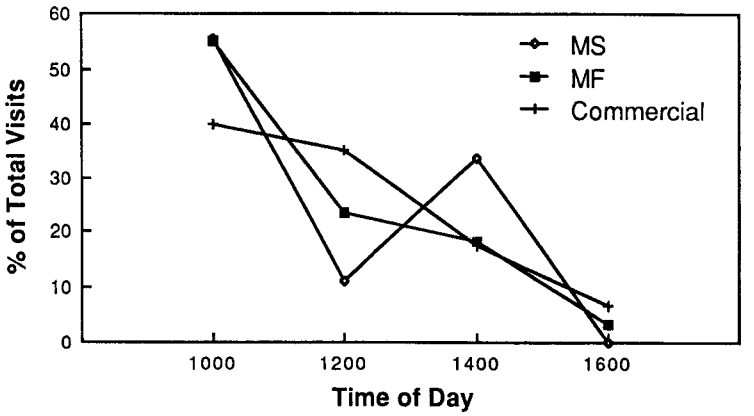

FIG. 1. Daily visitation patterns of A. angelicus to MS, MF, and commercial cotton, Texas High Plains, 1981.

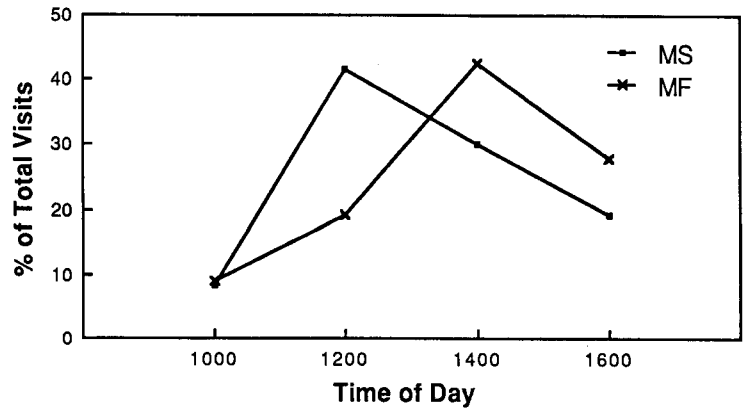

FIG. 2. Daily visitation patterns of honey bees to MS and MF cotton, Texas High Plains, 1981.

TABLE 5. Percentage of Total Foraging Time Spent on MS and MF lines[a/] by A. angelicus, Honey Bees, and Native Bees[b/], Texas High Plains, 1981.

	Species		
Line	A. angelicus	Honey bees	Native bees
MS	12.5 b	59.0 a	42.1 a
MF	87.5 a	41.0 a	57.9 a

[a/]Means in the same column followed by the same letter are not significantly different ($t<0.05$, paired comparisons t-test).

[b/] Computed from a total of 69,701, and 128 visits by A. angelicus, honey bees, and other native bees, respectively.

No differences in honey bee visitation to MS or MF lines were observed. Although a greater percentage of visits were made to the MS line than to the MF line by honey bees, the difference was not significant. In earlier studies, however, honey bees have been observed to concentrate on the MS line, and the presence of honey bees in great numbers on both lines observed in this study could have been due to the great number of colonies brought into the study area.

CONCLUSIONS

A. angelicus is a dominant species in the native bee complex of the Texas High Plains and provides an alternative to the use of honey bees for cotton pollination. A. angelicus visited both MS and MF cotton lines, yet a significant proportion of the visits were to the MF line. The species foraged in cotton primarily during the morning hours. Further study is needed to establish the signifigance of these behavioral characteristics relative to the pollination efficiency of A. angelicus in MS cotton.

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LITERATURE CITED

Berger, L. A. 1982. Agapostemon angelicus Cockerell and other wild bees as potential pollinators of male-sterile cotton on theTexas High Plains. M.S. Thesis. Oklahoma State University, Stillwater. 50 pp.

Bohart, G. D. 1971. Management of habitats for wild bees. Proc. Tall Timbers Conf. on Ecol. Animal Control by Habitat Management. Feb. 25-27.

Butler, G. D., F. E. Todd, S. E. McGregor, and F. G. Werner. 1960. Melissodes bees in Arizona cotton fields. Ariz. Agric. Exp. Stn.Tech. Bull. 139. 11 pp.

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

Jany, C. S., and D. L. Bush. 1982. Pollination of hybrid cotton by wild bees: Comparison of the High Plains of Texas with west central Texas. Proc. Beltwide Cotton Prod. Res. Conf., Natl. Cotton Council, Memphis, Tenn. pp. 91-92.

Laster, M. L. 1974. Increasing natural enemy resources through crop rotation and strip cropping, pp. 137-149. In F. G. Maxwell and F. A. Harris (eds.), Proc. Sum.

Inst. Biol. Control of Plant Insects and Disease. Univ. of Mississippi Press, Jackson, 647 pp.
McGregor, S. E. 1959. Cotton flower visitation and pollen distribution by honey bees. Science 129: 97-98.
McGregor, S. E. 1976. Insect pollination of cultivated crop plants. USDA Handbook 496. 411 pp.
Moffett, J. O. 1974. Honey bees and other insect visitors to normal and MS cotton. Ph.D. Dissertation. University of Wyoming, Laramie. 149 pp.
Moffett, J. O., H. B. Cobb, and D. R. Rummel. 1980. Bees of potential value as pollinators in the production of hybrid cottonseed on the High Plains of Texas. Proc. Beltwide Cotton Prod. Res.Conf., Natl. Cotton Coun., Memphis, Tenn. pp. 268-270.
Moffett, J. O., L. S. Stith, C. C. Burkhardt, and C. W. Shipman. 1976. Fluctuation of wild bee and wasp visits to cotton flowers. J. Ariz. Acad. Sci. 11: 64-68.
Moffett, J. O., L. S. Stith, and C. W. Shipman. 1978. Producing hybrid cottonseed on a field scale using honey bees as pollinators. Proc. Beltwide Cotton Prod. Res. Conf., Natl. Cotton Counc., Memphis, Tenn. pp. 77-80.
Niles, G. A., and C. V. Feaster. 1984. Breeding. In: R. J. Kohel and C. F. Lewis (eds.) Cotton. Monograph No.24. Agronomy Series. Am. Soc. Agron., Inc., Crop Sci. Soc. of Am., Inc., Soil Sci. Soc. Am., Inc. Madison, WI. 605 pp.
Parker, F. D. 1981. How effective are bees in pollinating sunflowers? J. Kansas Entomol. Soc. 54: 61-67.
Primack, R. B, and J. A. Silander. 1975. Measuring the relative importance of different pollinators to plants. Nature 255: 143-145.
Roberts, R. B. 1973. Bees of Northwestern America: Agapostemon (Hymenoptera: Halictidae). Ore. Agric. Exp. Stn. Tech. Bull. 125. 23 pp.
Robinson, R. R., J. H. Young, and R. D. Morrison. 1972. Strip-cropping effects on abundance of Heliothis-damaged squares, boll placement, total bolls, and yields in Oklahoma. Environ. Entomol. 1: 140-145.
Vaissiere, B. E., J. O. Moffett, and G. M. Loper. 1984. Honey bees as pollinators for hybrid cotton seed production of the Texas High Plains. Agron. J. 76: 1005-1010.
Vaissiere, B. E., S. J. Merritt, and D. L. Keim. 1985. Mellissodes thelypodii Cockerell : An effective pollinator of hybrid cotton on the Texas High Plains. (abst.). Proc. Beltwide Cotton Prod. Res. Conf., Natl. Cotton Counc., Memphis, Tenn. pp. 398-399.

RESPONSES OF GREENBUG[1/] TO DROUGHT STRESSED SMALL GRAIN HOSTS

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ABSTRACT

The maximum growth rate was determined for biotype E greenbug, Schizaphis graminum Rondani, populations feeding on five small grain host cultivars grown at four levels of water stress. 'Tokak', 'Will', and 'Schuyler' barleys, Hordeum vulgare L., along with susceptible 'Scout 66' wheat, Triticum aestivum L., and resistant (tolerant) 'Insave F.A.' rye, Secale cereale L., standards for comparison were grown hydroponically and stressed using polyethylene glycol as a matricum. Maximum greenbug density growth rates, based on linear regressions of log-transformed density data, were not influenced by increased water stress (0, -0.38, -0.75, and -1.13 MPa) on four of the five cultivars studied. 'Insave F.A.' rye grown at a stress level of -1.13 MPa had reduced greenbug population growth rates when compared to greenbugs on unstressed 'Insave F.A.'. Increased water stress resulted in quicker plant death and lower aphid density peaks in all cultivars tested. Greenbugs on 'Tokak' barley had the greatest population growth rate followed by 'Scout 66' wheat. The greenbug population growth rates were nearly identical for 'Will' and 'Schuyler' barleys which fell between the rates for 'Scout' wheat and 'Insave F.A.' rye.

INTRODUCTION

The response of greenbug (GB), Schizaphis graminum Rondani, to water stress of its host is important because the declining water supply and the semi-arid conditions of the Texas High Plains often result in drought-stressed small grains, whether grown under dryland or irrigated conditions.

Reports in the literature of aphid reproduction and development on water-stressed hosts are often confusing. Kennedy and Booth (1959) reported that Aphis fabae Scopoli reared on drought-stressed sugarbeets, Beta vulgaris L., had reduced reproduction. Kennedy et al. (1950) found that A. fabae had greater fecundity on senescing sugarbeet leaves than on middle-aged leaves under well-watered conditions. Wearing and van Emden (1967) observed no impact on survival and fecundity of A. fabae feeding on water-stressed Vicia fabae L. or marigolds, Calendula officinalis.

In some studies, measurements of water stress parameters have been unavailable or inaccurate. For example, Maxwell and Painter (1959) using levels of drought described as saturated, damp, and dry soil moisture determined that greenbugs excrete less honeydew when feeding on unwatered

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1/ Homoptera: Aphididae
2/ Approved as TA#22972 by the Texas Agricultural Experiment Station

barley, Hordeum vulgare L., as compared to those feeding on watered hosts, which indicates an apnid response to the water stress imposed on its host. Their results do not indicate differences in the ability of aphid populations to develop and reproduce, and the stress levels can not be accurately duplicated. Thus, there is a need for additional studies using updated techniques which accurately measure these parameters.

Sumner et al. (1983) developed a method to precisely control water stress by growing wheat, Triticum aestivum L., hydroponically and created water stress using polyethylene glycol as a matricum. They used this method to determine that a critical moisture level between -0.38 and -0.75 megapascals (MPa) on wheat reduced GB fecundity and longevity. Michels and Undersander (1986) showed GB to have reduced reproduction when reared on water-stressed sorghum, Sorghum bicolor L., (below -0.30 MPa). Both of these studies described reproductive response of GB to feeding on hosts in which the stress was accurately measured. However, these results from wheat and sorghum cannot be directly correlated to other GB hosts such as barley.

Greenbugs may have a variety of response to drought stress on various hosts. Therefore, the following laboratory study was conducted during the winter of 1985-86 to determine the relationship between GB population growth and four levels of drought stress imposed on three barley cultivars, wheat and rye, Secale cereale L.

MATERIALS AND METHODS

The technique developed by Sumner et al. (1983) was used to study the maximum population growth potential of biotype E greenbugs feeding on hydroponically grown and water-stressed barley, wheat, and rye. Seeds of 'Tokak', 'Will', and 'Schuyler' barleys, 'Scout 66' wheat, and 'Insave F.A.' rye were germinated in wet paper towels. After one wk, each seedling was transferred to a test tube apparatus which supported the plant and suspended the roots in a 50 mm tube of Hoagland's solution (Maynard and Barker 1970). The nutrient solution was changed every-other-day throughout the study. Two wks postgermination, the plants were stressed by the addition of polyethylene glycol to the Hoagland's solution, and each plant was infested with one, 3-day old, Biotype E greenbug. Stress levels were determined to be 0, -0.38, -0.75, and -1.13 MPa (±0.1 MPa) using Wescor® thermocouple psychrometers (Michels and Undersander 1986). Plants were grown in Biotron® environmental control chambers with a 12:12 photoperiod. Lighting was provided by four fluorescent and three 60 w incandescent growlights, and the temperature range was 22°-28°C.

The five cultivars were chosen based on the following criteria: 'Tokak' as a GB susceptible barley, 'Will' and 'Schuyler' as biotype E resistant barleys, 'Scout 66' wheat as a GB susceptible standard, and 'Insave F.A.' rye as a GB resistant standard.

Evaluations consisted of counting the number of GB on each plant at 1, 3, 5, 7, 9, 11, and 13 days postinfestation. The eight replications were conducted concurrently.

Peak GB density data, the maximum number of GB recorded for each plant, were subjected to 5x4 factorial analysis of variance based on a completely randomized design and significant means were separated by the Student-Newman-Keuls test (α=0.05). Cultivar means were compared for each stress level, and stress level means were compared for each cultivar. The number of days to reach peak GB density were analyzed in the same manner as the GB density data. Significant means were separated by Duncan's (1955) multiple range test (α=0.05).

Greenbug densities per plant were transformed to natural log values for linear regression analysis of density over time using the SAS (1985)

statistical analysis system for personal computers, version six. Values representing population declines, after peak GB density, were omitted from the regression analysis to obtain the maximum GB growth potential for each stress level of the hosts.

RESULTS AND DISCUSSION

The peak number of GB found on 'Tokak' and 'Schuyler' barleys declined significantly with increased water stress (Table 1). The peak number of GB per plant on 'Will' barley, 'Scout 66' wheat and 'Insave F.A.' rye followed this same general trend although differences among stress levels were not significant.

It is possible that the differences in peak GB densities were the result of PEG uptake by the plants resulting in toxicity to the greenbugs. Sumner et al (1986) showed the PEG (m_r=1000) was absorbed by wheat and translocated to GB; however, their toxicity study of PEG in artificial diets showed that greenbug fecundity and survival was not diminished. Two differences to note between this study and Sumner et al. (1986) are: 1) the molecular weight of PEG, m_r=7000 vs m_r=1000 and 2) maximum stress level, -1.13 MPa vs -0.90 MPa.

In general, as the stress level increased, the number of days to reach peak GB density declined, significantly so in the case of 'Insave F.A.' rye and 'Schuyler' barley (Table 2). Visual observations indicated that the reduced peak GB densities and number of days to the peak density were the result of a decrease in the plants' ability to support the aphid population with increased water stress, resulting in quicker plant death. Johnson et al. (1974) concluded that net photosynthesis in the flag leaves of wheat and barley was reduced to 0 at leaf water potentials of -0.33 MPa. All of the stress levels in this study exceeded -0.33 MPa, preventing additional plant growth from the time stress was applied and causing more rapid wilting of the plants. Thus, the ability of stressed plants to support GB was limited at -0.33 MPa while unstressed plants continued to grow for several days until the aphid population became the limiting factor.

Although lower peak GB densities were observed on the stressed plants, the linear regression analysis indicated that the rate for GB population growth within a cultivar was usually not reduced (Table 3). Throughout the study it appeared that if the plant maintained some level of metabolic activity (i.e. did not wither or die) GB were able to utilize the plant as a host. There was a point, however, where GB were unable to use the plant and would move off the plant. 'Insave F.A.' rye was the only cultivar that exhibited a weak difference in the regression slopes among stress levels (Fig. 1). The other cultivars did not exhibit a significant reduction in regression slopes with increased water stress, indicating that the rate for GB population increase within a cultivar was the same regardless of the water stress level.

Differences in GB population growth rates were observed among the five cultivars in the study (Fig. 2). 'Tokak' barley had the greatest aphid population growth potential as indicated by the slope of the regression line for the average of four stress levels (Table 3). 'Will' and 'Schuyler' barleys had nearly identical regression slopes and fell between the resistant and susceptible checks of 'Insave F.A.' rye and 'Scout 66' wheat, respectively. These trends are also reflected in the peak GB densities (Table 1) where 'Insave F.A.' rye had significantly fewer GB per plant than 'Tokak' barley or 'Scout 66' wheat at each of the stress levels.

The population growth rate of GB feeding on four of the five hosts studied was not significantly altered due to water stress imposed on the

TABLE 1. Mean Peak Numbers of Greenbugs per Plant for Small Grain Hosts Grown at Four Levels of Water Stress.

Cultivar	Water Stress Level[a]			
	0 MPa	-0.38 MPa	-0.75 MPa	-1.13 MPa
'Tokak' barley	133 A a[b]	97 A ab	39 AB b	61 A b
'Scout 66' wheat	90 AB a	64 AB a	59 A a	47 AB a
'Will' barley	66 B a	51 ABC a	44 AB a	55 AB a
'Schuyler' barley	78 B a	41 BC ab	33 AB b	33 AB b
'Insave F.A.' rye	10 C a	7 C a	8 B a	7 B a

[a] Average of eight replications.

[b] Means in a column followed by the same uppercase letter or means in a row followed by the same lowercase letter are not significantly different (α=0.05, Student-Newman-Keuls test).

TABLE 2. Mean Days to Reach Peak Greenbug Density on Small Grain Hosts Grown at Four Levels of Water Stress.

Cultivar	Water Stress Level [a]				R^2
	0 MPa	-0.38 MPa	-0.75 MPa	-1.13 MPa	
'Tokak' barley	11.50 AB a	10.50 AB a	8.75 A a	9.00 ABC a	0.41
'Scout 66' wheat	12.25 A a	11.00 Ab a	10.25 A a	10.25 AB a	0.48
'Will' barley	13.00 A a	12.75 A a	10.25 A a	10.50 A a	0.41
'Schuyler' barley	13.00 A a	12.50 A a	10.25 A ab	8.00 BC b	0.52
'Insave F.A.' rye	10.25 B a	9.00 B ab	8.00 A ab	6.25 C b	0.55
R^2	0.48	0.47	0.60	0.60	

[a] Average of eight replications.

[b] Means in a column followed by the same uppercase letter or means in a row followed by the same lowercase letter are not significantly different (α=0.05, Duncan's Multiple Range test).

TABLE 3. Linear Regression Equations [a] for Greenbug Densities on Small Grain Hosts Grown at Four Levels of Water Stress.

Cultivar	Stress Level (MPa)	Regression Equation			No. observations
		Slope (±SE)	Y-Intercept	R^2	
'Insave F.A.' rye (resistant standard)	0	0.240 (0.035)	-0.250	0.57	37
	-0.38	0.234 (0.037)	-0.236	0.59	30
	-0.75	0.216 (0.046)	-0.525	0.57	19
	-1.13	0.141 (0.034)	-0.329	0.52	18
	combined	0.225 (0.020)	-0.349	0.54	104
'Schuyler' barley	0	0.364 (0.020)	-0.311	0.86	55
	-0.38	0.328 (0.017)	-0.512	0.88	54
	-0.75	0.369 (0.023)	-0.663	0.86	45
	-1.13	0.366 (0.022)	-0.314	0.90	30
	combined	0.356 (0.011)	-0.468	0.85	184
'Will' barley	0	0.369 (0.020)	-0.616	0.86	55
	-0.38	0.365 (0.020)	-0.640	0.87	54
	-0.75	0.352 (0.023)	-0.381	0.85	43
	-1.13	0.342 (0.021)	-0.490	0.85	46
	combined	0.357 (0.010)	-0.537	0.85	198
'Scout 66' wheat (susceptible standard)	0	0.402 (0.020)	-0.436	0.79	53
	-0.38	0.395 (0.033)	-0.263	0.79	42
	-0.75	0.395 (0.032)	-0.395	0.77	45
	-1.13	0.443 (0.023)	-0.433	0.91	38
	combined	0.399 (0.013)	-0.365	0.83	176
'Tokak' barley	0	0.435 (0.020)	-0.301	0.91	50
	-0.38	0.469 (0.022)	-0.353	0.91	45
	-0.75	0.424 (0.024)	-0.303	0.89	38
	-1.13	0.411 (0.029)	-0.334	0.84	38
	combined	0.439 (0.012)	-0.334	0.89	171

[a] Greenbug densities/plant transformed to natural logorithms before regression analysis.

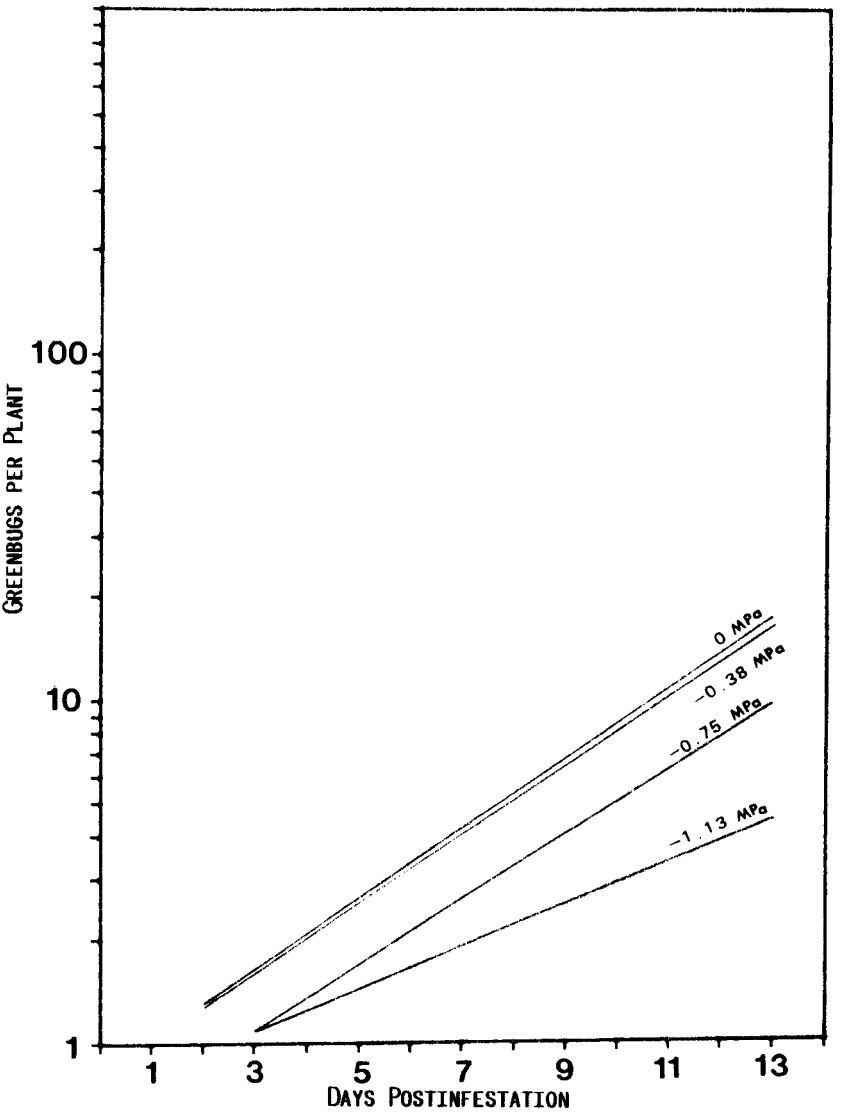

FIG. 1 Linear regression of greenbug density on 'Insave F.A.' rye at four levels of water stress.

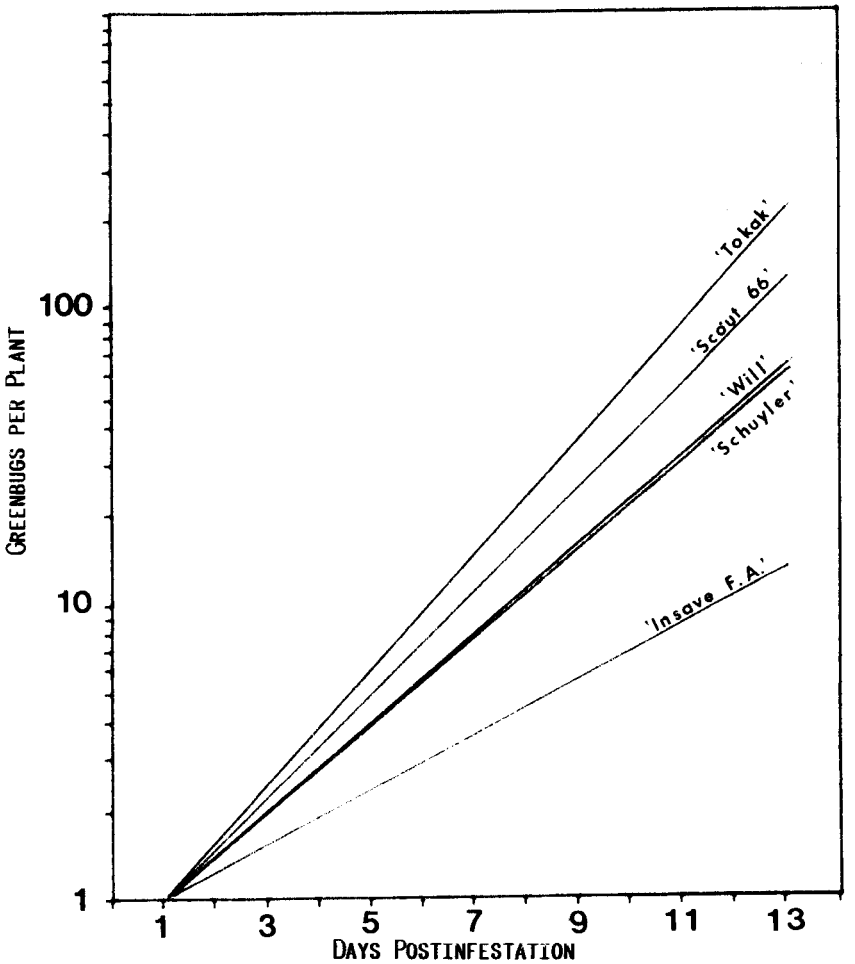

FIG. 2 Linear regressions of greenbug density data for populations reared on five hosts, averaged over four levels of water stress.

host. Greenbugs feeding on 'Insave F.A.' rye had decreased population growth with increased water stress. However, increased water stress resulted in quicker plant death and lower peak GB densities for all hosts studied. 'Tokak' barley had the greatest GB population growth rate followed by 'Scout 66' wheat, 'Will' barley, 'Schuyler' barley and 'Insave F.A.' rye, respectively.

The results of this study indicate that GB population growth rates on small grains are influenced indirectly by water stress insofar as increasing water stress hastens plant death. The regression analyses indicate that GB population densities increase at roughly the same rate, regardless of the stress level, until they kill the plant or the plant becomes unacceptable as a host. These data indicate that in field situations additional water cannot be used as a management tool in regard to GB since the aphid density will continue to increase on well-watered plants up to a point where it becomes the limiting factor for plant growth.

LITERATURE CITED

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

Johnson, R. R., N. M. Frey, and D. N. Moss. 1974. Effect of water stress on photosynthesis and transpiration of flag leaves and spikes of barley and wheat. Crop Sci. 14: 728-731.

Kennedy, J. S., and C. O. Booth. 1959. Responses of Aphis fabae Scop. to water shortage in host plants in the field. Entomol. Exp. Appl. 2: 1-11.

Kennedy, J. A., A. I. Hotson, and C. O. Booth. 1950. The distribution of aphid infestation in relation to leaf age. I. Aphis fabae Scop. on spindle trees and sugar beet plants. Ann. Appl. Biol. 37: 651-679.

Maxwell, F. G., and R. H. Painter. 1959. Factors affecting the rate of honeydew deposition by Therioaphis maculata (Buck.) and Toxoptera graminum (Rond.). J. Econ. Entomol. 52: 368-373.

Maynard, D. N., and A. V. Barker. 1970. Nutriculture. USDA Coop. Ext. Serv. Publ. #41.

Michels, G. J., Jr., and D. J. Undersander. 1986. Temporal and spatial distribution of the greenbug (Homoptera: Aphididae) on sorghum in relation to water stress. J. Econ. Entomol. 79: 1221-1225.

SAS Institute. 1985. SAS Users Guide: Statistics. SAS Institute, Cary, NC.

Sumner, L. C., K. W. Dorschner, J. D. Ryan, R. D. Eikenbary, R. C. Johnson, and R. W. McNew. 1986. Reproduction of Schizaphis graminum (Homoptera: Aphididae) on resistant and susceptible wheat genotypes during simulated drought stress induced with polyethylene glycol. Environ. Entomol. 15: 756-762.

Sumner, L. C., J. T. Need, R. W. McNew, K. W. Dorschner, R. D. Eikenbary, and R. C. Johnson. 1983. Response of Schizaphis graminum (Homoptera: Aphididae) to drought-stressed wheat, using polyethylene glycol as a matricum. Environ. Entomol. 12: 919-922.

Wearing, C. H., and H. V. van Emden. 1967. Studies on the relations of insect and host plant. I. Effects of water stress in host plants on infestations by Aphis fabae Scop., Myzus persicae (Sulz.), and Brevicoryne brassicae (L.). Nature (London) 213: 1051-1052.

SEASONAL SHIFT IN SPECIES COMPOSITION OF SPIDER MITES[1] ON CORN IN THE WESTERN GREAT PLAINS

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ABSTRACT

Spider mites in samples collected from corn by growers and crop consultants were identified by Cooperative Extension Service personnel in Kansas and Texas. The Banks grass mite, Oligonychus pratensis (Banks), and the twospotted spider mite, Tetranychus urticae Koch, were present in corn fields in both states. Seasonal shifts in the proportion of the two species were observed. Banks grass mites were present from June through August, whereas twospotted spider mites were rarely collected during June but were commonly collected in late July and August. This shift in species composition is important, because it corresponds with the period of time when growers are making acaricide and insecticide applications and may be associated with control failures.

INTRODUCTION

Spider mites are a major economic threat to corn production in the western Great Plains. Ehler (1973) reported that the Banks grass mite (BGM), Oligonychus pratensis (Banks), was the predominant spider mite infesting corn in the Texas High Plains; however, the twospotted spider mite (TSM), Tetranychus urticae Koch, was present also.

Over the last decade, spider mite control failures have been reported throughout this area. Archer and Bynum (1978) and Perring et al. (1981) suggested that BGM had developed resistance to many of the commonly used miticides, which explained many of the reported control failures. However, some field entomologists and crop consultants have blamed control failures on the presence of TSM.

Our reexamination, in 1981, of a collection of spider

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mites mounted on slides from a 1979 survey of corn fields in southwest Kansas by M. W. Johnson indicated that a species shift had occurred during the 1979 growing season. The percent TSM in the spider mite samples increased as the season progressed (Buschman et al. 1984). Logan (1981) reported BGM in Colorado corn fields in early spring; whereas, TSM generally was not found in corn fields until mid-to late season. Also, he found that BGM was easily controlled with the commonly used acaricides, while TSM was essentially unaffected.

The purpose of this study was to investigate the frequency of twospotted spider mites in corn fields of the western Great Plains.

MATERIALS AND METHODS

A mite identification program was initiated in Kansas in 1983. Corn growers, county agents, crop consultants and chemical company representatives were invited through articles in extension newsletters to submit mite samples to the Southwest Area Extension Office for identification. Cooperators were asked to send in samples of mites from fields in which they wanted an identification. Samples generally consisted of mite-infested leaves in plastic bags. Cooperators were asked to report the date of collection, to indicate the location of the field and to provide notes on recent pesticide applications. Five to 20 spider mites from each sample were mounted on slides for examination with a phase contrast microscope at 400X. The presence (BGM) or absence (TSM) of the empodial claw was used to identify the mites (Feese 1976, Logan et al. 1983). The number of mites of each species found on each slide along with the collection data were recorded. Although a few samples were collected from eastern Kansas, data presented in this paper are limited to samples from the western third of Kansas, because this is the area of the state where spider mites are a perennial problem (Mock et al. 1981).

A similar program was initiated by the Texas Agricultural Extension Service in 1984. Interested cooperators were provided vials and mailing tubes and asked to mail specimens to the Agricultural Research and Extension Centers (AREC) in Lubbock and Amarillo. Cooperators removed mites from plants in the field and placed them in a vial containing alcohol. Mites were mounted at the AREC and identified as described above.

Two two-way analysis of variance tests were conducted [state of collection (n=2) vs month of collection (n=4) and year/state (n=6) of collection vs month of collection (n=4)] on the percent of fields with TSM using the NONORTHO program of MSTAT 4.0 (MSTAT Development Team 1985). Means were separated using Duncan's multiple range test with the RANGE program of MSTAT 4.0. Before analysis, the data were modified by the Johnson and Kotz angular transformation, arcsin $\sqrt{(Y+3/8)/(N+3/4)}$ where Y = number of fields with TSM and N = number of fields in sample (Sokal and Rohlf 1981).

RESULTS AND DISCUSSION

In both states, the initial mite identification program started with only a limited number of cooperators submitting samples (Table 1). However, interest increased as more cooperators became aware of the program and of the importance of proper mite identification in selecting appropriate control strategies. The number of samples submitted to both programs declined sharply in 1986. Lower mite populations and the development of a visual mite identification technique, which was proposed by Logan (1981) and further developed by T. O. Holtzer and J. A. Kalisch (Sloderbeck et al. 1985), allowed some of the cooperators to identify mites in the field.

TABLE 1. Number of Counties, Fields, Cooperators, and Mites identified in Kansas and Texas Cooperative Extension Service Spider Mite Identification Programs.

State/Year	Counties	Fields	Cooperators	Mites identified
Kansas				
1983	8	39	9	441
1984	8	113	19	2007
1985	12	106	25	1271
1986	11	26	11	366
Texas				
1984	7	56	8	--[a]
1985	11	251	27	3178

[a] Total number of mites not recorded.

Twospotted spider mites were found in about a third of the total samples submitted (Table 2). The frequency of detecting twospotted spider mites in the samples increased as the season progressed. In all years and in both states, the incidence of fields where TSM were detected was very low in May and June; but by August or September, TSM were often present in fields.

Statistical analysis of the data showed that the effects of state of collection on the percent of fields with TSM were not significant ($F=0.05$, $df=1$, $P>0.5$). The effects of year/state were also not significant ($F=2.30$, $df=5$, $P=0.115$). However, the effects of month of collection were significant ($F=14.54$, $df=3$, $P<0.001$). The frequency of TSM in fields was 3.2c, 27.3bc, 37.5b and 94.7a percent for June, July, August, and September, respectively (means followed by the same letter were not significantly different, $P>0.05$, Duncan's multiple range test).

TABLE 2. Seasonal Occurrence of Banks Grass Mites (BGM) and Twospotted Spider Mites (TSM) in Corn from Samples Submitted for Identification. 1983-86.

State/ Year	Month	Number of fields with BGM only	TSM only	Mixed Population	% of fields with TSM
Kansas					
1983	June	4	0	0	0
	July	13	0	0	0
	August	13	0	1	7
	September	1	5	2	87
	TOTAL	31	5	3	
1984	May	1	0	0	0
	June	4	0	0	0
	July	27	8	20	51
	August	16	19	17	69
	September	0	0	1	100
	TOTAL	48	27	38	
1985	June	4	1	0	20
	July	42	19	15	45
	August	10	3	12	60
	TOTAL	56	23	27	
1986	May	1	0	0	0
	June	3	0	0	0
	July	10	5	3	44
	August	4	0	0	0
	TOTAL	18	5	3	
Texas					
1984	June	15	0	0	0
	July	20	4	1	20
	August	4	10	2	75
	TOTAL	39	14	3	
1985	June	9	0	0	0
	July	143	21	7	16
	August	49	5	8	21
	September	0	2	7	100
	TOTAL	201	28	22	
TOTAL	May	2	0	0	0
	June	39	1	0	3
	July	255	57	46	29
	August	96	37	40	45
	September	1	7	10	94
	GRAND TOTAL	393	102	96	

Most of the samples were submitted during late July and early August, when treatment decisions were being made. Twospotted spider mites were present in a considerable number of the fields during this time period (Table 2). With the growing evidence that currently labeled acaricides are ineffective in controlling TSM (Logan 1981, and T. O. Holtzer and T. L. Archer, personal communication), it is important to determine the spider mite species present in a corn field prior to treatment.

The data in this study did not come from fields sampled at random. Many of the samples were submitted from fields in which the cooperator suspected there might be a predominance of TSM. The data could, therefore, be biased toward TSM. Although this bias may have inflated the recorded incidence of TSM, it does not change the basic conclusion that the incidence of TMS increases during the season. This shift in spider mite species during the growing season has also been observed in individual fields in Texas (Pickett and Gilstrap 1985) and in Kansas (Buschman et al. 1984). These investigators reported that only BGM was collected from the study fields early in the season (June and early July); but that later in the season, TSM could be found in the same fields and occasionally became the predominate species. The importance of the data collected in this study is in showing that a shift in the spider mite species in corn is not an isolated occurrence observed in a few fields. The shift appears to be a widespread phenomenon in the western Great Plains.

The reason for the shift from BGM to TSM is unclear. Logan (1981) suggested that the BGM overwintered in corn fields, and thus was present in fields in early spring; whereas, TSM infestations were secondary in nature and occurred "spontaneously" in mid- to late season. Pickett and Gilstrap (1985) theorized that the difference in colonization of fields could be related to differences in the diapause requirements of the two species. However, Buschman et al. (1984) observed that the species shift occurred during the time period when corn fields were being treated with pesticides for corn borers and spider mites. The data gathered in this study on pesticide usage in the fields being sampled were incomplete. However, of the 22 fields sampled in Texas during 1984 for which acaricide treatment data were available, over half of the fields that had been treated with monocrotophos contained twospotted spider mites. Pickett and Gilstrap (1985) indicated that the proportion of TSM increased from 20 to 100% following two applications of monocrotophos in one of their study fields.

In summary, we can conclude that BGM is the predominant species present in corn fields in the western Great Plains during June and July; but the incidence of TSM begins increasing in July, and this species may become predominant by August or September in some fields. Further structured surveys are needed to establish the actual percentage of fields infested with TSM since the data recorded here may have been biased in favor of fields suspected of containing this species. Further studies are needed to determine why this species shift occurs.

ACKNOWLEDGEMENT

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LITERATURE CITED

Archer, T. L., and E. D. Bynum. 1978. Pesticide resistance by arthropod pests of feed grains. Southwest. Entomol. 3: 251-259.

Buschman, L. L., G. L. Dick, and P. E. Sloderbeck. 1984. Early season Banks grass mite populations give way to late season twospotted spider mite populations. 1984 Field Day Report. Garden City Branch, Kansas Agric. Exp. Sta. Rep. of Progress. 453: 24-25.

Ehler, L. E. 1973. Spider mites associated with grain sorghum and corn in Texas. J. Econ. Entomol. 66: 220.

Feese, H. D. 1976. A biological study of the Banks grass mite, Oligonychus pratensis (Banks), in Kansas. Ph. D. Dissertation. Kansas State Univ., Manhattan, Kansas. 34 pp.

Logan, J. A. 1981. Control of spider mites on corn in northeastern Colorado. pp 75-80. In Proc. 11th Annual Colorado Crop Protection Inst.

Logan, J. A. B. D. Congdon, and J. K. Alldredge. 1983. Ecology and control of spider mites on corn in northeastern Colorado. Colo. State Univ. Exp. Sta. Bull. 5 5S. 41 pp.

Mock, D. E., H. L. Brooks, J. J. Durkin, J. M. Good, W. M. Hantsbarger, D. L. Keith, W. B. Massey, and W. P. Morrison. 1981. Insect pest management for corn on the western Great Plains. Bull. C-612 Coop. Ext. Serv., Manhattan, Kansas. 36 pp.

MSTAT Development Team. 1985. MSTAT: A microcomputer program for the design, management, and analysis of agronomic research experiments, version 4.0. Michigan State Univ., East Lansing.

Perring, T. M., T. L. Archer, E. D. Bynum, Jr., and K. A. Hollingsworth. 1981. Chemical evaluation for control of the Banks grass mite, Oligonychus pratensis(Banks), on field corn. Southwest. Entomol. 6: 130-135.

Pickett, C. H., and F. E. Gilstrap. 1985. Dynamics of spider mite species (Acarina: Tetranychidae) composition infesting corn. J. Kansas Entomol. Soc. 58: 503-508.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry, 2nd ed. W. H. Freeman and Company, San Francisco. 859 pp.

Sloderbeck, P. E., L. L. Buschman, and R. A. Higgins. 1985. Managing spider mites on field corn and grain sorghum. Kansas Coop. Ext. Serv. Entomol. MF-762. 6 pp.

DEVELOPMENTAL BIOLOGY OF TYPHLODROMUS OCCIDENTALIS (NESBITT)[1/] UNDER THREE TEMPERATURE REGIMES

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ABSTRACT

The developmental biology of Typhlodromus occidentalis (Nesbitt) was determined at three fluctuating temperature regimes, and life tables were constructed. The fluctuating temperatures and means of the three regimes were: 15.0 - 30.0°C ($\bar{x}$=22.7°); 19.4 - 33.6°C ($\bar{x}$=26.6°); and 23.1 - 38.6°C ($\bar{x}$=30.5°). The intrinsic rate of natural increase, r_m, was highest at the intermediate temperature regime, but net reproduction rate, R_o, was greatest in the lowest temperature regime. Predatory capabilities for the protonymphal, deutonymphal and adult stages on eggs of the carmine spider mite, Tetranychus cinnabarinus (Boisduval) were noted at each of the cyclic temperature regimes.

INTRODUCTION

Typhlodromus occidentalis (Nesbitt) is an important natural enemy of several species of mites found in the family Tetranychiidae. Recently, it has been shown to be an effective predator in orchards and vineyards in central California of the Pacific and two-spotted spider mites, Tetranychus pacificus (McGregor) and T. urticae (Koch), respectively (Hoy et al. 1982). Furthermore, with its predatory effectiveness well documented, T. occidentalis has been investigated for possible resistance to agricultural chemicals (Roush and Plapp 1982).

The genus, Galendromus (= Typhlodromus), is by far the most abundant phytoseiid mite on plants in Arizona (Tuttle and Muma 1973). Because of the continued widespread use of insecticides in southern Arizona, particularly on cotton, Gossypium sp., continued genetic improvement of T. occidentalis for pesticide resistance will be of utmost importance if this predator is to assume a major role in the biological control of plant-feeding mites. The importance of this predator in southern Arizona, however, will be dependent upon the effects of southern Arizona's unique desert climate on its biology and, in turn, on its predatory potential. The effects of temperature on the biology of T. occidentalis were investigated in the present study.

MATERIALS AND METHODS

All investigations were conducted in modified freezers with single-switch cam-programmed recording temperature controllers (Partlow Temperature Control Model RFC 52). A photoperiod of 12:12 L:D was maintained in all temperature cabinets with three, 20-watt daylight (General Electric) fluorescent lamps.

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Cams were cut to provide daily fluctuating temperatures averaging 22.7° (15.0-30.0°), 26.6° (19.4-33.6°) and 30.5°C (23.1-38.6°), which corresponded with the mean monthly temperatures for April, May and June, respectively, for Yuma, Arizona. The temperature ranges per cabinet were selected to reflect the actual field temperatures of a cotton-growing area in Arizona. These data were obtained from Climatological Data - Arizona (Dept. of Commerce, National Oceanic and Atmospheric Administration). Relative humidity in the cabinets ranged from 56 to 95%, differing slightly from cabinet to cabinet.

Lima bean, Phaseolus vulgaris L., plants were grown in a greenhouse and leaves of uniform size and age were removed, placed in 9-cm petri dishes and used as the substrate on which the mites developed. The leaves were approximately 7-14 days old and of such size that they would fit in the petri dishes without coming into contact with the sides. Tetranychus cinnabarinus were reared in a greenhouse to serve as prey for T. occidentalis, and at 7 to 10 day intervals, new colonies were initiated in the laboratory from this source. The colonies were prepared by floating a bean leaf on water in a petri dish or by placing leaves on sterile cotton lint, saturated with tap water. Gravid female spider mites were placed on a leaf with a no. 00 camel's hair brush.

Colonies of T. occidentalis were also established by using the petri-dish bean leaf method. Twenty-five to 50 gravid tetranychid females were placed on a bean leaf with 5 to 10 gravid typhlodromid females. A second method consisted of placing 20 to 25 gravid tetranychid females on a bean leaf and allowing them to oviposit for 48 to 72 hours before introducing five gravid typhlodromid females.

Studies were conducted by placing 10 petri-dishes simultaneously in all three environators. Adult female longevity was measured by making daily observations every 24 hours. Progeny were counted and removed daily, and observations continued until the death of the females occurred.

Developmental studies were initiated by allowing gravid adult females to oviposit for 8 to 12 hours. Observations were made every 24 hours until the eggs hatched. Daily observations were continued to determine the duration of all immature stages.

Prey consumption by immature and adult females was measured by placing 15 host eggs on a 5.1 cm^2 bean leaf disc. Counts were made 24 hours later. The number consumed was calculated from the number that was left uneaten. The unconsumed eggs were removed and replaced daily with fresh eggs.

The parents of T. occidentalis used to initiate these studies were obtained from the Division of Biological Control, Department of Entomology, University of California, Riverside.

The mean and standard deviation were calculated for longevity, consumption and fecundity for each temperature regime. Analysis of variance was also performed on these data after they were grouped within each category. Data that were determined to be significant were further analysed by the Least Significant Difference (LSD) technique. Procedures were followed according to Little and Hills (1978).

Life tables were constructed for T. occidentalis according to the method of Birch (1948) as elaborated by Howe (1953) and Watson (1964). The statistic r_m (the actual rate of increase of a population under specific constant environmental conditions) was calculated by the equation: $\Sigma\ e^{-r_m x}\ l_x m_x = 1$ in which x equals the pivotal age group, l_x equals the probability of survival to age x, m_x equals the number of female offspring produced at age x and e is base of natural logarithms.

The net reproduction rate, R_o, is the factor by which a population will multiply per generation. It was calculated by the sum of the respective $l_x m_x$ columns [$R_o = \Sigma\ (l_x m_x)$]. The mean generation time, T, was calculated from the formula

$$T = \frac{\log_e R_o}{r_m}$$

RESULTS AND DISCUSSION

Effect of Temperature on the Life Cycle of T. occidentalis. Table 1 presents the effects of temperature on developmental time for the immature stages of T. occidentalis. With each increase in temperature developmental time for each stage was shortened. Mean developmental time from egg to adult was almost 4 days at the mean temperature of 30.5°C, increasing by one day with a drop in mean temperature to 26.6° and doubling to almost 8 days developmental time at the lowest mean temperature, 22.7°C.

Others working at temperatures close to the 22.7°C regime used in the present study have reported similar developmental times. Laing (1969) found that T. occidentalis developed from egg to adulthood in 8.7 days at a temperature of 20.3°, and Lee and Davis (1968) reported 6.3 days at 23.8°C. Smith (1965) observed T. fallacis to complete the immature stages in 7.3 days at 21.1°C.

Effect of Temperature on Adult Female Longevity. Table 2 summarizes the data showing the effect of temperature on adult female longevity of T. occidentalis. Mean longevity ranged from 30.8 days at 22.7° to 19.5 days at 30.5°C. Longevity was significantly greater in the 22.7° regime when compared to the two higher regimes. These data agree with those of Smith (1965) who worked with T. fallacis. He observed that T. fallacis showed a decrease in longevity with an increase in temperature. However, they differ somewhat from those of Laing (1969) and Sharma (1966), both of whom were working with T. occidentalis. Laing (1969) reported adult female longevity averaged only 20 days at 20.3°C, and Sharma (1966) reported it to be 17.7 days at 25.6°C. Their results were obtained at constant temperatures rather than with fluctuating temperatures as used in the present study, but the means were similar to those of Laing (1969) and Sharma (1966).

Effect of Temperature on the Preoviposition Period. The preovipositional period for T. occidentalis females declined with each increase in temperature. Mean preovipositional periods at the mean temperature regimes of 22.7°, 26.6° and 30.5°C were 2.43 $\pm$ 0.48, 1.91 $\pm$ 0.42 and 1.11 $\pm$ 0.21 days, respectively. Those reported by Laing (1969) and by Lee and Davis (1968) were 3.2 days at 20.3°C and 1.3 days at 23.8°C, respectively.

Effect of Temperature on Rate and Duration of Oviposition. Table 3 shows the effect of temperature on the rate and duration of oviposition by T. occidentalis. There was little difference in the daily rate of ovipositon among the three temperature regimes. However, temperature did affect duration of ovipositon, resulting in a significantly longer oviposition period for females held at the lowest temperature regime, 15.0-30.0°C. This resulted in a greater number of progeny produced at this regime.

Both Sharma (1966) and Lee and Davis (1968) found considerably lower ovipositional rates with T. occidentalis at temperatures closely approximating those in the two lower regimes of the present study. However, the ovipositonal rate of 2.2 eggs per day at 20.3°C in Laing's (1969) study is similar to that found in the present study. Similarities in duration of ovipostion were also found.

Effect of Temperature on the Consumptive Capacity of T. occidentalis. Table 4 shows the mean egg consumption for the various stages of T. occidentalis and the mean total consumption for all stages at the three temperature regimes. The adult stage consumed the greatest number of eggs, regardless of the temperature under which they were held. Relatively little difference in egg consumption between the protonymphal and deutonymphal stages was noted. The larval stage was not observed feeding on any prey.

Temperature had a highly significant impact on prey consumption by T. occidentalis adults and on total consumption; as temperature increased, feeding also increased. However, in the protonympal stage, egg consumption was significantly less only at the lowest temperature, and no temperature effects were observed in the deutonymphal stage.

TABLE 1. Temperature Effects on the Life Cycle of T. occidentalis.

Temperature °C Range	Temperature °C $\bar{X}$	Number observed	Average Number of Days Each Stage (±SD) Egg	Larva	Protonymph	Deutonymph	Total[a] Means
15.0 - 30.0	22.7	38	4.21 ± .38	1.13 ± .33	1.26 ± .25	1.30 ± .36	7.90a
19.4 - 33.6	26.6	38	2.22 ± .38	.74 ± .25	.97 ± .54	.99 ± .27	4.92 b
23.1 - 38.6	30.5	38	1.70 ± .52	.62 ± .22	.77 ± .50	.77 ± .24	3.92 b

[a] Means followed by different letters are significantly different (P<0.05) and separated by the LSD (Little and Hills 1978).

TABLE 2. Temperature Effects on Adult Female Longevity of T. occidentalis.

Temperature °C Range	Temperature °C $\bar{X}$	Number observed	Longevity in days Average[a] (± SD)	Range
15.0 - 30.0	22.7	42	30.8 ± 19.66a	14 - 52
19.4 - 33.6	26.6	47	23.0 ± 14.55 b	10 - 46
23.1 - 38.6	30.5	37	19.5 ± 7.5 b	9 - 40

[a]Totals followed by different letters are significantly different (P<0.05) and separated by the LSD (Little and Hills 1978).

TABLE 3. Temperature Effects on Oviposition Duration and Rate of T. occidentalis.

Temperature °C Range	$\bar{X}$	Number Observed	Number Days X (± SD)[a]	Daily Rate X (±SD)	Mean Number Progeny
15.0 - 30.0	22.7	41	22.24 ± 9.02a	2.41 ± 1.00	53.5 ± 10.2a
19.4 - 33.6	26.6	47	14.70 ± 6.28 b	2.29 ± .93	33.6 ± 7.9 b
23.1 - 38.6	30.5	37	13.02 ± 6.44 b	2.27 ± .81	29.6 ± 8.1 b

[a] Totals followed by different letters are signigicantly different ($p<0.05$) and separated by the LSD (Little and Hills 1978).

TABLE 4. Mean and Total Egg Consumption by the Different Stages of T. occidentalis at Three Temperature Regimes.

Temperature °C	Protonymph	Deutonymph	Adult	Total Means[a]
15.0 - 30.0 $\bar{X}$ = 22.7	1.77	2.56	3.55	7.88a
19.4 - 33.6 $\bar{X}$ = 26.6	3.21	3.31	9.51	16.03 b
23.1 - 38.6 $\bar{X}$ = 30.5	4.14	3.64	13.65	21.43 c

[a] Totals followed by different letters are significantly different ($P<0.05$) and separated by the LSD (Little and Hills 1978).

Effect of Temperature on Population Increase. The greatest intrinsic rate of increase, 0.192, occurred at the intermediate temperature regime ($\bar{x}$=26.6°C), with lesser rates (0.182) at the higher regime and at the lower regime (0.158). Net reproduction rates, R_o's, were inversely proportional to temperature; as the temperatures were increased, the R_o's declined from 17.31 to 12.30 to 9.97 for the temperature regimes of 22.7°, 26.6° and 30.5°C, respectively. Little difference was noted in the mean generation time, T, between the two higher temperature regimes, but it was significantly extended at the lowest regime; for successively increasing temperature regimes they were 18.03, 13.07 and 12.64 days at 22.7°, 26.6°, and 30.5°C, respectively.

LITERATURE CITED

Birch, L. C. 1948. The intrinsic rate of natural increase of an insect population. J. Anim. Ecol. 17: 15-26.

Howe, R. W. 1953. The rapid determination of the intrinsic rate of increase of an insect population. Ann. Appl. Bio. 40: 134-151.

Hoy, M. A., W. W. Barnett, and W. D. Reil. 1982. Large scale releases of pesticide resistant spidermite predators. Calif. Agr. Jan-Feb., Vol 35, Nos. 1 and 2: 8-10.

Laing, J. E. 1969. The life history and life table of Metaseiulus occidentalis. Ann. Entomol. Soc. Am. 61: 978-982.

Lee, M. S., and D. W. Davis. 1968. Life history and behavior of the predatory mite Typhlodromus occidentalis in Utah. Ann. Entomol. Soc. Am. 61: 251-257.

Little, T. M., and F. J. Hills. 1978. Agricultural Experimentation Design and Analysis. New York. John Wiley and Sons, Inc. 350 pp.

Roush, R. T., and F. W. Plapp. 1982. Biochemical genetics of resistance to aryl carbamate insecticides in the predaceous mite Typhlodromus occidentalis. J. Econ. Entomol. 75: 304-307.

Sharma, N. 1966. Factors influencing the effectiveness of Typhlodromus occidentalis Nesbitt as a predator of Tetranychus urticae Koch. MS Thesis, University of California, Berkeley. 169 pp.

Smith, J. C. 1965. A laboratory and greenhouse evaluation of Typhlodromus fallacis as a predator of Tetranychus spp. Ph.D. dissertation. Louisiana State University, Baton Rouge. 93 pp.

Tuttle, D. M., and M. H. Muma. 1973. Phytoseiidae (Acarina: Mesostigmata) inhabiting agricultural and other plants in Arizona. Ariz. Agr. Exp. Sta. Bull. 208. 55 pp.

Watson, T. F. 1964. Influence of host plant condition on population increase of Tetranychus telarius (Linnaeus) (Acarina: Tetranychidae). Hilgardia. 35: 273-322.

ATTRACTION OF LABORATORY-REARED, IRRADIATED MEXICAN FRUIT FLIES[1/] TO MALE-PRODUCED PHEROMONE IN THE FIELD

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ABSTRACT

Male-produced pheromone of the Mexican fruit fly, Anastrepha ludens (Loew), was evaluated as an attractant for conspecific, gamma-irradiated flies in field experiments from 1985 to 1986 in the Lower Rio Grande Valley of Texas. Pheromone emitted by cigarette filters attracted male and female flies equally while pheromone from rubber septa was not attractive. Pheromone-baited McPhail traps captured 16X more flies than pheromone-baited Pherocon® Tent™ traps. McPhail traps containing yeast hydrolysate captured 3X more flies than the most attractive pheromone dose (10 ME) in McPhail traps. Number of flies captured decreased approximately linearly with distance from the central release site. Number of flies captured was constant during the first 3 days after flies were released, then catches decreased 50% on the fourth day. Sex ratio in all traps was close to 1:1; however, McPhail traps with yeast hydrolysate caught significantly more males (male:female = 53:47). Approximately 2.1% of the released flies were recaptured.

INTRODUCTION

The McPhail trap containing torula yeast hydrolysate and borax in water is the standard trap for detection of the Mexican fruit fly (MFF), Anastrepha ludens (Loew) (Baker et al. 1944, Shaw et al. 1970). This trap has many disadvantages including bulk, fragility, poor attractiveness, and attraction of non-target species. These problems have created interest in developing new MFF attractants such as pheromones that could be used in more manageable traps.

A pheromone produced by male MFF is highly attractive to virgin females in laboratory bioassays (Robacker and Hart 1986) but is not attractive to mated females (Robacker et al. 1985). This pheromone also may be attractive to males based on studies with other Tephritidae (Fletcher 1968, Perdomo et al. 1976, Ohinata et al. 1977).

The principal objectives of this work were to: 1. determine if male-produced pheromone of the MFF is attractive to laboratory-reared, irradiated male and female flies in the field; 2. evaluate pheromone in two traps using two dispensers; and 3. evaluate pheromone relative to the standard McPhail trap containing yeast hydrolysate.

1/Diptera: Tephritidae.

MATERIALS AND METHODS

Insects. Flies were from a culture maintained for at least 50 generations with no wild-fly introductions. Nine thousand sexually immature, 4-7 day old flies irradiated with 7000-9150 rads (Cobalt 60 source) 1 to 3 days prior to adult eclosion were released at the center tree of the test area every 3-4 days during all experiments. Female flies became responsive to pheromone in the laboratory at age 7 days (Robacker et al. 1985). No data on male responsiveness to pheromone are available.

Pheromone Extract. Extract was prepared by grinding abdomens of mature, virgin, unirradiated males in hexane as described previously (Robacker and Hart 1985). Pheromone treatments were formulated at concentrations of 1, 10 and 100 male equivalents (ME) in 200 µl of hexane.

Experimental Design. Traps were placed on the NW sides of trees in a citrus grove ca. 1 m above the ground. Test trees were in five concentric rings around the central, fly-release point. The first ring was two trees distant (ca. 13 m) from the center and each successive ring was two trees beyond the previous one, offset counterclockwise by one tree to prevent straight-line rows of traps from the center to the outermost ring. Each ring contained one replication of each treatment (bait and/or trap type). Experiments were replicated over time, each replication lasting 1-4 days depending on the experiment. At least 3 days elapsed between all replications.

Experiment 1. This experiment was conducted in a 16 ha grapefruit (Citrus paradisi MacFad.) grove near Mission, Texas. Trap baits were 1, 10 and 100 ME of pheromone extract, or torula yeast hydrolysate and borax in water. Catches in baited traps were compared to those in unbaited (blank) traps. Baits were tested in McPhail traps. Pheromone was dispensed from cigarette filters suspended in the entrance holes on the undersides of the traps. The trapping agent was 300 ml of water in the blank and pheromone-baited traps, and 300 ml of yeast hydrolysate in the yeast-baited traps. Traps were collected 1 day after initiation of the test. Five replications of the experiment were conducted between April and July, 1985.

Experiment 2. This experiment was conducted in a 5 ha grapefruit grove near Weslaco, Texas. Trap baits tested in Pherocon® Tent™ traps (Zoecon Corp., Palo Alto, CA) were unbaited and 1, 10 and 100 ME of pheromone extract. Baits tested concurrently in separate McPhail traps were 10 ME of extract and yeast hydrolysate. Pheromone was dispensed from cigarette filters in three replications and from rubber septa in four replications. Trapping agents in McPhail traps were the same as in Experiment 1. The trapping agent in Pherocon® traps was Stickem®. Traps were moved one position counterclockwise within rings each day for 4 days. Flies were collected each day. Baited cigarette filters were replaced daily and baited septa were replaced after 2 days. Yeast hydrolysate was replaced daily. The seven replications were conducted between April and September, 1986.

Experiment 3. This experiment was conducted in the Weslaco grove. Traps and baits were the same as in Experiment 1, except that an additional McPhail trap containing no bait or water was included in each ring of traps. Pheromone dispensers were rubber septa that were replaced after 2 days. Traps were moved, flies collected and yeast hydrolysate replaced daily for 4 days as in Experiment 2. Four replications were conducted during October and November, 1986.

Pheromone Emission from Dispensers. Cigarette filters and rubber septa were treated with 100 ME of pheromone extract in 200 µl of hexane

injected into filters or allowed to soak into septa. Filters and septa were put into traps in the field. For each replication with filters, one filter was extracted immediately after pheromone application and another was extracted after 1 day in the field. For each replication with septa, one septum was extracted immediately, one after 1 day, and one after 2 days in the field. Extractions were performed by soaking the dispenser in 4 ml of hexane for 24 h followed by another 4 ml hexane rinse. These extracts were combined and analyzed by gas chromatography (Robacker and Hart 1985). Four replications of filters and two of septa were conducted between April and June, 1986.

Statistical Analyses. Pheromone dosage effects on captures of males, females, and males plus females were determined. All replications of Experiments 1 and 2 that used cigarette filters as dispensers were combined into one analysis of variance (AOV), and all replications of Experiments 2 and 3 that used rubber septa were combined into another AOV. Each replicate contained data from either McPhail traps or Pherocon® traps treated with 0, 1, 10 and 100 ME of pheromone. Individual means were compared by least significant differences (LSD).

Trap types were compared using Experiment 2 data. Flies captured in McPhail traps containing 10 ME plus water were compared to catches in Pherocon® traps containing 10 ME by a t-test. Yeast hydrolysate was compared to other baits in McPhail traps. Yeast hydrolysate, water only and empty traps were compared using Experiment 3 data. Yeast hydrolysate was compared to 10 ME dispensed from cigarette filters using data from Experiments 1 and 2. Comparisons were by t-tests.

The effect of distance from the central release site on fly catch was investigated by regression of catch on ring number. Sex ratios of flies captured by different traps and baits were compared by Chi-square tests.

RESULTS AND DISCUSSION

Pheromone Emission from Dispeners. Cigarette filters treated with 100 ME of pheromone extract emitted 77-89 ME of the four components during 1 day in the field (Table 1). Thus, 11-23 ME of the components remained on filters after 1 day. These data show that all four components were available for emission during the 24 h test period, at least for the 100 ME treatment. While other explanations are possible, the data suggest that ratios of the components in emissions at any time were similar to those in extract. If this is true, then ratios were similar to those emitted by calling males (Robacker and Hart 1985).

Rubber septa emitted lower amounts of the four components on each day of the two day test than cigarette filters emitted during a 1 day test (Table 1). Septa emitted more of the alcohols (Z3N, ZZ36N) on the first day than on the second day while the opposite was true for the lactones (ANA, EPI). These data suggest that ratios of the components emitted at most times from septa did not reflect ratios in the extracts or those emitted by calling males.

Pheromone Attractiveness and Dispenser Effects. Pheromone doses of 1 and 10 ME on cigarette filter dispensers attracted both male and female flies (Table 2). This is the first demonstration of attraction of males to male-produced pheromone in this species. Filters treated with 100 ME and all rubber-septa pheromone treatments were not more attractive than 0 ME. The inability of the filters with 100 ME to attract flies may be an overdose effect. The inability of pheromone-treated rubber septa to attract flies may have been caused by the unusual ratios of the components emitted by the septa (Table 1).

TABLE 1. Mean Pheromone Amounts Emitted from Cigarette Filters and Rubber Septa Treated with 100 Equivalents of Male Abdominal Extract (ME) and Left in the Field for One and Two Days, Respectively.

Component[b]	Amounts Emitted[a] from: Filters Day 1	Septa Day 1	Septa Day 2
Z3N	82 (7.2)	67 (0.9)	19 (9.4)
ZZ36N	77 (9.6)	67 (0.9)	19 (10)
ANA	89 (2.4)	12 (7.2)	38 (24)
EPI	86 (1.0)	10 (4.8)	41 (22)

[a] ME/day (± S.E.); 1 ME = the amount of each component extractable from 1 male abdomen.
[b] Z3N = (Z)-3-nonenol; ZZ36N = (Z,Z)-3,6-nonadienol; ANA = anastrephin (RR + SS isomers); EPI = epianastrephin (RR + SS isomers).

TABLE 2. Mean Captures of Irradiated Mexican Fruit Flies per Trap-Day Using Cigarette Filters or Rubber Septa to Emit Pheromone Baits.

Pheromone Dose (ME)	Filters[a] Males	Filters[a] Females	Septa[a] Males	Septa[a] Females
0	0.2 a	0.1 a	0.3 a	0.3 a
1	0.6 b	0.5 b	0.2 a	0.2 a
10	0.6 b	0.5 b	0.3 a	0.2 a
100	0.3 ab	0.2 ab	0.2 a	0.2 a

[a] Means in the same vertical column followed by the same letter are not significantly different at the 5% level by LSD.

Trap Effects on Pheromone Attractiveness. The McPhail trap was superior to the Pherocon® trap based on Experiment 2 data in which pheromone was dispensed from cigarette filters. The mean (± S.E.) catch by McPhail traps with 10 ME (containing water) was 7.4 (2.2) flies per trap. The mean catch by Pherocon® traps with 10 ME was 0.46 (0.10) flies per trap. The difference was highly significant by a t-test ($P < 0.01$).

Since Pherocon® traps did not contain water, the effect of water on catch in McPhail traps was tested using Experiment 3 data. The mean catch by the McPhail trap (0 ME) with water was 1.2 (0.6) flies per trap. The mean catch by the McPhail trap (0 ME) without water was 0.3 (0.1) flies per trap. The difference was not significant ($P > 0.1$ by a t-test).

Comparison of Pheromone and Yeast Hydrolysate. Yeast hydrolysate was not significantly more attractive than pheromone according to data from Experiments 1 and 2 ($P = 0.07$). Mean capture by the McPhail trap with yeast hydrolysate was 15.8 (5.0) flies per trap. Mean capture by the McPhail trap with 10 ME dispensed from cigarette filters was 5.6 (1.9) flies per trap.

These results differ from those of Perdomo et al. (1975, 1976) in which sticky traps baited with living, caged males were more attractive to both male and female A. suspensa than McPhail traps baited with yeast hydrolysate. Reasons for the discrepancy include species differences, characteristics of living males such as sound production (Webb et al.

1983), more optimal pheromone emission, and use of gamma-irradiated flies in the present work.

Effect of Distance on Fly Capture. Fly catch decreased with distance from the central release site. The number captured in ring 5 was 18% of the catch in ring 1. The decrease in catch fit the emperically derived equation:

catch per trap per day = 8.9 - 1.6 (ring number).

The linear regression coefficient was significant ($P < 0.01$). The coefficient of determination (R^2) was 94.6%.

The linear regression suggests that no flies would be captured beyond 5.6 rings or about 72 m from the release site. Theoretically, fly capture should be possible at any distance, so long as flies live long enough to disperse that far. In fact, Shaw et al. (1967) recaptured a small percentage (< 0.01%) of laboratory-reared, tepa-sterilized MFF at 3-23 miles (5-37 km) from release sites. Nevertheless, the linear-regression equation is valuable because it describes the rapid decline in fly density over relatively small distances from the release site.

Fly Catch Following a Release. The number of flies captured was nearly constant during the first 3 days following a release of flies then declined about 50% on the fourth day. Mean catches (flies/trap) for applicable replications were: day 1 = 3.3; day 2 = 4.2; day 3 = 3.5; and day 4 = 1.6. The catch on day 4 was significantly lower than on day 2 ($P < 0.05$ by a t-test), but catches on day 4 were not significantly different from catches on days 1 and 3. Also, catch at different distances from the release site did not change with the number of days since the last release.

These results suggest that half of the flies either died, left the groves, or did not respond to the traps after 3 days. Shaw et al. (1967) recaptured three laboratory-reared, tepa-sterilized MFF 10-12 months after release, which indicates a long life for this species under favorable conditions. Also, as discussed above, Shaw et al. (1967) recaptured a few flies at 5-37 km from release sites. Their results suggest that flies may have been leaving our groves rather than dying after 3 days. However, it is also possible that most flies died after a few days, leaving only a small percentage for long-range dispersal. We have no evidence to decide between these possibilities.

Sex Ratio. All trap/bait combinations except the McPhail trap with yeast hydrolysate captured statistically equal numbers of males and females. However, the 53% males captured in McPhail traps with yeast hydrolysate was significantly different from a 50:50 ratio ($P < 0.01$ by Chi square).

Our results agree with those of Perdomo et al. (1976) in that approximately equal sex ratios of A. suspensa were captured in pheromone-baited traps. However, our data differ from those of Perdomo et al. (1976) and Calkins et al. (1984) in which 58-74% of the flies (A. suspensa) captured in McPhail traps with yeast hydrolysate were females.

Percent Flies Recaptured. Approximately 6100 flies were captured out of ca. 288,000 released in the three experiments for an overall recovery rate of 2.1%. Due primarily to lower trap density, Holler et al. (1984) captured only ca. 0.1% of the same irradiated, laboratory-reared MFF strain released by airplane in groves in the lower Rio Grande Valley of Texas during 1982-83. While recovery in the present work was higher than that of Holler et al. (1984), it was lower than the 14-30% recoveries of A. suspensa in similar experiments (Perdomo et al. 1976, Calkins et al. 1984). Species differences and differences in procedure such as use of living males as baits (Perdomo et al 1976) and more traps per hectare (Calkins et al. 1984) make comparisons difficult.

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LITERATURE CITED

Baker, A. C., W. E. Stone, C. C. Plummer, and M. McPhail. 1944. A review of studies on the Mexican fruitfly and related Mexican species. USDA Misc. Publ. No. 531. 155 pp.

Calkins, C. O., W. J. Schroeder, and D. L. Chambers. 1984. Probability of detecting Caribbean fruit fly, Anastrepha suspensa (Loew) (Diptera: Tephritidae), populations with McPhail traps. J. Econ. Entomol. 77: 198-201.

Fletcher, B. S. 1968. Storage and release of a sex pheromone by the Queensland fruit fly, Dacus tryoni (Diptera: Trypetidae). Nature. 219: 631-632.

Holler, T. C., J. L. Davidson, A. Saurey, and R. Garcia. 1984. Release of sterile Mexican fruit flies for control of feral populations in the Rio Grande Valley of Texas and Mexico. J. Rio Grande Valley Hort. Soc. 37: 113-121.

Ohinata, K., M. Jacobson, S. Nadagawa, M. Fujimoto, and H. Higa. 1977. Mediterranean fruit fly: Laboratory and field evaluation of synthetic sex pheromone. J. Environ. Sci. Health. A12: 67-78.

Perdomo, A. J., R. M. Baranowski, and J. L. Nation. 1975. Recapture of virgin female Caribbean fruit flies from traps baited with males. Fla. Entomol. 58: 291-295.

Perdomo, A. J., J. L. Nation, and R. M. Baranowski. 1976. Attraction of female and male Caribbean fruit flies to food-baited and male-baited traps under field conditions. Environ. Entomol. 5: 1208-1210.

Robacker, D. C., and W. G. Hart. 1985. (Z)-3-nonenol, (Z,Z)-3,6-nonadienol, and (S,S)-(-)-epianastrephin: male produced pheromones of the Mexican fruit fly. Entomol. Exp. Appl. 39: 103-108.

Robacker, D. C., and W. G. Hart. 1986. Behavioral responses of male and female Mexican fruit flies, Anastrepha ludens, to male-produced chemicals in laboratory experiments. J. Chem. Ecol. 12: 39-47.

Robacker, D. C., S. J. Ingle, and W. G. Hart. 1985. Mating frequency and response to male-produced pheromone by virgin and mated females of the Mexican fruit fly. Southwest. Entomol. 10: 215-221.

Shaw, J. G., M. Sanchez-Riviello, L. M. Spishakoff, P. Trujillo G, and F. Lopez D. 1967. Dispersal and migration of tepa-sterilized Mexican fruit flies. J. Econ. Entomol. 60: 992-994.

Shaw, J. G., F. Lopez-D, and D. L. Chambers. 1970. A review of research done with the Mexican fruit fly and the citrus blackfly in Mexico by the Entomology Research Division. Bull. Entomol. Soc. Am. 16: 186-193.

Webb, J. C., T. Burk, and J. Sivinski. 1983. Attraction of female Caribbean fruit flies, Anastrepha suspensa (Diptera: Tephritidae), to the presence of males and male-produced stimuli in field cages. Ann. Entomol. Soc. Am. 76: 996-998.

TOXICITY AND REPELLENCY OF SOYBEAN AND COTTONSEED OILS TO THE SWEETPOTATO WHITEFLY[1] AND THE COTTON APHID[2] ON COTTON IN GREENHOUSE STUDIES[3]

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ABSTRACT

Bioassays against the sweetpotato whitefly, Bemisia tabaci (Gennadius), and the cotton aphid, Aphis gossypii Glover, were conducted with emulsions of soybean and cottonseed oil in greenhouse studies. Adult sweetpotato whiteflies avoided a 5% soybean oil treatment to cotton, Gossypium hirsutum L., seedlings for as long as 7 days. Egg viability was reduced by 84% with a 10% cottonseed oil spray. Treatment of whitefly larvae with 2.5 and 5% soybean oil sprays resulted in a 90% or greater reduction in the number of larvae and pupae. Cotton aphid nymphal and adult populations were also reduced by foliar sprays of the oils. Transpiration loss was not significantly different from cotton seedlings sprayed with 2.5 or 5% soybean oil or water.

INTRODUCTION

The sweetpotato whitefly, Bemisia tabaci (Gennadius), has become increasingly important as a pest of cotton and other crops in Arizona since 1981 (Duffus and Flock 1982, Duffus et al. 1986). The distribution of sweetpotato whiteflies on the underside of leaves, their high reproductive potential, and their resistance to pesticides contribute to the difficulty in controlling the insect with conventional spray applications (Johnson et al. 1982, Prabhaker et al. 1985, and Dittrich et al. 1985). Cotton aphid, Aphis gossypii (Glover), infestations in Arizona and California have been of minor importance and only sporadically require control action in limited local areas. Both insects produce honeydew which has been implicated in the worldwide problem of sticky cotton, although stickiness in cotton may also result from other causes (Perkins 1987).

Cotton aphid populations on cotton plants were reduced in Israel following a spraying of Bacillus thuringiensis in a cottonseed oil carrier (G. D. Butler, unpublished data). The need for an effective control agent for the sweetpotato whitefly and the cotton aphid on cotton prompted us to conduct greenhouse studies to determine the potential of soybean and cottonseed oils as pesticides. The experiments were conducted at the Western Cotton Research Laboratory, Phoenix, Arizona, in 1987.

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[1] Homoptera: Aleyrodidae

[2] Homoptera: Aphididae

[3] This paper presents the results of research only. Mention of a proprietary product does not constitute an endorsement by the USDA. This paper does not recommend the pesticide uses reported, nor does it imply that they have been registered by the appropriate governmental agencies.

MATERIALS AND METHODS

General. 'Stoneville 825' variety cotton, Gossypium hirsutum L., seedlings growing in 10-cm^2 plastic pots with one or two true leaves were used in all studies. All treatments were applied with a 1-l Polyspray 2 hand pump sprayer, and the tops and bottoms of the leaves were sprayed to runoff.

Oils were either a crude cottonseed oil product supplied by Traders Oil Mill Co., Fort Worth, Texas, or a refined commercial cooking soybean oil, Wesson Oil^R, Beatrice/Hunt-Wesson, Inc., Fullerton, Calif. Emulsions were prepared by adding 0.5% surfactant (Tween-80) to the oil and then diluting the oil to correct percentages with water. Controls in all experiments were infested or non-infested plants sprayed with water only.

Sweetpotato Whitefly. The repellent effect of soybean oil on sweetpotato whitefly was determined by collecting adults with a vacuum cleaner aspirator from a greenhouse culture reared on cotton plants. Several hundred adults were scattered over 14 soybean oil-treated plants set on greenhouse benches in a randomized block design, and whiteflies were allowed to randomly select plants of their choice. The same number of water-treated plants were controls. Leaves of oil-treated and water-treated control plants were examined prior to initiation of the experiment to determine that no whiteflies were on them. Adults only, adults and eggs, or adults and larvae were counted on the plants 1 to 7 days following treatment. The experiments were replicated 4 to 12 times.

The effects of oil treatments on sweetpotato whitefly eggs and larvae were determined by placing untreated, uninfested seedlings in a 105 x 68 x 105-cm screen cage. Several thousand sweetpotato whitefly adults collected as previously described were introduced into the cage. Plants were removed in 2 to 3 days and examined to verify the presence of eggs. One series of plants was sprayed immediately to determine the effect of the oil treatments on eggs, and a second series of plants with eggs was held for 7 days until eggs hatched and the plants were then sprayed. The effect of oil on sweetpotato whitefly larvae was determined by counting all larval stages on six 1-mm^2 samples per 1st and 2nd true leaf. The experiment was replicated five times.

Cotton Aphid. The effect of cottonseed oil on cotton aphids was determined by placing uninfested cotton seedlings in the same size screen cage as was used in whitefly studies. Cotton aphid-infested leaves were picked from cotton plants maintained in the greenhouse for rearing aphids and scattered over the uninfested plants. After 3 to 4 days to allow aphids to transfer to the cotton seedlings, plants were treated with oils or water (controls) as described for sweetpotato whiteflies. Numbers of cotton aphid nymphs and adults were counted on days 2 and 4 following treatment. The experiment was replicated five times.

Effect of Soybean Oil on Cotton Leaf Transpiration. To determine if the oil treatments affected leaf stomatal opening, thus causing damage by reduced plant transpiration, the 10 cm^2 pots containing cotton plants (6 to 8-leaf stage) were wrapped in aluminum foil; and five plants in each treatment were sprayed with 2.5 to 5% soybean oil or water as previously described. Watering was discontinued, and the pots with the plants were subsequently weighed on days 2, 3, 4, 6 and 7 after treatment to determine their weight loss as a function of water loss through transpiration, a standard technique used by plant physiologists (J. W. Radin, personal communication). Controls were water-treated plants and the experiment was replicated five times.

Statistical Analysis. Data were analyzed by analysis of variance procedures, and Duncan's (1955) multiple range test (0.05 level of significance) was used to separate means.

RESULTS AND DISCUSSION

Sweetpotato Whitefly. The numbers of whitefly adults settling on cotton plants was significantly reduced for four days following treatment with 5% soybean oil as compared to numbers settling on water-treated plants (Experiment 1, Table 1). This was further reflected in reduced numbers of whitefly eggs on the same sampling dates. This effect on adults was evident for seven days after treatment (Experiment 2, Table 1). Twenty percent soybean oil provided over a 99% reduction in numbers of whitefly adults on day 3 following oil treatment, and as expected, a 95% reduction in the number of larvae on day 6 after oil treatment (Experiment 3, Table 1).

TABLE 1. Repellent Effect of Soybean Oil on Sweetpotato Whitefly as Measured by Number of Adults, Eggs, and Larvae on Oil or Water-Treated Cotton Leaves up to 7 Days after Treatment

Stage	Treatment	Mean no. of days after treatment[ab] 1	2	3	4	6	7
		Experiment 1					
Adult	Soybean oil 5%	0a	5a	18a	27a	--	--
	Water (control)	79b	123b	156b	210b	--	--
Egg	Soybean oil 5%	0.3a	4.4a	13a	53a	--	--
	Water (control)	120b	92b	171b	313b	--	--
		Experiment 2					
Adult	Soybean oil 5%	4a	--	3a	--	--	52ab
	Soybean oil 2.5%	14a	--	14a	--	--	38a
	Water (control)	90b	--	74b	--	--	60b
		Experiment 3					
Adult	Soybean oil 20%	--	--	0.5a	--	--	--
	Soybean oil 10%	--	--	1.0a	--	--	--
	Soybean oil 5%	--	--	2.2a	--	--	--
	Water (control)	--	--	204.2b	--	--	--
Larvae	Soybean oil 20%	--	--	--	--	17a	--
	Soybean oil 10%	--	--	--	--	118b	--
	Soybean oil 5%	--	--	--	--	254c	--
	Water (control)	--	--	--	--	445d	--

[a] Means in a column within an experiment not followed by the same letter are significantly different ($P = 0.05$, Duncan's multiple range test).
[b] Experiment 1, means of 7, 7, 7, and 9 replications on days 1, 2, 3, and 4, respectively. Experiment 2, means of 12 replications. Experiment 3, means of 4 replications.

When sweetpotato whitefly eggs were treated with 10% crude cottonseed oil, the mean number of first instar larvae 8 days after treatment was significantly reduced ($P \leq 0.05$, Table 2). There was a mean of 51 eggs per treated cotton plant as compared to 321 eggs on untreated control plants.

When sweetpotato whitefly larvae were treated with soybean oil (2.5 and 5%) on cotton seedlings, there was a 90% or greater reduction in the number of larvae and pupae. There were no significant differences in the number of larvae treated with 10% crude cottonseed oil or 2.5 or 5%

refined soybean oil. However, significantly fewer pupae were found on plants treated with 10% crude cottonseed oil than on plants treated with 1, 2, or 2.5% refined soybean oil ($P \leq 0.05$, Table 2).

TABLE 2. Mean[a] Number of Sweetpotato Whitefly Larvae at 6 Days and Pupae at 4 to 15 Days on Cotton Leaves after Treatment of Larvae with Soybean or Cottonseed Oil

Treatment	Mean number of stage at days post treatment[a]		
	Larvae	Pupae	
	6	4	15
Crude cottonseed oil 10%	4a	24a	2a
Soybean oil 5%	26a	—	—
Soybean oil 2.5%	49a	204b	55b
Soybean oil 2.0%		204b	55b
Soybean oil 1%		258b	26b
Water (control)	294b	410b	141c

[a] Means of 5 replications. Means within a column not followed by the same letter are significantly different ($P \leq 0.05$, Duncan's multiple range test).

Cotton Aphid. Crude cottonseed oil (10%) and 5% and 2.5% refined soybean oil significantly reduced cotton aphid numbers on cotton seedlings 2 and 4 days after treatment ($P \leq 0.05$, Table 3). Mortality percentages 2 days after treatment were 93, 93, and 63%, respectively, for crude cottonseed oil, and 5 and 2.5% for refined soybean oil.

TABLE 3. Mean[a] Number of Cotton Aphid Nymphs and Adults and Percent Mortality on Days 2 and 4 After Treatment with Plant-Derived Oils or Water

Treatment	Days after treatment (No. aphids)		% Mortality (2 days post treatment)
	2	4	
Crude cottonseed oil (10%)	8 a	12 a	93 a
Soybean oil (5%)	11 a	15 a	93 a
Soybean oil (2.5%)	39 b	56 b	63 b
Water (control)	69 c	102 c	40 c

[a] Means of 8 replications. Means within a column not followed by the same letter are significantly different ($P \leq 0.05$, Duncan's multiple range test).

Cotton Leaf Transpiration. Seven days after treatment with 2.5% or 5% refined soybean oil, cotton plant weights were reduced 52% and 48%, respectively, of the initial weight as compared to 45% for cotton plants treated with water (Table 4). Oil- and water-treated plant weights decreased at approximately the same rates. There were no significant differences between treatments and controls on any of the sampling dates, showing that water loss due to transpiration was not affected by the oil treatments.

TABLE 4. Mean[a] Percentages of Initial Weight of Cotton Plants on Days 2, 3, 4, 6 and 7 After Treatment with 2.5% or 5% Wesson Oil or Water

Treatment	2	3	4	6	7
Soybean oil (2.5%)	90	77	67	48	43
Soybean oil (5.0%)	91	81	71	52	47
Water (control)	90	79	69	50	46

[a] Means of 5 replications. No significant differences on sampling dates.

Oils have been used as insecticides and acaricides and as pesticide additives or synergists (Coudriet et al. 1985). Plant oils are considered physical poisons which interfere with respiration in insects and mites. Some plant oils possess compounds that cause chemical poisoning (Hesler and Plapp 1986). Much of the current research with oils, particularly cottonseed oil used for cotton insect control, has been associated with ultra low-volume oil spraying, a subject reviewed by Robinson and Slosser (1986).

In our studies, whitefly adults avoided oil-treated plants for 7 days following treatment which resulted in a significant reduction in the number of immature forms present on treated plants. Treated eggs had an 84% reduction in hatch, and treated larvae had a 90% mortality. Cotton aphids were reduced by 85 to 88% following treatments. The beneficial uses of plant oils in agriculture are well documented, and the results of our supportive studies indicate that soybean or cottonseed oils may have potential for control of sweetpotato whitefly and cotton aphid under field conditions. The most serious problem to be solved will be to apply the oil spray under field conditions in a manner to provide coverage of the undersides of the cotton leaves where the sweetpotato whiteflies and a majority of the cotton aphids are located. The urgent need for an effective control agent for sweetpotato whitefly justifies additional research on the use of oils on cotton and other crops.

LITERATURE CITED

Coudriet, D. L., N. Prabhaker, and D. E. Meyerdirk. 1985. Sweetpotato whitefly (Homoptera: Aleyrodidae): Effects of neem-seed extract on oviposition and immature stages. Environ. Entomol. 14: 776-779.

Dittrich, V., S. O. Hassan, and G. H. Ernst. 1985. Sudanese cotton and the whitefly: a case study of the emergence of a new primary pest. Crop Prot. 4: 161-176.

Duffus, J. E., and R. A. Flock. 1982. Whitefly transmitted disease complex of the desert southwest. Calif. Agric. 36: 4-6.

Duffus, J. E., R. C. Larsen, and H. Y. Liu. 1986. Lettuce infectious yellows virus--a new type of whitefly-transmitted virus. Phytopathology 76: 97-100.

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

Hesler, L. S., and F. W. Plapp, Jr. 1986. Uses of oils in insect control. Southwest. Entomol. Suppl. No. 11: 1-8.

Johnson, W., C. Toscano, T. Reynolds, S. Sylvester, K. Kido, and E. Natwick. 1982. Whiteflies cause problems for southern California growers. Calif. Agric. 35: 24-26.

Perkins, H. H., Jr. 1987. Sticky cotton. pp. 53-55, In Proc. Western Cotton Prod. Conf., Phoenix, AZ.

Prabhaker, N., D. L. Coudriet, and D. E. Meyerdirk. 1985. Insecticide resistance in the sweetpotato whitefly, Bemisia tabaci (Homoptera: Aleyrodidae). J. Econ. Entomol. 78: 748-752.

Robinson, J. R. C., and J. E. Slosser. 1986. Controlled droplet application technology for ultra low volume-oil spraying of insecticides in cotton. Southwest. Entomol. Suppl. No. 11: 9-17.

EFFECT OF ALDICARB TREATMENTS TO COTTON ON BEMISIA TABACI[1] AND APHIS GOSSYPII[2] POPULATIONS IN ISRAEL[3]

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ABSTRACT

An experiment was conducted at Yagur, Israel during 1986 to evaluate the effect of aldicarb on sweetpotato whitefly, Bemisia tabaci (Gennadius), and cotton aphid, Aphis gossypii Glover, population development in cotton, Gossypium hirsutum L. Aldicarb (1.6 kg/ha) at the time of planting did not significantly affect B. tabaci population development. In-furrow treatments of aldicarb (13 kg/ha) applied on 15 July or applied at planting (18 April) and 15 July reduced whitefly-day accumulations; however, the rate of increase following these treatments was great enough that economic infestation levels were predicted to occur during September. A. gossypii was effectively controlled by the single 15 July aldicarb application.

INTRODUCTION

The sweetpotato whitefly, Bemisia tabaci (Gennadius), is a serious pest of cotton, Gossypium spp., throughout the world. Feeding on plant phloem, B. tabaci weakens the plant, vectors cotton leaf crumple disease and secretes honey-dew which results in sticky lint and stimulates black sooty mold development (Butler et al. 1986). Another insect which produces honeydew and has been abundant in Israeli cotton in recent years is the cotton aphid, Aphis gossypii Glover (Broza 1986). A. gossypii has recently become more of a problem again in several cotton-growing areas of the United States (King et al. 1987), and populations of A. gossypii were particularly severe in Alabama, California and Oklahoma during 1986. High populations in Alabama were primarily attributed to pyrethroid use and failures of chloropyrifos, dicrotophos and monocrotophos to adequately control the aphid (King et al. 1987).

A recent discussion of the chemical control of B. tabaci by Sharaf (1986) indicated that early applications of soil insecticides seemed most effective. Aharonson et al. (1984) reported that a 31 May application of aldicarb effectively controlled B. tabaci during June and July when populations were low and causing little damage. An application toward the end of July was too late to provide effective control, but treatment at the end of June resulted in higher aldicarb residues in the leaves and gave better whitefly control during the latter half of the cotton-growing season. These authors suggested that aldicarb applied at the end of June

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[1] Homoptera: Aleyrodidae.

[2] Homoptera: Aphididae.

[3] This article reports the results of research only. Mention of a proprietary product does not constitute an endorsement or a recommendation for its use by the USDA or the University of Haifa.

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might be sufficient to provide control of the whitefly throughout the growing season, thus eliminating the need for additional foliar sprays. Recent studies by Prabhaker et al. (1985) have shown that a broad spectrum of resistance to organophosphorous and synthetic insecticides has developed in B. tabaci in southern California, thus precluding the use of foliar sprays of these materials for control.

Because of the increasing incidence of resistance and the problems associated with conventional foliar applications, we conducted a study to evaluate aldicarb applied in either a single or dual treatment in early and mid-season, to suppress B. tabaci and A. gossypii populations. Here, we report the result of our 1986 studies.

MATERIALS AND METHODS

Experimental procedures. A 2.0-ha experimental field, located at Yagur, Israel, was planted with the variety 'Acala SJ-2' on 18 April 1986. The field was sprinkler-irrigated. All aldicarb treatments were made with a tractor-mounted soil applicator. Experimental treatments included: (1) aldicarb at the rate of 1.6 kg/ha on 18 April (sprinkler-irrigated on 25 April), (2) aldicarb at the rate of 13 kg/ha on 15 July, (3) aldicarb at the rate of 1.6 kg/ha on 18 April (sprinkler-irrigated on 25 April) plus 13 kg/ha on 15 July, and (4) untreated control plots. The experiment was replicated 4 times in a randomized complete block design.

B. tabaci adults drop from the undersides of cotton leaves when disturbed so a beating technique was used to sample whitefly adults (Butler et al. 1986). Each of ten plant terminals (ca. 5 leaves per terminal) was struck three times with a 1-m stick over an open carton (20 x 30 cm) with a yellow plastic bottom coated with a thin layer of vegetable oil. The number of adults adhering to this sticky bottom was counted after each sample. The plastic bottom was then wiped clean with an oil-soaked cloth and used for the next sample. Whitefly adults were sampled on 6, 13, 23 July, 3, 17, 20, 26 August, and 2 September.

Field counts of both adult and nymphal A. gossypii were made on the first or second fully expanded leaf in the 'Acala SJ-2' cotton, with the aid of a head-magnifier (10x). Aphids were counted on samples of 100 leaves selected at random from each plot on 28 July, 8 and 15 August, and 50 leaves were sampled on 22, 28 August, and 4 September.

Data analysis. A randomized block analysis of variance and Duncan's (1955) multiple range test were used to determine the degree to which B. tabaci and A. gossypii populations were reduced by the various treatments on a given date. However, we were also interested in the magnitude and duration of the insect populations that survived each treatment. Cuperus et al. (1982) and Hamilton et al. (1986) have shown that arthropod pest damage is a function of pest density and can also be influenced by the length of time the crop is exposed to a particular population density. Therefore, we converted whitefly and aphid counts to insect-days (ID) (Hamilton et al. 1986) which combines both population density and time into a single expression: $ID = \{(D_i + D_{i-1})/2\} \cdot N$, where D_i = current density, D_{i-1} = previous density and N = No. of days between samples. Linear regression models, $y = a + b \cdot x$, where y = ID and $x = \log_{10}$ (Julian date), were fitted to the ID data to compare ID accumulations between each treatment and the untreated check plots. Regression equations for individual treatment comparisons were tested for differences ($H_o : a_1 = a_2, b_1 = b_2$) using a general linear F test (Neter and Wasserman 1974). In this test, rejection of the null hypothesis implies that either the y-intercepts (a), slopes (b), or both regression coefficients between two treatments are significantly different.

To further examine the impact of adult populations, laboratory (Butler et al. 1983) and greenhouse (G.D.B., unpublished data) estimates of B. tabaci fecundity (average of 6.9 eggs per female per day [at 32°C]

and 75% egg hatch) were used to predict subsequent egg and first-instar larval recruitment in each treatment. Projections were made for the period 3 August to 2 September and included total egg-days expected to accumulate and total eggs and larvae per plant per day.

RESULTS AND DISCUSSION

Whitefly populations. Throughout the season, we found no significant differences ($P > 0.05$) in mean B. tabaci density between the untreated check and 18 April aldicarb-treated plots (Table 1). The most consistent differences were observed in August, where whitefly densities in the dual (18 April and 15 July) aldicarb-treated plots were significantly less than those in the untreated check and 18 April aldicarb plots.

Regression analysis (Fig. 1A, Table 2) also indicated that the aldicarb treatment applied 18 April (1.6 kg/ha) did not significantly reduce whitefly-day accumulations ($F = 0.75$; $df = 2,10$; $P > 0.05$) compared with the untreated check. However, aldicarb (13 kg/ha) applied on 15 July did significantly reduce whitefly-day accumulations ($F = 19.67$; $df = 2,9$; $P \leq 0.01$). The dual application of aldicarb had the greatest impact on reducing whitefly-days (Fig. 1A). Although the dual treatment provided significantly better control when compared to the untreated check ($F = 36.09$, $df = 2$; $P \leq 0.01$), it was not significantly different from the single 15 July treatment ($F = 3.34$; $df = 2,8$; $P > 0.05$). The corresponding projections of B. tabaci egg and larval recruitment for each treatment from 3 August to 2 September (Table 3) reflect the adult density (Table 1) and whitefly-day (Fig. 1A) trends.

TABLE 1. Mean Number[a] of Adult B. tabaci in Untreated and Aldicarb-Treated Acala SJ-2 Cotton, Yagur, Israel, 1986.

Sampling Date	Untreated	Aldicarb Treatments (kg/ha) 18 Apr[b] (1.6)	15 July (13)	18 Apr + 15 July (1.6+13)
6 July	2.6 A[c]	1.9 A	-[d]	-
13 July	4.1 A	2.6 A	-	-
23 July	10.6 A	8.0 A	3.4 A	1.3 A
3 August	45.6 A	40.8 A	17.0 AB	8.7 B
17 August	143.2 A	162.3 A	41.2 B	37.6 B
20 August	206.0 A	216.2 A	129.7 AB	85.2 B
26 August	275.2 A	314.8 A	136.7 AB	111.9 B
2 September	212.4 A	249.2 A	126.1 A	111.4 A

[a] Means based on 40, ten-plant terminals (ca. 5 leaves each).
[b] Treatment was applied at planting.
[c] Means across columns followed by the same letter are not significantly different ($P = 0.05$; Duncan's [1955] multiple range test).
[d] Data were not collected for these plots until after aldicarb treatments were applied.

Although the 15 July aldicarb treatment and 18 April + 15 July dual application significantly reduced whitefly-day accumulations over the season (Fig. 1A), the actual density estimates on 2 September were not significantly different (Table 1) and still as high as 126 and 111 adults per plant, respectively (check = 212 per plot). Given the rate of population increase (all are exponential) in July and August for the dual aldicarb application (Table 1), the projected populations (based on $y = a + bx$; where $y = \log_{10}$ of adults and $x =$ Julian day) in the dual treatment

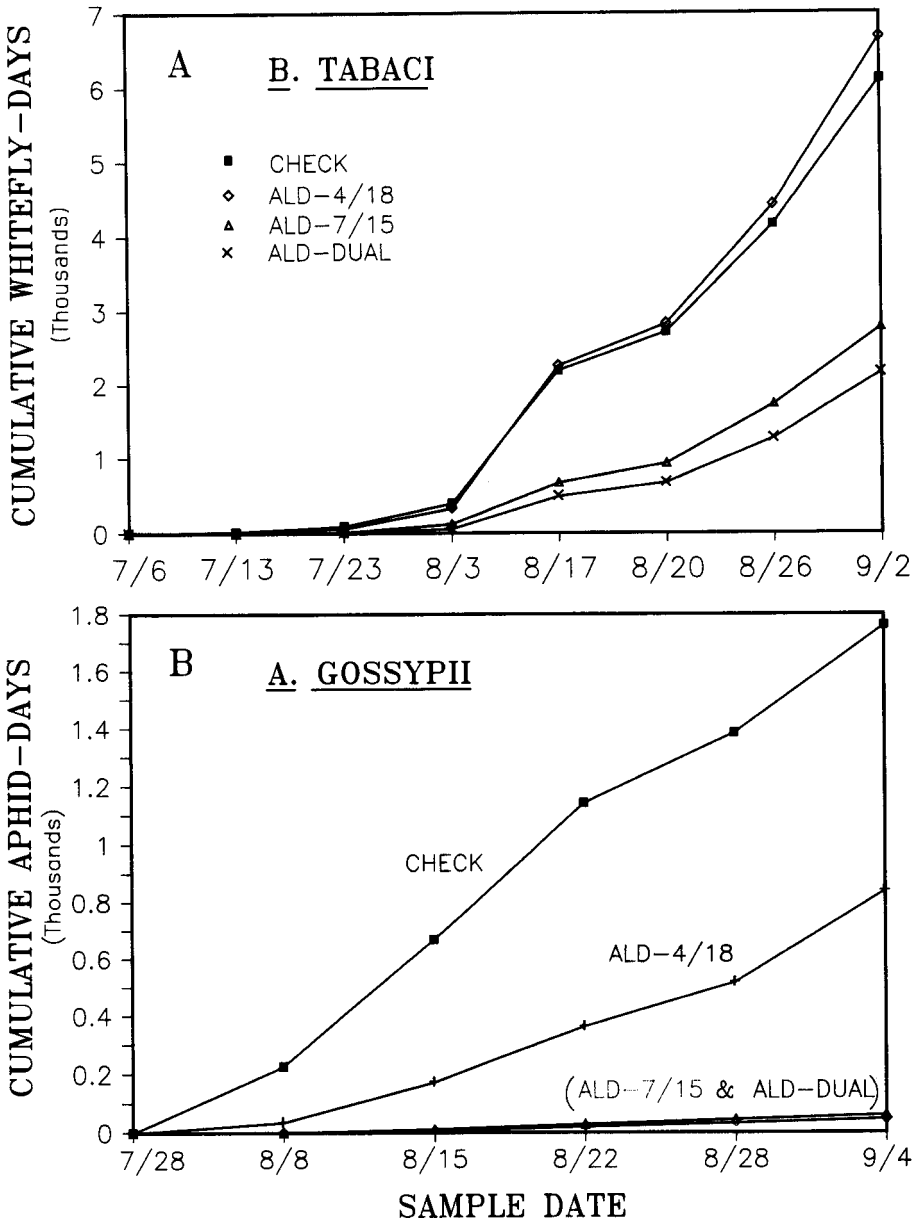

FIG. 1. Cumulative whitefly-days (B. tabaci) (A) and aphid-days (A. gossypii) (B) in untreated and aldicarb-treated cotton, Yagur, Israel, 1986.

and untreated check would actually converge by 18 September. Thus, the primary benefit of the aldicarb treatments was to reduce population pressure in July and August and thereby minimize crop damage due to direct feeding.

TABLE 2. Linear Regression Models[a] of Whitefly and Aphid-Day Accumulations in Untreated and Aldicarb-Treated Acala SJ-2 Cotton, Yagur, Israel, 1986

	B. tabaci	R^2	*A. gossypii*	R^2
Untreated check	Y = -18.30 + 0.112(x)	0.99	Y = -10.18 + 0.072(x)	0.94
Aldicarb (18 April)	Y = -20.81 + 0.123(x)	0.99	Y = -20.23 + 0.110(x)	0.96
Aldicarb (15 July)	Y = -22.16 + 0.124(x)	0.99	Y = -23.51 + 0.112(x)	0.97
Aldicarb (18 April & 15 July)	Y = -26.88 + 0.143(x)	0.99	Y = -29.24 + 0.137(x)	0.92

[a] Y = cumulative insect-days; x = $\log_{10}$ of Julian dates from 187 (6 July) to 245 (2 September) for *B. tabaci*, and 209 (28 July) to 247 (4 September) for *A. gossypii*.

TABLE 3. Predicted Number of *B. tabaci* Egg-Days, and Eggs and Larvae Produced Per Day Per Plant in Untreated and Aldicarb-Treated Acala SJ-2 Cotton, Yagur, Israel, 1986

		Aldicarb Treatments (kg/ha)		
	Untreated Acala SJ-2	18 Apr[b] (1.6)	15 July (13)	18 Apr + 15 July (1.6+13)
Total Egg-Days[a]	18,307	20,475	7,049	5,382
$\bar{x}$ No. Eggs/Day	390	436	150	114
$\bar{x}$ No. Larvae/Day	292	327	112	86

[a] Projections are for the period 3 August to 2 September, and they are based on initial adult densities (Table 1) and fecundity and percent egg hatch data (at 32°C) from Butler et al. (1983) and G.D.B. (unpublished data).
[b] Treatment was applied at planting.

Populations that continue to develop in mid- to late-September, however, occur at a time when mature open cotton is most susceptible to honeydew contamination. These results are similar to those of Butler and Henneberry (1983), who observed that whitefly adult populations increased at the same rate in untreated Arizona cotton fields and in fields with a mid-July aldicarb treatment; mid-September populations were similar in treated and untreated fields.

Aphid populations. From 28 July to 15 August, *A. gossypii* populations in all aldicarb-treated plots were significantly ($P \leq 0.05$) less than those in the untreated check plots (Table 4). However, from 22 to 28 August, aphid densities in the 18 April aldicarb-treated plots were

not significantly different from the untreated check plots, and by 4 September, there were no significant differences among treatments.

TABLE 4. Mean Number[a] of A. gossypii Per 100 Cotton Leaves Following Various Aldicarb Treatments to Acala SJ-2 Cotton, Yagur, Israel, 1986.

		Aldicarb Treatments (kg/ha)		
Sampling Date	Untreated	18 Apr[b] (1.6)	15 July (13)	18 Apr + 15 July (1.6+13)
28 July	1840 A[c]	320 B	16 B	9 B
8 August	2292 A	601 B	38 B	22 B
15 August	10366 A	3331 B	137 B	280 B
22 August	3172 A	2093 A	219 B	229 B
28 August	4919 A	3073 A	189 B	289 B
4 September	5767 A	6465 A	190 A	167 A

[a] Means based on 400 leaves on 28 July, 8 and 15 August; 200 leaves on all other dates.
[b] Treatment was applied at planting.
[c] Means across columns followed by the same letter are not significantly different (P = 0.05; Duncan's [1955] multiple range test).

Aldicarb applied 18 April (1.6 kg/ha) significantly reduced aphid-day accumulations ($F = 15.09$; $df = 2,6$; $P \leq 0.01$) (Fig. 1B, Table 2), but the final population on 4 September (Table 4) was actually higher than that in the untreated plots. Aldicarb applied 15 July (13 kg/ha) was just as effective as the dual aldicarb treatments applied 18 April and 15 July ($F = 0.32$; $df = 2,6$; $P > 0.05$). The dual application, however, was much more effective than the single application on 18 April ($F = 68.73$; $df = 2,6$; $P \leq 0.01$).

The objective of this experiment was to provide information necessary for developing a pest management program for cotton in Israel, with particular emphasis on the control of the primary pest, B. tabaci. However, B. tabaci and A. gossypii are becoming increasingly important late-season pests of cotton in the United States (Butler et al. 1986, King et al. 1987). Because our results for B. tabaci were comparable to those of an earlier Arizona study (Butler and Henneberry 1983) it appears early crop termination (e.g., early September) remains the most effective method of minimizing late-season lint contamination in both Israel and the southwestern United States. However, based on the impact of the 15-July aldicarb treatment on A. gossypii, the potential for such control in A. gossypii management programs in the United States warrants further investigation.

LITERATURE CITED

Aharonson, N., L. Muszkat, and I. Neubaur. 1984. Accumulation pattern and insecticidal effect of aldicarb in cotton following soil treatment on the control of the tobacco whitefly (Bemisia tabaci). Parasitica 12: 127-134.

Broza, M. 1986. An aphid outbreak in cotton fields in Israel. Parasitica 14: 81-85.

Butler, G. D., Jr., and T. J. Henneberry. 1983. Sweetpotato whitefly, Bemisia tabaci, 1982 research results. Univ. of Ariz. Agr. Expt. Sta. Series P-59: 113-116.

Butler, G. D., Jr., T. J. Henneberry, and T. E. Clayton. 1983. Bemisia tabaci (Homoptera: Aleyrodidae): development, oviposition, and

longevity in relation to temperature. Ann. Entomol. Soc. Am. 76: 310-313.
Butler, G. D., Jr., T. J. Henneberry, and W. D. Hutchison. 1986. Biology, sampling and population dynamics of Bemisia tabaci. Agri. Zool. Rev. 1: 167-195.
Cuperus, G. D., E. B. Radcliffe, D. K. Barnes, and G. C. Marten. 1982. Economic injury levels and economic thresholds for the pea aphid, Acyrthosiphon pisum (Harris), on alfalfa. Crop Protection 1: 453-463.
Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics. 11: 1-42.
Hamilton, G. C., F. C. Swift, and R. Marini. 1986. Effects of Aphis pomi (Homoptera: Aphididae) density on apples. J. Econ. Entomol. 79: 471-478.
King, E. G., J. R. Phillips, and R. B. Head. 1987. 40th annual conference report on cotton insect research and control, pp. 171-193. In Proceedings, Beltwide Cotton Production Research Conference. Dallas, TX.
Neter, J., and W. Wasserman. 1974. Applied linear statistical models. Irwin, Homewood, IL.
Prabhaker, N., D. L. Coudriet, and D. E. Meyerdirk. 1985. Insecticide resistance in the sweetpotato whitefly, Bemisia tabaci (Homoptera: Aleyrodidae). J. Econ. Entomol. 78: 748-752.
Sharaf, N. 1986. Chemical control of Bemisia tabaci. Agr. Ecosystems and Environ. 17: 111-127.

RESPONSES OF FEMALE MEXICAN FRUIT FLIES[1/] AT VARIOUS DISTANCES FROM MALE-PRODUCED PHEROMONE

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ABSTRACT

Distances from which male-produced pheromone stimulated flying (flight activation) and upwind movement of virgin female Mexican fruit flies, Anastrepha ludens (Loew), were determined. The experiment was conducted in a hallway where behavior of insects caged at various distances downwind from a pheromone source was monitored. Pheromone amounts were 0.1, 1, 10 and 100 male equivalents (ME) applied to filter paper, resulting in release rates of 50-100% during a half hour test. Pheromone elicited responses as far as 8 m from the source. Most upwind movement occurred at 0.1 m from the source. Increased flying was the dominant behavior at greater distances. Effects decreased with decreasing pheromone concentration. Maximum upwind displacement was 25-30% in response to 100 ME at 0.1 m, 15 min after pheromone application to the source.

INTRODUCTION

Pheromones emitted by male Mexican fruit flies, Anastrepha ludens (Loew), attract conspecific virgin females (Esponda-Gaxiola 1977, Robacker and Hart 1986) and possibly conspecific males (Fletcher 1968, Perdomo et al. 1976, Ohinata et al. 1977, Robacker and Hart 1986). However, the distance over which attraction occurs has not been studied. This information is needed to understand the interaction of chemical, visual and acoustical courtship signals and to evaluate the potential of pheromone as a trap bait. Therefore, we determined the distances from a pheromone source that virgin female Mexican fruit flies respond behaviorally to various pheromone concentrations. Both activation to flight and upwind movement of flies were measured.

MATERIALS AND METHODS

Insects. Flies were from a culture maintained for at least 50 generations with no wild-fly introductions. Flies were held in 0.3 X 0.3 X 0.3 m aluminum-framed, aluminum-screened cages in the laboratory. Temperatures ranged from 20 to 25°C and relative humidity was 40 to 70% at non-test times. During tests, relative humidity was usually greater than 70% because tests were conducted in a cooled hallway open to the outside. Photoperiod was shifted so the 14 h light phase ended at 1000 h. Flies were sexually active from ca. 0600-1000 h under these conditions (Robacker et al. 1985).

[1/]Diptera: Tephritidae

Experimental Procedures. Pheromone treatments were 0, 0.1, 1, 10 and 100 male equivalents (ME) of abdominal extract in 100 µl of hexane. Extract was prepared by grinding abdomens from 7-20 day-old, sexually active, virgin males in hexane. The extracted abdomens remained in hexane over night. The extract was then filtered through glass wool and concentrated under a stream of nitrogen (Robacker and Hart 1985). Extract was stored at -20°C.

A hallway (30 X 2.5 X 2 m) served as a wind tunnel for the bioassays. Airflow was created by a prevailing southeasterly wind aided by a large exhaust fan at the downwind end of the hallway. Wind movements were monitored during one day with an anemometer and smoke. The pheromone dispenser, a 3 X 3 cm filter-paper square, was suspended 0.5 m above the floor, 6 m from the upwind end of the hall. A cage (described above) containing 100 sexually active female flies ranging in age from 9-35 days old was put at each of seven distances downwind from the source. Sexually active females were defined as virgin females over 8 days old (Robacker and Hart 1985). Distances were 0.1, 1, 2, 4, 8, 12 and 18 m from the pheromone source. Each cage was elevated 0.3 m from the floor.

Each bioassay was conducted from 0730-0900 h. One pheromone treatment was tested daily. Five replications of the experiment were conducted and each replication contained the five pheromone amounts tested in random order. The same insects were used on successive days to test all pheromone amounts in each repliction. Cages were positioned at 0730 h. At 0800 h, the numbers of flies on the upwind and downwind screens and the number flying during a 5-sec observation period were counted in each cage. This procedure was repeated two more times at 5-min intervals. At 0815 h, one of the five pheromone amounts was applied to the filter-paper source. Five more counts were conducted at 5-min intervals.

Flight activation was calculated as follows. For each cage, the mean number of insects flying during the three 5-sec observations taken prior to pheromone application was subtracted from the mean number flying during the five observation periods after pheromone application. The 0 ME treatment (control) was corrected in the same way, and then subtracted from each pheromone and distance treatment mean. These calculations were designed to correct for any possible effects from individual cages of flies and for any non-pheromone related changes in flight activity that may have occurred between the beginning and end of the daily test, respectively. The result was the net flying activity in response to pheromone.

Upwind movement of flies was calculated by subtracting the number of flies on the downwind screen from the number on the upwind screen for each cage. Mean differences were corrected for cage and time-of-day effects as described above. The result was the net upwind movement of flies in response to pheromone.

Total response was calculated as the sum of net flight activation and net upwind movement. This calculation is valid since flying and upwind movement are different expressions of response to pheromone by different flies at the same time. Analyses of variance were conducted on flight activation, upwind movement and total response before subtraction of 0 ME effects, and the analyses included the 0 ME data. Statistical analyses were conducted before subtraction of 0 ME effects so that pheromone effects could be compared to 0 ME by the least significant difference method.

Release Rates from Filter Paper. Release rates were estimated by putting 10 and 100 ME of extract onto filter paper squares in an airflow of 2-3 m/sec for 0.5 h. The papers were then soaked in 5 ml of hexane overnight and rinsed with another 5 ml of hexane. The solutions were

combined and analyzed by gas chromatography as described previously (Robacker and Hart 1985). Two replications of each amount were conducted.

RESULTS AND DISCUSSION

On the wind-speed test day, winds in the hallway averaged 1.2 m/sec ranging from 1.0 to 1.6 m/sec at various positions over the course of a 1 h period. Wind speed inside cages averaged 0.8 m/sec ranging from 0.6 m/sec in the cages at 1 and 2 m from the pheromone source to 1.1 m/sec in cages at 0.1 m from the pheromone source. It appeared that the cage at 0.1 m partially blocked air passage to the cage at 1 m, and the cage at 1 m similarly affected the cage at 2 m. Smoke plumes indicated that turbulence inside cages was minimal and that air moved reliably from the upwind to the downwind sides of the cages. Wind speeds during pheromone-test days undoubtedly varied above and below 1.2 m/sec in the hallway, but there was no reason to suspect that general air patterns were different from those recorded on the wind-speed test day.

Total response (flight activation plus upwind movement) to the 100 ME treatment was significantly greater ($P \leq 0.05$) than response to 0 ME at each distance downwind from the pheromone source from 0.1 to 8 m (Fig. 1). Response to 10 ME was significantly greater ($P < 0.05$) than response to 0 ME at 0.1, 1 and 4 m, and nearly so ($P \leq 0.1$) at 2 m. Response to 1 ME was significantly greater ($P \leq 0.05$) than response to 0 ME at 0.1 and 2 m, and nearly so ($P < 0.06$) at 1 m. Response to 0.1 ME was significantly greater ($P \leq 0.05$) than response to 0 ME at 0.1, 1, 2 and 8 m. Taking into account both concentration and distance effects, it is reasonable to conclude that flies responded to 100 ME as far as 8 m from the source, to 10 ME as far as 4 m, and to 0.1 and 1 ME as far as 2 m.

Partitioning total response into flight activation and upwind movement of flies showed that the two behaviors did not occur in the same ratio to each other at each distance. Upwind movement was the major behavior exhibited at 0.1 m for all 4 pheromone treatments, making up 67% of the total response. Mean upwind movements at 0.1 m for the 0.1, 1, 10 and 100 ME treatments were 5.3, 13.0, 14.8 and 14.2 flies/cage, respectively. These means were all significantly greater than the control ($P \leq 0.05$). Conversely, flying was the principal behavior at the greater distances. For example, flying was 33% of the total response at 0.1 m, then increased to 72, 64, 76 and 73% of the total response at 1, 2, 4 and 8 m. Most likely, flying in response to pheromone would eventually result in upwind movement of flies although it was not shown in this work.

Pheromone amounts emitted per half hour by filter papers treated with 10 and 100 ME of extract, respectively, were: (Z)-3-nonenol - 9.9 (s.d. = 0.0) ME and 96.2 (1.1) ME; (Z,Z)-3,6-nonadienol - 9.7 (0.1) ME and 92.9 (1.8) ME; anastrephin - 7.7 (1.0) ME and 46.0 (5.5) ME; and epianastrephin - 7.4 (0.9) ME and 44.7 (9.6) ME. Robacker and Hart (1985) defined a ME as the amount of each pheromone component extracted from one abdomen, but they showed that calling males emit different amounts and ratios of the components than were found in abdomens. Extrapolating from data of Robacker and Hart (1985), the amounts emitted by the 10 and 100 ME filter papers approximate those emitted by ca. 70 and 700 males, respectively, calling for the same length of time as the exposure period. Thus, the amount of pheromone emitted by a single calling male was estimated to be about the same as from the 0.1 ME treatment. This amount elicited significant upwind movement from 0.1 m ($P < 0.05$) and flight activation from both 0.1 and 1 m ($P \leq 0.05$) as compared to 0 ME.

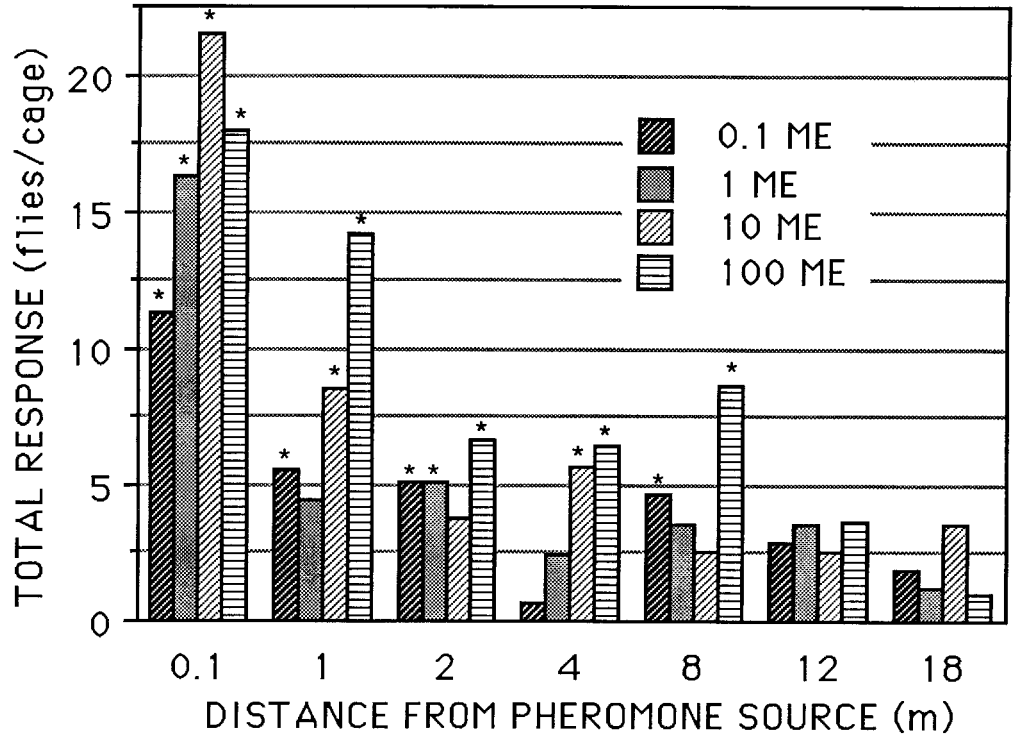

FIG. 1. Total response (flight activation plus upwind movement) by virgin female Mexican fruit flies at various distances downwind from four quantities of male-produced pheromone. Bars with * are significantly greater than responses to the 0 ME treatment at the 5% level by LSD.

Male aggregation for mating has not been proven in this species, but is well-known from many other tephritids including Anastrepha suspensa (Loew) (Burk 1981). The present data suggest that a group of 5-10 males would theoretically elicit more attraction than an individual male, based on the assumption that some or all of the males emitted pheromone. This assumption seems reasonable since males in groups stimulate each other to produce pheromone in some tephritids (Burk 1984, McDonald 1987). Whether or not the gain in attractiveness would result in a gain in fitness for males in groups is beyond the scope of this discussion.

Under conditions of 100 ME, 0.1 m downwind from the source, and 15 min after pheromone application, 25-30% of the virgin females gathered on the upwind screen. While this is a substantial response, upwind movement and flight activation to smaller amounts of pheromone and at greater distances were much lower. These results suggest that field traps emitting as much as 100 ME of pheromone per hour might attract virgin female flies from ca. 0.1 to a few meters, if laboratory-reared and wild females respond similarly. Thus, a trap on a tree may attract some virgin females on that tree and perhaps some from an adjacent tree. Robacker and Hart (1986) demonstrated that laboratory-reared males were not greatly attracted to pheromone in laboratory tests, and Robacker et al. (1985) showed that mated females were not attracted. Together, these findings show that, for laboratory-reared flies, male-produced pheromone of A. ludens is attractive only to virgin females over relatively short distances.

ACKNOWLEDGMENT

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LITERATURE CITED

Burk, T. 1981. Signaling and sex in acalyptrate flies. Fla. Entomol. 64: 30-43.

Burk, T. 1984. Male-male interactions in Caribbean fruit flies, Anastrepha suspensa (Loew) (Diptera: Tephritidae): Territorial fights and signalling stimulation. Fla. Entomol. 67: 542-547.

Esponda-Gaxiola, R. E. 1977. Contribucion al estudio quimico del atrayente sexual de la mosca Mexicana de la fruta, Anastrepha ludens (Loew). M.S. Thesis, Instituto Technologico y de Estudios Superiores de Monterrey, Monterrey, N. L. Mexico.

Fletcher, B. S. 1968. Storage and release of a sex pheromone by the Queensland fruit fly, Dacus tryoni (Diptera: Trypetidae). Nature. 219: 631-632.

McDonald, P. T. 1987. Intragroup stimulation of pheromone release by male Mediterranean fruit flies (Diptera: Tephritidae). Ann. Entomol. Soc. Am. 80: 17-20.

Ohinata, K., M. Jacobson, S. Nadagawa, M. Fujimoto, and H. Higa. 1977. Mediterranean fruit fly: Laboratory and field evaluation of synthetic sex pheromone. J. Environ. Sci. Health. A12: 67-78.

Perdomo, A. J., J. L. Nation, and R. M. Baranowski. 1976. Attraction of female and male Caribbean fruit flies to food-baited and male-baited traps under field conditions. Environ. Entomol. 5: 1208-1210.

Robacker, D. C., and W. G. Hart. 1985. (Z)-3-nonenol, (Z,Z)-3,6-nonadienol and (S,S)-(-)-epianastrephin: male produced pheromones of the Mexican fruit fly. Entomol. Exp. Appl. 39: 103-108.

Robacker, D. C., and W. G. Hart. 1986. Behavioral responses of male and female Mexican fruit flies, Anastrepha ludens, to male-produced chemicals in laboratory experiments. J. Chem. Ecol. 12: 39-47.

Robacker, D. C., S. J. Ingle, and W. G. Hart. 1985. Mating frequency and response to male-produced pheromone by virgin and mated females of the Mexican fruit fly. Southwest. Entomol. 10: 215-221.

THREECORNERED ALFALFA HOPPER[1/] RESPONSE TO SIX STICKY TRAP COLORS[2/]

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ABSTRACT

Adult threecornered alfalfa hopper (TCAH), Spissistilus festinus (Say), response to six colors was monitored with painted sticky traps for four weeks during the 1987 growing season in a soybean, Glycine max (L.) Merrill., field. Numbers of TCAH caught on yellow colored sticky traps were significantly greater than numbers caught on the other colors. A consistent proportion and significantly greater number of males than females were caught on all colors, indicating no sexual influence on specific response to any of the colors and a higher rate of flight activity by males.

INTRODUCTION

The initial steps of host selection by insects are often mediated by visual stimuli such as color (Lloyd 1921, Broadbent 1948, Kennedy et al. 1961). Homopteran insects have been reported to respond differently to various colors (MacDowall 1972, Roach and Agee 1972, Kieckhefer et al. 1976, Alverson et al. 1977, Yudin et al. 1987). Various types of colored insect trapping devices have been used to evaluate population levels and dispersal patterns as part of pest management strategies (Elliot and Kemp 1979, Adams et al. 1983, Meyerdirk and Oldfield 1985). Preliminary tests showed that threecornered alfalfa hopper (TCAH) adults can be caught on conventional yellow aphid sticky traps (Mueller unpublished data).

The objectives of this study were to determine the effectiveness of different colors in attracting and catching adult TCAH and to compare sex ratios caught on different colored traps with sex ratios collected in sweep net samples.

MATERIALS AND METHODS

Tangle-trap® coated traps used for this study were constructed of 30.5 cm X 61 cm plywood boards bolted to 1.3 m long, 2.5 cm diameter aluminum conduit. Both sides of four boards were brush painted with one heavy coat

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1/ Homoptera: Membracidae

2/ Published with the approval of the Director, Arkansas Agric. Exp. Stn. and supported in part by an Arkansas Soybean Promotion Board Grant.

of each of the following enamel paints: crimson 254[3], canary yellow E110[4], dublin green 263[3], bold blue 251[3], satin white 262[3], and jet black 258[3]. Colors were selected on the basis that blue, green, yellow, and red occupy major parts of the visible electromagnetic spectrum while black and white represent lowest and highest reflective properties, respectively. The six enamel paint colors were colorimetricly analysed with a HunterLab® D25-9 tristimulus colorimeter utilizing illumination representing daylight with a correlated color temperature of approximately 6500 K.

The experimental design was a randomized complete block with four replications and six treatment colors. On 28 July 1987, traps were placed 7.7 m apart in furrows of a Bragg soybean field planted on 76 cm row spacing. Each of the six colors were randomly arranged in each of four furrows. Traps in replicates 1 and 3 faced east-west while traps in replicates 2 and 4 faced north-south. Replicates were placed 7.7 m (9 rows) apart, and conduits were driven into the ground so that the bottoms of the traps were at the top of the plant canopy, ca. 60 cm above the ground. TCAHs were removed weekly for four wk, placed in vials of kerosene and brought to the laboratory for sexing. Weekly sweep net samples consisting of ten sets of ten sweeps were taken with a 38 cm diameter sweep net to compare TCAH sex ratio in the field with ratios caught on the colored sticky traps. Male TCAH percentages were transformed to arcsines. Data were analyzed with t-tests and F-tests with mean separations by Duncan's (1955) multiple range test.

RESULTS AND DISCUSSION

Colorimetric analysis of the six enamel paint colors with the Hunter L,a,b Opponent Color Scales (Table 1) showed that reflectance decreased in the following order: white, yellow, red, green, blue, and black. Lightness of the colors decreased in the following order: white, yellow, green, red, blue, and black. Green and yellow occupy 490-590 nm wavelengths of the electromagnetic radiation spectrum, with yellow (560-590 nm) being the most attractive to TCAH adults (Fig. 1). Measurement of chromaticity dimensions (opponent color scales)(Table 1) showed that yellow had a low amount of redness and high amount of yellowness. Green had relatively moderate levels of greenness and yellowness.

The number of adult TCAH caught on yellow sticky traps was significantly greater than numbers caught on the five other colors (Fig. 1). Green traps caught the second greatest numbers, and numbers on green traps were significantly different from the numbers caught on red, white, blue, or black traps. The numbers of TCAH caught on replicates one, three, and four were not significantly different from each other over the four weeks of the study. Replicate two, facing north-south, caught significantly fewer TCAH than the others. The other north-south oriented traps (replicate four) caught the greatest numbers of TCAH so catches were not associated with trap orientation. No significant differences were found among the compass orientations. Significantly greater numbers of TCAH were caught during the first two weeks than the last two weeks of the study.

Results of this study are similar to those obtained by Alverson et al. (1977). They reported that significantly greater numbers of cicadellids and aphids were captured on yellow sticky traps than on white, green, avocado, red, or sky blue traps. Yellow is a major component of the

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[3] Manufactured by Red Devil Paints and Chemicals, an Insilco Company, Mt. Vernon, NY

[4] Manufactured by Pratt & Lambert, Inc. Buffalo, NY

Table 1. Color Spectrum Measurements with Reference to Reflectiveness, Lightness, Degree of Redness to Greenness, and Yellowness to Blueness from Colored Sticky Traps.

Sticky Trap Color	Percent Reflectance	Lightness[1/]	Red (+) to Green (-)[2/]	Yellow (+) to Blue (-)[3/]
White	86.0	91.50	-0.76	4.89
Yellow	63.0	64.08	5.86	33.96
Green	19.5	35.25	-16.70	10.97
Red	52.5	29.94	32.53	11.13
Blue	12.5	22.81	-1.96	-18.50
Black	2.5	15.26	0.05	-0.10

1/ Numbers represent degree of lightness (100) to darkness (0)(Hunter's colorimeter designation L).
2/ Numbers represent degree of redness (+) to greenness (-)(Hunter's colorimeter designation a).
3/ Numbers represent degree of yellowness (+) to blueness (-) (Hunter's colorimeter designation b).

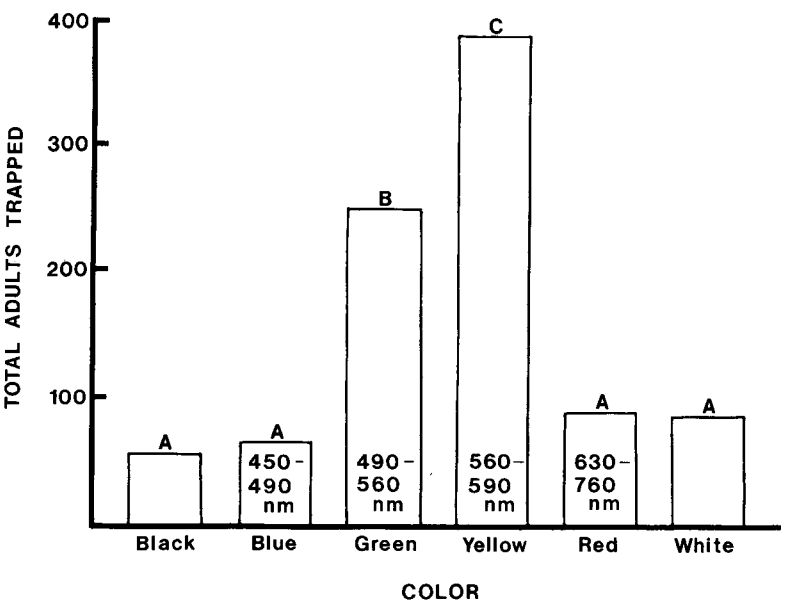

Fig. 1. Frequency distribution of TCAH adults caught on sticky traps of six different colors in 1987. Columns headed by the same letter are not significantly different (P<0.05;Duncan's (1955) multiple range test). Typical wavelength ranges are shown.

reflected light from green leaves. Yellow, opaque plastic cards coated with a sticky substance were shown to be effective for monitoring adult beet leafhoppers (Meyerdirk and Oldfield 1985). Similarly, yellow sticky traps may be used to monitor TCAH activity in a soybean field.

Significantly greater numbers ($P<0.05$) of males than females were caught on each of the trap colors (Table 2). Percentage of males caught on sticky traps did not change significantly with color of trap or week of study. Sweep net samples, however, indicated consistently lower male percentages than were caught on the colored sticky traps (Table 3). Similarly, Meyer and Colvin (1985) showed that male sharpnosed leafhoppers, Scaphytopius magdalensis (Provancher), outnumbered females on yellow sticky traps by 6:1. Meyerdirk and Oldfield (1985) also reported that males dominated the sex ratio during a study on the evaluation of trap color and

Table 2. Number of Adult TCAH and Proportion of Males Caught on Six Different Colors of Sticky Traps in a Soybean Field during 1987.

Trap Color	Total Adults[1/]	No. Males	% Males[1/]
Yellow	392 C	360	91.8 A
Green	252 B	219	86.9 A
Red	89 A	80	89.9 A
White	84 A	74	88.1 A
Blue	64 A	52	81.3 A
Black	57 A	48	84.2 A

[1/] Numbers followed by the same letter in a column are not significantly different ($P<0.05$;Duncan's (1955) multiple range test).

Table 3. Percentages of Male TCAH Caught on All Colors of Sticky Traps and in Sweep Net Samples in a Soybean Field During 1987.

Week	Color Sticky Traps[1/]	Sweep Net[1/]
1	86.0 B	64.0 A
2	85.5 B	67.0 A
3	87.7 B	50.0 A
4	92.2 B	0.0 A

[1/] Numbers followed by the same letter in a row are not significantly different (t-test ($\alpha=0.05$)).

height placement for monitoring the beet leafhopper, Circulifer tenellus (Baker). These data indicate that TCAH males are more active flyers than females and apparently there is no sexual influence on specific responses to colors.

Other insects were attracted to specific colors during this experiment. Although actual counts were not made, more tabanids (Diptera) appeared to be attracted to white, green, and blue than to yellow, red, or black. Alverson et al. (1977) reported similar responses by cyclorrhaphous Diptera which showed an overwhelming phototactic response to glossy white and sky blue-painted traps. Thrips (Thripidae) appeared to be attracted to white more than to the other colors, which agrees with results of Yudin et al. (1987). Lepidoptera, specifically Pieridae and Papilionidae, appeared to be attracted to red.

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LITERATURE CITED

Adams, R. G., C. H. Domeisen, and L. J. Ford. 1983. Visual trap for monitoring pear psylla (Homoptera: Psyllidae) adults on pears. Environ. Entomol. 12: 1327-1331.

Alverson, D. R., J. N. All, and R. W. Matthews. 1977. Response of leafhoppers and aphids to various colored sticky traps. J. Ga. Entomol. Soc. 12: 336-341.

Broadbent, L. 1948. Aphis migration and the efficiency of the trapping method. Appl. Biol. 35: 379-394.

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

Elliot, W. M., and W. G. Kemp. 1979. Flight activity of the green peach aphid (Homoptera: Aphididae) during the vegetable growing season at Harrow and Jordan, Ontario. Pro. Entomol. Soc. Ont. 110: 19-28.

Kennedy, J. S., C. O. Booth, and W. J. S. Kershaw. 1961. Host finding by aphids in the field. III. Visual attraction. Ann. Appl. Biol. 49: 1-21.

Kieckhefer, R. W., D. A. Dickmann, and E. L. Miller. 1976. Color responses of cereal aphids. Ann. Entomol. Soc. Am. 69: 721-724.

Lloyd, L. 1921. Notes on color tropism of Asterochiton (Aleurodes) vaporariorum Westwood. Bull. Entomol. Res. 12: 355-359.

MacDowall, F. D. H. 1972. Phototactic action spectrum for whitefly and the question of color vision. Can. Entomol. 104: 299-307.

Meyer, J. R., and S. A. Colvin. 1985. Diel periodicity and trap bias in sticky trap sampling of sharpnosed leafhopper populations. J. Entomol. Sci. 20: 237-243.

Meyerdirk, D. E., and G. N. Oldfield. 1985. Evaluation of trap color and height placement for monitoring Circulifera tenellus (Baker) (Homoptera: Cicadellidae). Can. Entomol. 117: 505-511.

Roach, S. H., and H. R. Agee. 1972. Trap colors: preference of alate aphids. Environ. Entomol. 1: 797-798.

Yudin, L. S., W. C. Mitchell, and J. J. Cho. 1987. Color preference of thrips (Thysanoptera: Thripidae) with reference to aphids (Homoptera: Aphididae) and leafminers in Hawaiian lettuce farms. J. Econ. Entomol. 80: 51-55.

PARASITES OF HICKORY SHUCKWORM[1/] AND PECAN NUT CASEBEARER[2/] WITH FIVE NEW HOST-PARASITE RECORDS[3/]

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ABSTRACT

Three parasite species Phanerotoma fasciata Provancher (Hymenoptera: Braconidae), Apanteles epinotiae Viereck (Hymenoptera: Braconidae) and Calliephialtes grapholithae (Cresson) (Hymenoptera: Ichneumonidae) were found to cause observed parasitism of 9.6, 2.6 and 1.8%, respectively, in 1982 and 26.5, 5.2, and 3.9%, respectively, in 1983, in larvae of overwintering hickory shuckworm, Cydia caryana (Fitch) (Lepidoptera: Tortricidae). Lower numbers of three other parasite species were found, among which Bracon variabilis (Provancher) (Hymenoptera: Braconidae), has not been reported previously from hickory shuckworm.

Larvae and pupae of first summer generation pecan nut casebearer, Acrobasis nuxvorella Neunzig (Lepidoptera: Pyralidae), were parasitized by at least 24 species belonging to 10 families in two orders. Of these, Eupelmus limneriae Howard (Hymenoptera: Eupelmidae), Goniozus columbianus Ashmead (Hymenoptera: Eulophidae), Tetrasticus sp. (Hymenoptera: Eulophidae) and Zatropis tortricidis Crawford (Hymenoptera: Pteromalidae) were new records.

Total observed parasitism of first summer generation pecan nut casebearer caused by all parasites collectively ranged from 13.6 to 47.1% in different locations in 1983 and 1984. Observed parasitism by each parasite species in different locations at different times are reported.

INTRODUCTION

Hickory shuckworm (HS), Cydia caryana (Fitch) (Lepidoptera: Tortricidae), and pecan nut casebearer (PNC), Acrobasis nuxvorella Neunzig (Lepidoptera: Pyralidae), are two of the three key pests of pecan, Carya illinoensis (Wang.) K. Koch (McWhorter et al. 1979, Harris 1983). Parasitism is an important factor in natural control of these two indigenous pests, and identification of species of parasites may be useful in pest management programs. Numerous species of parasites of HS and PNC have been reported from the southern and southeastern United States. Adair (1930) reported six species of parasites of HS in Mississippi. Nickels et al. (1950) found seven species in Texas. Calcote and Hyder (1979) found 3 parasite species emerging from overwintering HS larvae in Texas.

1/ Lepidoptera: Tortricidae
2/ Lepidoptera: Pyralidae
3/ Approved by the Director of TAES as TA 23223.

Gill (1930) reported four parasite species of PNC in Georgia. Bieberdorf (1948) reported 60.7% parasitism of PNC larvae in Stillwater, Oklahoma. Heinrichs (1968) found four parasite species of PNC collected from infested petioles of mockernut hickory in Anderson County, Tennessee in 1967. Nickels (1931) and Nickelset al. (1950) reported 26 species of primary parasites and five species of hyperparasites of PNC in Central, Western and Southern Texas.

The present research was conducted to determine the parasitic species on HS and PNC and to compare with earlier findings.

MATERIALS AND METHODS

Pecan shucks were obtained from Brownwood, Texas during commercial harvesting of pecan in December 1982 and 1983 for the investigation of hickory shuckworm parasites. Infested pecan shucks were broken into small pieces and checked for the presence of larvae by opening the galleries. The numbers of live larvae, dead larvae, dead parasites and empty cocoons left by parasites already emerged in the field were recorded. Live larvae were left within the gallery in the piece of shuck and placed separately in vials stoppered with cotton and maintained at 25°±2°C. The parasites that emerged were collected for identification.

Infested pecan nut clusters were collected from Adriance research pecan orchard in Robertson County (500 clusters), and from Wilson orchard in Brazos County (99 clusters), June 24, 1983. In 1984, nut clusters were collected on June 7 from Adriance orchard (1280), June 5 from Riverview Park in Seguin in Guadalupe County (1000), and June 2 from Hidden Valley Farms in Hamilton, Hamilton county (140), in 1984. Clusters were placed individually in vials and maintained at room temperature. Emerging PNC adults and parasites were collected and recorded daily. In the case of parasite emergence, host remnants and empty parasite cocoons were saved for future reference. After emergence ceased in ca. 4 wks, the remaining nutlets were dissected and checked for any dead larvae, dead pupae and empty pupal cases of both PNC and parasites.

The collected parasites were identified to species by personnel at the Insect Identification and Beneficial Insect Introduction Institute, USDA/ARS, Beltsville, Maryland. Some specimens were deposited in the US National Museum, when no comparable specimens were found. The rest were curated and deposited in the Insect Collection of the Entomology Department, Texas A&M University, College Station.

RESULTS AND DISCUSSION

Parasites of Hickory Shuckworm. Six species of parasites were found to attack overwintering HS larvae in Brownwood. The most commonly found parasites were the two braconids, Phanerotoma fasciata Provancher and Apanteles epinotiae Vierieck and an ichneumonid Calliephialtes grapholithae (Cresson). Parasitism by these three species ranged from 1.8 to 26.5 percent (Table 1). Two braconids, Macrocentrus instabilis Muesebeck and Bracon variabilis (Provancher), and an ichneumonid, Mastrus sp. were found in lower numbers. Bracon variabilis was found on only one occasion during this study, and this species has not been reported previously from HS.

TABLE 1. Observed Percent Parasitism of Overwintering Hickory Shuckworm Larvae in Brownwood.

Parasite species	Observed parasitism % 1982-83	1983-84
Phanerotoma fasciata	9.6	26.5
Apanteles epinotiae	2.6	5.2
Calliephialtes grapholithae	1.8	3.9
Total parasitism	14.0	35.6

Three of the parasites P. fasciata, A. epinotiae and C. grapholithae caused 14% observed parasitism in Brownwood in 1982-83 and 35.6% in 1983-84. Phanerotoma fasciata caused the highest observed percent parasitism by a single species in Brownwood in the winters of 1983 and 1984 (Table 1). The order of observed parasitism was consistent over the 2 yrs., with A. epinotiae and C. grapholithae being second and third, respectively (Table 1).

Apanteles epinotiae had emerged in the field by the time samples were gathered in December of each year. All records of this parasite were made from empty cocoons, except for a few that contained fully grown adults which failed to emerge. Therefore, the parasitism was estimated on the basis of counts of total empty cocoons and dead adults left in the galleries, rather than total adult parasite emergence, unlike in the other two cases. Nickels et al. (1950) reported that A. epinotiae parasitized pecan nut casebearer larvae overwintering in hibernacula. This probably explains how this parasite survives in winter after emergence from HS.

Parasites of Pecan Nut Casebearer. First summer generation PNC larval and pupal collections in 1983 yielded 14 species of parasites belonging to seven familes, and those of 1984 yielded 19 species of parasites belonging to nine familes in two orders. There was a total of 24 species in the parasite complex of PNC (Table 2). Four of the parasite species found in this study have not been reported previously from PNC. The number of parasite species observed at a given location was related to the sample size and a large sample is needed to ensure locating those that occurred at a low density.

Total parasitisms of 33.8% and 47.1% were observed in Robertson and Brazos Counties, respectively, in the first summer generation of PNC in 1983. The majority of PNC moths and some of the parasites have already emerged in the field before the clusters were collected in June, 1983. The total number of emerging insects, on which the calculation of percent parasitism is based, was corrected by adding the number of empty parasite cocoons left in clusters. No field emergence prior to collection was observed in 1984 from samples gathered from June 2-7.

Calliephialtes grapholithae, which caused highest observed parasitism in 1983 in Adriance Orchard, was not recovered from PNC collected in the same orchard in 1984 where sampling was done on an earlier date than in the previous year. Since C. grapholithae preferentially oviposits on fifth and fourth stage PNC larvae (Nickels et al. 1950), early sampling may have missed possible parasitism.

TABLE 2. Percent Parasitism of First Summer Generation Pecan Nut Casebearer Parasites in Different Locations[a/]

Order, Family and Species	1983		1984		
	ADR	WIL	ADR	SEG	HAM
Order: HYMENOPTERA					
Bethylidae					
Goniozus columbianus Ashmead[b/]		5.3		0.2	
Goniozus fratellus Evans	1.4	5.3		0.2	
Goniozus punctaticeps (Kieffer)				0.2	
Braconidae					
Agathis acrobasidis (Cushman)	1.4				
Apanteles epinotiae Viereck				0.4	
Bracon cushmani (Muesbeck)			1.5	0.4	
Bracon variabilis (Provancher)	5.4	26.3	4.5	1.4	
Macrocentrus instabilis Muesbeck			1.5	2.8	1.7
Orgilus lateralis (Cresson)		5.3			1.7
Phanerotoma tibialis (Haldeman)				0.5	
Chalcididae					
Brachymeria hammari (Crawford)		0.7			
Eulophidae					
Dimmockia sp.		0.7			
Euderus acrobasidis (Crawford)		0.7			
Eulophidae					
Euderus sp. (prob. purpureus Yoshimoto)				0.7	
Tetrasticus sp.[b/]	0.7			0.7	
Eupelmidae					
Eupelmus amicus Girault	6.1			0.5	
Eupelmus limneriae Howard[b/]	0.7			0.2	
Ichneumonidae					
Calliephialtes grapholithae (Cresson)	11.4				
Diadegma sp.				1.7	
Pristomerus austrianus Townes and Townes			4.5	3.2	5.1
Temelucha sp.			1.5	2.1	3.4
Perilampidae					
Perilampus sp.	0.7			0.2	
Pteromalidae					
Zatropis tortricidis Crawford[b/]				3.7	
Order: DIPTERA					
Tachinidae					
unidentified species	0.7		3.0	0.4	1.7

[a/] ADR = Adriance Orchard, WIL = Wilson Orchard, SEG = Riverview Park, Seguin, HAM = Hidden Valley farms, Hamilton.
[b/] New parasite records.

Eupelmus amicus (Girault) is hyperparasitic on Brachymeria hammari, Calliephialtes grapholithae and Bracon variabilis, while Perilampus sp. is on Apanteles epinotiae and Calliephialtes grapholithae (Nickels et al. 1950). The Dimmockia sp. found may also be a hyperparasite, because the known species of Dimmockia are usually hyperparsitic on Bracondae (Thompson 1955).

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LITERATURE CITED

Adair, H. S. 1930. The hickory or pecan shuckworm. Quar. Bull. State Plant Board of Mississippi. 9: 1-3.

Bieberdorf, G. A. 1948. Life cycle studies on the pecan nut casebearer, Acrobasis caryae Grote. Proc. Okla. Acad. Sci., Univ. of Oklahoma, Norman. 1948: 32-35.

Calcote, V. R., and D. E. Hyder. 1979. Occurrence of a bimodal emergence pattern in the hickory shuckworm. J. Econ. Entomol. 72: 701-702.

Gill, J. B. 1930. Notes on parasites of pecan nut casebearer. Nat. Pecan Growers Assoc. Bull. 4: 70-75.

Harris, M. K. 1983. Integrated pest management of pecans. Ann. Rev. Entomol. 28: 291-318.

Heinrichs, E. A. 1968. The pecan nut casebearer, Acrobasis caryae (Lepidoptera: Pyralidae), on mockernut hickory, Carya tomentosa. J. Kans. Entomol. Soc. 41: 236-239.

McWhorter, G. M., J. G. Thomas, M. K. Harris, and H. W. Van Cleave. 1979. Pecan Insects of Texas. Tex. Agric. Ext. Ser. Pub. B-1238. 18pp.

Nickels, C. B. 1931. The insect parasites of the pecan nut casebearer in Texas. Proc. Nat. Pecan Growers Assoc. College Station, Texas. 30: 58-62.

Nickels, C. B., W. C. Pierce, and C. C. Pinkney. 1950. Parasites of the pecan nut casebearer (Acrobasis caryae) in Texas. U.S. Dept. Agric. Tech. Bull. 1011. 21 pp.

Thompson, W. R. 1955. A catalogue of the parasites and predators of insect pests. Sec. 2. Part 3. Commonwealth Inst. of Biol. Control. Belleville. Ont., Canada 191-332.

MIXED PLANTINGS OF UPLAND MALE STERILE AND PIMA RESTORER FOR INCREASED BEE[1/] POLLINATION IN PRODUCTION OF F_1 INTERSPECIFIC HYBRID COTTON SEED[2/]

D. D. Davis[3/], F. L. Carter[4/], and E. L. Jaycox[5/]

ABSTRACT

Honeybees, Apis mellifera L. (Hymenoptera: Apidae) have been reported to have a strong tendency to fly from flower to flower in the same row, rather than across rows. A mixed planting of a Gossypium hirsutum L. male sterile line and a Gossypium barbadense L. fertility-restorer line, when compared to a check treatment composed of the same two strains planted in alternating pairs of rows, produced a significantly higher yield of fuzzy F_1 interspecific hybrid seed per unit area. Although the mixed planting produced 44% more than the check, F_1 hybrid seed yield was only 561 kg ha^{-1} for a 3-year average. Production problems unrelated to pollination caused yields to vary widely from year to year, but there was no interaction between treatments and years. Further advances in seed production technology are needed before interspecific hybrid seed can be produced on a commercial scale.

INTRODUCTION

An interspecific F_1 hybrid cotton has been shown to have improved yield and fiber properties. Interspecific cotton hybrid 'NX-1' was released for commercial increase in 1979. This is an upland (Gossypium hirsutum L.) X Pima (Gossypium. barbadense L.) strain that has exceeded the Acala check variety by 10 percent and has exceptional staple length and fiber strength (Davis et al. 1986), yet all attempts to increase this strain from 1979 through 1982 failed because the yield of F_1 hybrid seed was uneconomically low, never exceeding 1000 kg of seedcotton per ha. Furthermore, the purity of the hybrid was unacceptably low, falling to 55 percent pure in 1982.

An experiment in Arizona in 1982 (Loper and Davis 1985) indicated that honeybees disperse upland pollen more abundantly than Pima pollen. Since a Pima strain is being used as the pollen source for the interspecific hybrid, this is a very serious problem. Given approximately equal sources the disparity in pollen distribution was greater than 4:1. Moreover, it was found that floral stigmas on sterile upland rows grown adjacent to a Pima pollinator were strongly contaminated with upland pollen from a distant source indicating greater range of dispersal of the upland type. Honeybees also show a strong preference for the cytoplasmic male sterile (MS) line (also referred to as an A-line) used as the female parent for hybrid seed production when compared to the fertility restoration (RF) line (also referred to as a R-line) used in the cross (Loper and

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Davis 1985, Moffatt et al. 1975). Jaycox and Davis (unpublished) in a survey of over 100,000 A-line and R-line flowers in 1982 found a 5:1 disparity in visitation frequency favoring the MS line. Carter et al. (1984) showed the number of seed per boll on an upland male sterile was low, indicating deficient movement of G. barbadense pollen to the upland MS flowers. Inadequate pollination results directly in reduced yield due to increased boll shedding and fewer seed per boll. Therefore, when pollen must be transferred to upland MS from a Pima RF line yields will be reduced. Furthermore, there is likely to be contamination by upland pollen, unless the upland MS strain is well isolated from fertile upland cotton.

Vaissiere (Bernard Vassiere, Texas A&M Univ., College Station, TX, personal communication) found that honeybees had a strong tendency to fly from flower to flower on adjacent plants within the same row in the field on the Texas High Plains. Theoretically, this type of bee behavior would be inefficient for seed production because the standard practice is to plant the MS and the RF lines in alternating pairs of rows. The principal objective of this experiment was to determine if the level of F_1 seed production could be increased by growing a mixture of MS and RF plants within all rows.

MATERIALS AND METHODS

Experiments were conducted about 1.5 km west of Las Cruces, NM in 1983, 1984 and 1985 in an area isolated from other fields of upland cotton. The test site soil was classified as a fine-loamy mixed thermic typic torrifluvent. Treatments were: [a] the check, a planting pattern of two, 102 cm rows of Pima RF (R-line) alternating with two rows of upland MS (A-line) (2A x 2R), and [b] the mixed treatment (MIX), seeded as an approximate 9:1 mixture of A-line vs R-line seeds in all rows of the plot. The two parent lines used to comprise the treatments were the parental lines of interspecific hybrid NX-1, released by the New Mexico Agricultural Experiment Station in 1979 (Davis et al. 1986). The particular upland (A-line) used was designated 'c5-1e' and the Pima R-line R-G. Seedling survival for the two parental types in the MIX treatment was variable, so final stands showed a considerable range between plots of the two parental types. In all cases, there was a preponderance of male sterile plants in all rows, and there were no rows that did not contain several plants of the restorer line parent. In 1984 only, plots were thinned so the pollen parent plants averaged one per 2 m of row length. In 1985 plots were not thinned, and the proportion of pollinator was considerably higher due to uneven germination.

Plot size varied from 392 to 710 m^2. In 1983, plots were 12 1-meter rows wide and 30 meters long. In 1984, 24-row plots were used, 29 meters long. The 1985 plots were 12 rows X 32 m. In order to isolate the effects of the separate treatments only the two center rows, or in a few cases two rows near the center when the two center rows did not have acceptable stands, were used for yield determinations.

Planting dates varied widely from season to season. A split planting was used in 1983. The late blooming R-line was planted 1 May, and the early blooming A-line on 11 May. There was an attempt to lengthen the effective bloom period by planting earlier in 1984, so both strains were planted 11 April. This resulted in the appearance of first blooms on the A-line by 11 June. This was 2 weeks earlier than other commercial cotton fields in the immediate area. As a result, the experimental field served as a trap crop for pink bollworm, Pectinophora gossypiella (Saunders), and this insect heavily damaged the 1984 crop. The 1985 planting was delayed until 20 May when the major portion of pink bollworm moths going into hibernation in the fall of 1984 had emerged.

Twenty colonies of honeybees were moved adjacent to the site each year at the onset of significant bloom in the late blooming (R-line)

parent. Honeybee colonies contained two or three supers having eight or more combs of brood. Since honey bees have a large flight range, it was not possible to saturate the area.

Harvest was by means of a 1-row IHC spindle picker about 1 December of each year giving all bolls produced before frost ample time to open. Since the two treatments are dissimilar in the ratio of lint to seed in the seedcotton is was necessary to determine actual seed outturn by ginning 200 g subsamples of the machine picked cotton on a hand gin. From each hand-ginned subsample 200 seed were taken at random and scored as fuzzy or lacking fuzz fibers. From these measurements the true yield of F_1 hybrid seed could be calculated as (Seedcotton wt. X % seed fraction X % fuzzy seed).

The experimental design was a simple factorial of 2 treatments X 3 years X 4 blocks. Analysis was by SAS analysis of variance.

RESULTS AND DISCUSSION

Table 1 shows the results of SAS Analysis of Variance procedures for the three variables measured. Yield results for 1983 had already been reported in detail by Carter et al. (1985). From their data we have extracted the yields for the 2A X 2R and MIX treatments in order to present a combined analysis of three years data. Treatment effects were significant for all three. Treatment effect for yield was almost significant at the 1% level (probability of greater F was 0.0146). Actual seed yields are shown in Table 1. The greatest variability in yield was due to the effect of years, but there was no significant interaction of years X treatments. The mixed planting was higher yielding in all three years of the experiment. Year 1983 showed the only satisfactory yield level. Average for the two treatments was 891 kg ha^{-1} that year, and the mixed treatment produced 1067 kg ha^{-1}, equivalent to 950 lbs/acre. Planting date was about normal for the region that year, and there was unusually favorable weather for maturation in the autumn. No significant insect damage was sustained on the 1983 crop.

Unusual production problems prevented satisfactory yields in 1984 and 1985. A devastating infestation of pink bollworms developed in August and September 1984, resulting in 45% seed damage and when combined with unpickable locules, an estimated 60% yield loss resulted. Insecticide was not used because of potential destruction of honeybee colonies serving as

TABLE 1. Performance of an A-line and R-line Mixture as Compared to an Alternating Row Pattern of 2 rows A-line and 2 rows R-line for 3 Years at Las Cruces, New Mexico.

Source of variability	Seed outturn	Proportion F_1 vs R-line seed	Yield F_1 seed
	---%---	---------%-------	kg ha^{-1}
Treatments			
Mixture	62.8b[a]	58.8b[a]	561a[b]
Check	66.3a	99.4a	409b
Years			
1983	68.4a[a]	83.9a	897a[a]
1984	60.8c	77.3a	207b
1985	64.4b	76.1a	322b

[a] Lower case letters indicate significant differences at the 0.001 level.

[b] Lower case letters indicate a significant difference at the 0.0146 level.

pollinators. Pink bollworms are rarely a severe problem in the Las Cruces area, and damage was already heavy before the extent of the problem was realized. Thus, 1984 should have approached the 600 kg ha^{-1} level in the absence of the pink bollworm. Since large numbers of pink bollworm pupae were expected to overwinter in the field in 1984-85, a late planting was made in 1985 (20 May) to allow for suicidal emergence and dispersion of the overwintering moths, and the problem did not recur. However, late planting was, in itself, severely limiting to 1985 yield potential. A 20 May planting is at least 2 wk too late for G. barbadense to perform well in the Las Cruces area, and it was late August before the R-line came into full bloom. Therefore, F_1 seed production on the A-line was limited to top crop bolls, and 1985 yields were also significantly lower than the 1983 crop.

Seasonal effects upon yield apparently did not bias the treatment effect, as the interaction of years X treatments was not significant. Average production of F_1 hybrid seed was 561 kg ha^{-1} for the mixture, which was 44% higher than the check. We conclude that a mixed planting of male sterile and restorer line can significantly raise production of interspecific hybrid seed as compared to a planting pattern using alternate rows of MS and RF lines.

Figure 1 shows that the reason for the greater seed production in the mixed plantings was not due to pollen availability per se. Throughout the entire season there was a higher ratio of RF line flowers to sterile flowers in the 2A X 2R plots than in the Mix plots. The 2A X 2R yielded only 157 kg ha^{-1} as compared to 262 for MIX, yet the 2A X 2R treatment had an approximate 3:1 ratio of fertile to sterile flowers as compared to the MIX treatment. Late in the season the discrepancy in bloom ratio was very pronounced. In 1984 the number of bees averaged 2 or more per 100 blooms until the very end of the pollination season and were well dispersed throughout the field. This suggests that the superior yield of the MIX indicates that the available blooms were more effectively arranged to take advantage of the propensity of the bees to work along the row.

Yield of F_1 seed per row within the MIX was only 70% as great as the A-line rows of the 2A x 2R treatment. This was due primarily because of the competition of the R-line plants in the row. As estimated by percentage of fuzzy seed the A-line rows of the 2A x 2R treatment derived 99+% of their yield from the A-line plants (Table 1 variable 3), the yield from the MIX rows was composed of only 59% of seed from the A-line plants, as 41% (determined by the percentage of slick seeds) came from intermixed R-line plants. The negative intra-row competition effect was more than compensated in the MIX treatment because every row produced F_1 hybrid seed. In the 2A X 2R treatment only half of the rows were female A-line rows which produced F_1 seed while the other half produced R-line seed exclusively.

Because F_1 hybrid seed and Pima R-line seed were harvested together in bulk in the MIX treatment, the two seed types had to be separated before the F_1 hybrid could be used for planting seed. The two types are radically different in seed coat vestiture, and mechanical separation was readily accomplished. The G. barbadense R-line seed were mostly free of linter fibers, while seed grown on the A-line were densely fuzzy. Two passes over a shaker type seed cleaner fitted with two slotted screens was sufficient to give a fuzzy fraction of F_1 seed that was about 95% pure.

Despite the increase in yield due to mixed planting, the yield levels obtained in the production of hybrid seed were only marginal. Methods will have to be devised to give another 25 to 50% increase in F_1 hybrid seed yield to put interspecific hybrid production on a secure basis. Methods of changing honeybee behavior by genetically modifying the floral structure of the R-line parent are being explored as a way to augment bee pollination. Honey bees seem to have a particular preference for G. hirsutum flowers, which are white and contain cream pollen (Loper and

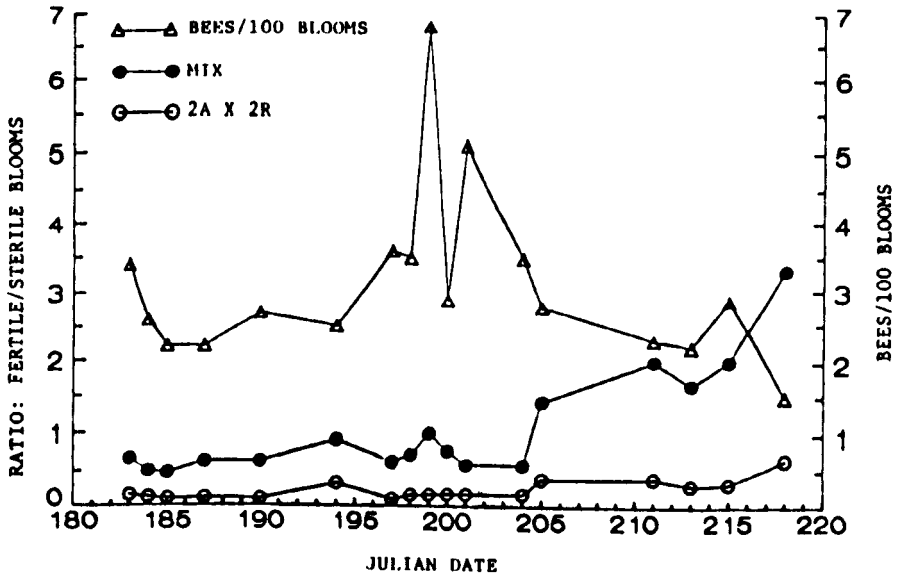

FIG. 1. Ratio of fertile to sterile blooms in treatment plots as compared to total bee populations available for cross-pollination during the critical flowering period in 1984.

Davis 1985, Loper 1987). Similar effects due to floral color have been noted in the Brassicaceae (Stanton et al. 1986). Breeding efforts to transfer white flower phenotype to G. barbadense R-lines are well advanced and should produce lines suitable for testing by 1988.

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LITERATURE CITED

Carter, F. L., D. D. Davis, and E. R. Jaycox. 1984. Effect of planting pattern on cross pollination in Hybrid NX-1 seed production. Proc. Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN. pp. 103-132.

Davis, D. D., J. R. Barrow, C. Roberts, N. R. Malm, and C. Barnes. 1986. Hybrid Cotton in New Mexico: A chronology of development, 1967 to 1984. N. M. Agric. Exp. Stn. Bull. 724.

Loper, G. M. 1987. Effect of distance on honeybee (Apis mellifera, L.) dispersal of Pima (Gossypium barbadense) and upland (G. hirsutum) cotton pollen. (Abstract) Proc. Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN. (in press).

Loper, G. M., and D. D. Davis. 1985. Disparity of cotton pollen dispersal by honeybees visiting upland and Pima pollen parents. Crop Sci. 25: 585-88.

Moffett, J. O., L. S. Stith, C. C. Burkhardt, and C. W. Shysman. 1975. Influence of cotton genotypes on floral visits of honeybees. Crop Sci. 15: 782-784.

Stanton, M. L., A. A. Snow, and S. N. Handel. 1986. Floral evolution: attractiveness to pollinators increases male fitness. Science 232: 1625-1627.

SCARAB ACTIVITY AND PREDATION AS MORTALITY FACTORS OF THE BUFFALO FLY, HAEMATOBIA IRRITANS EXIGUA,[1] IN CENTRAL QUEENSLAND

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ABSTRACT

Differential screening techniques and pitfall trap collections of dung fauna were used to evaluate scarab activity and predation as mortality factors of the buffalo fly, Haematobia irritans exigua (de Meijere), at a site in central Queensland, Australia. Six species of introduced scarabs have been established at this location. These tests indicated that the activity of these scarabs and predation by other fauna periodically caused significant reductions in the numbers of buffalo flies emerging from cattle dung pats. Scarab activity was considered to be the most important mortality factor since it was associated with low buffalo fly emergence more frequently than was predation.

INTRODUCTION

The presence of other dung fauna has been shown to reduce populations of dung-breeding flies in pasture ecosystems in several studies (Thomas et al. 1983, Macqueen and Beirne 1975, Wingo et al. 1974, Thomas and Morgan 1972, Blume et al. 1970, and Valiela 1969). In central Missouri, Thomas and Morgan (1972) used differential screening techniques to exclude insects of various sizes from dung pats. They found that mortality of the horn fly, Haematobia irritans (L.), in exposed dung pats was greater than 90%, and predation by coleopterous insects in the families Staphylinidae, Hydrophilidae, and Histeridae caused the greatest mortality. These authors concluded that dung inhabiting scarabs did not cause significant mortality in the horn fly. Similar results were reported in studies on the mortality factors of the immature stages of the face fly, Musca autumnalis (DeGeer), in central Missouri (Thomas et al. 1983). Wingo et al. (1974) found that the dung inhabiting scarab complex in central Missouri consisted mainly of Aphodius spp., Ataenius sp. and small native Onthophagus spp., which although periodically abundant, did not cause significant disruption of cattle dung pats and therefore, did not cause any competitive mortality on dung-breeding flies.

Roth et al. (1983) used differential screening techniques in a study on mortality factors of the horn fly in central Texas; they found levels of predation similar to those reported in Missouri, and scarab competition was a significant mortality factor of the horn fly. The scarab complex included several large native scarab species and the introduced African scarab Onthophagus gazella (F.). Definite

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relationships were demonstrated between horn fly mortality and populations of scarabs and predators. There was a significant negative correlation between the numbers of Philonthus spp. (Staphylinidae) and the number of horn flies emerging from dung pats from which scarabs had been excluded.

Since 1965 the Commonwealth Scientific and Industrial Research Organization has had an active program of importation and release of exotic dung-removing scarabs in Australia (Bornemissza 1976). The purpose of this program was to improve pasture by accelerating dung removal and to reduce populations of the buffalo fly, Haematobia irritans exigua (de Meijere) and the bush fly, Musca vetustissima Walker (Waterhouse 1974, Bornemissza 1976). Macqueen (unpublished data) found that six exotic scarabs were established at a field site near Rockhampton, Queensland, and emergence of buffalo flies from dung pats was frequently reduced by dung fauna.

The present study was conducted to determine the relative importance of scarab activity and predation as mortality factors of the buffalo fly at the Rockhampton field site.

MATERIALS AND METHODS

The land, cattle, and management practices at the Craighoyle field station have been described by Macqueen et al. (1986). The field study was conducted with naturally deposited cow pats on which buffalo flies were allowed to oviposit. This was accomplished by observing cattle for defecation, waiting for the buffalo flies to complete oviposition (ca. 3-4 min), and then covering the dung pat with one of three types of cages. The first type of cage was a simple cattle excluder fabricated with heavy gauge wire designed to prevent damage to the cow pat by the movement of cattle in the pasture. This cage allowed all dung fauna access to the dung. Cow pats covered with these cages comprised the exposed treatment. The second type of cage had 4.2 mm mesh wire attached to the inside of the cattle excluder frame. This mesh effectively excluded the introduced dung beetles, but allowed entrance of most potential predators. The third treatment consisted of a cattle excluder fitted with a 0.42 mm mesh nylon screen to prevent entrance of all dung fauna. The dung pat treatments were left in the pasture for five days, and then the cages were removed. The dung pats and a divot of the surrounding soil were placed in containers fitted with cone traps to collect emerging buffalo flies and held in an insectary under ambient conditions until fly emergence was completed.

Six dung-baited, pitfall traps similar to those used by Roth et al. (1983) were placed in the pasture on the day each field test was initiated. These traps were used to monitor populations of scarabs and insect predators during the five days each test was in the pasture. Three of the traps were covered with scarab excluder cages to determine if these cages prevented predators from entering the traps.

Each field test consisted of five replications of each of the exposed scarab excluder and fauna excluder treatments. A total of seven field tests were conducted at roughly monthly intervals from September 1984 to April 1985 (the spring and summer season in Australia).

RESULTS AND DISCUSSION

Based upon comparisons of test means with unpaired t tests, buffalo fly emergence was significantly lower ($t < 0.05$) from exposed dung pats than from those which had all fauna excluded in all but one of the tests (Table 1). Buffalo fly emergence from the scarab excluder treatments was significantly lower than from the fauna excluder control in five of the seven tests. Mean buffalo fly emergence from the exposed dung pats

TABLE 1. Influence of Dung Fauna on Buffalo Fly Survival.

Test no.	Date	Mean no. buffalo flies/cow pat[a/] Exposed	Scarabs excluded	All fauna excluded
1	18 Sept. 1984	6.8a	9.0b	160.2c
2	5 Nov. 1984	4.8a	4.8a	34.4a
3	4 Dec. 1984	0.0a	8.8a	84.8b
4	14 Jan. 1985	36.4a	43.8a	167.0b
5	25 Feb. 1985	54.8a	230.8b	400.4b
6	25 Mar. 1985	46.8a	98.8a	284.0b
7	25 Apr. 1985	7.6a	69.8b	259.2c
Grand mean[b/]		22.4a	70.8b	198.5c

[a/]Treatment means in each test followed by the same letter are not significantly different ($t < 0.05$, unpaired t-test).

[b/]Treatment data pooled for all seven tests, means followed by the same letter are not significantly different ($t < 0.05$, unpaired t-test).

was significantly lower than the emergence from the scarab excluder pats in three of seven tests. There was no buffalo fly emergence from the exposed treatment in the 4 December 1984 test.

When the data from all seven tests were pooled and treatment means compared by unpaired t tests (Table 1), the grand mean for the exposed treatments was 22.4 buffalo flies/dung pat. This was significantly lower ($t < 0.05$) than both the grand mean for the scarab excluder and fauna excluder treatments. The grand mean for the scarab excluder treatments (70.8 buffalo flies/dung pat) was significantly lower than the grand mean of the fauna excluder treatments (198.5 buffalo flies/dung pat). The exposed and the scarab excluder treatments averaged 89.7 ± 8.0% and 72.2 ± 15.5% mortality, respectively, compared to the fauna excluder control. We assumed there was no mortality due to dung fauna in the fauna excluder treatments.

Data on the relationship between the scarab catches in the pitfall traps and the mean number of emergent buffalo flies per dung pat from exposed treatments are shown in Fig. 1. We collected five of the six introduced dung beetle species reported to be established at the Craighoyle location. Onthophagus sagittarius (F.) was not collected, and Onitis viridulus Boheman occurred in very low numbers. The bulk of the dung beetle complex was comprised of the four species Onthophagus gazella (F.), Sisyphus spinipes Thunberg, Euoniticellus intermedius (Reiche), and Liatongus militaris (Castelnau). Linear regression analysis of the relationship between the mean number of scarabs per trap and the adjusted percent mortality (mean numbers of buffalo flies from exposed treatment - mean number of buffalo flies from fauna excluder control -1 X 100) indicated there was a significant positive correlation coefficient of 0.762 ($P=0.05$). The predicted 100% mortality intercept occurred at a population of 523 scarabs per trap, and the predicted mortality with no scarabs present was 80.6%. The estimate of the 100% mortality intercept is probably high since it was influenced by a mean pitfall trap collection of 800+ scarabs per trap in the third (4 December 1984) test where 100% mortality did occur. In the seventh test (25 April 1985) there was 97% mortality with a mean pitfall trap collection of 327 scarabs per trap. Examination of the mean number of buffalo flies/dung pat versus the pitfall trap catches of scarabs and predators may give a more practical indication of the number of fauna needed to suppress the buffalo fly. When the number of scarabs caught

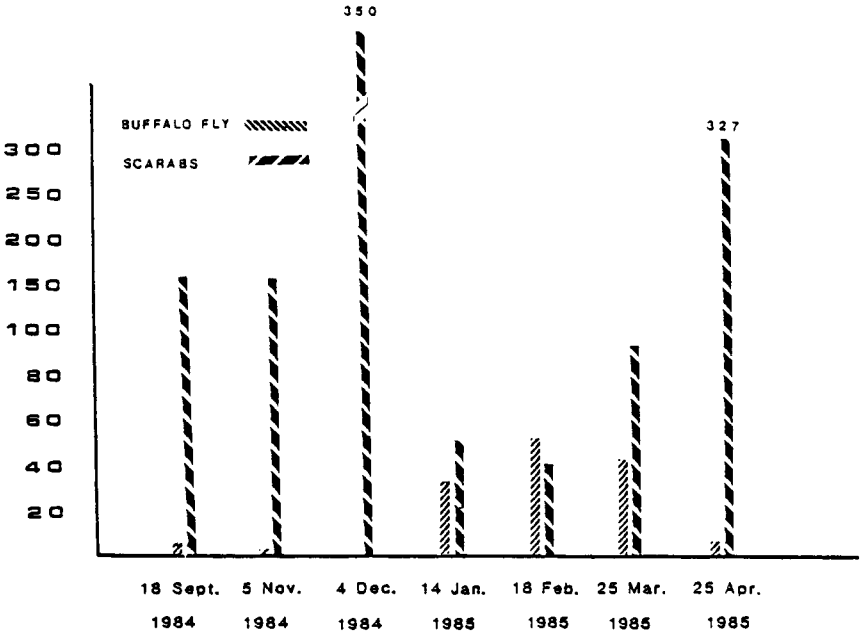

FIG. 1. Relationship between the mean number of buffalo flies emerging from cattle dung pats exposed to all dung fauna and the mean number of scarabs collected from pitfall traps baited with cattle dung.

was between 170 and 850/trap, less than ten buffalo flies per dung pat emerged. This occurred in four of the seven tests. When catches of scarabs were below 150/trap, buffalo fly emergence ranged from 36.4 to 54.6 per dung pat.

Predaceous arthropods collected in the pitfall traps included seven species of staphylinidae and one species of Histeridae. The Staphylinidae included three Philonthus and two Aleochara species, one Xantholinae species, and some small Aleocharinae species of undetermined genera. Comparisons of catches from pitfall traps covered by cattle excluders with traps covered by scarab excluders indicated that the scarab excluders did not have a statistically significant (P=0.05) effect on catches of these predators (Roth et al. unpublished data).

The relationship between predator numbers from pitfall traps and mean number of buffalo flies per dung pat from pats protected by scarab excluders is shown in Fig. 2. Linear regression analysis of the mean number of predators per pitfall trap and adjusted percent mortality in the scarab excluder treatments resulted in a significant (P=0.05) positive correlation coefficient of 0.790. The predicted 100% mortality intercept occurred at 57.7 predators per trap and the predicted mortality with no predators/trap was 52%.

In this case the predicted number of predators needed to cause 100% mortality may be a low estimate. In the test trap, catches of 51.3 and 60.8 predators per trap coincided with 86% and 89.7% mortality, respectively. When pitfall trap catches of predators were above 50/trap, less than ten buffalo flies per dung pat emerged from the scarab excluder treatments; but when predator numbers were below 25/trap buffalo fly emergence ranged from 39 - 250 flies per dung pat.

The results of this study indicate that scarab activity was a more important mortality factor of the buffalo fly than predation at the

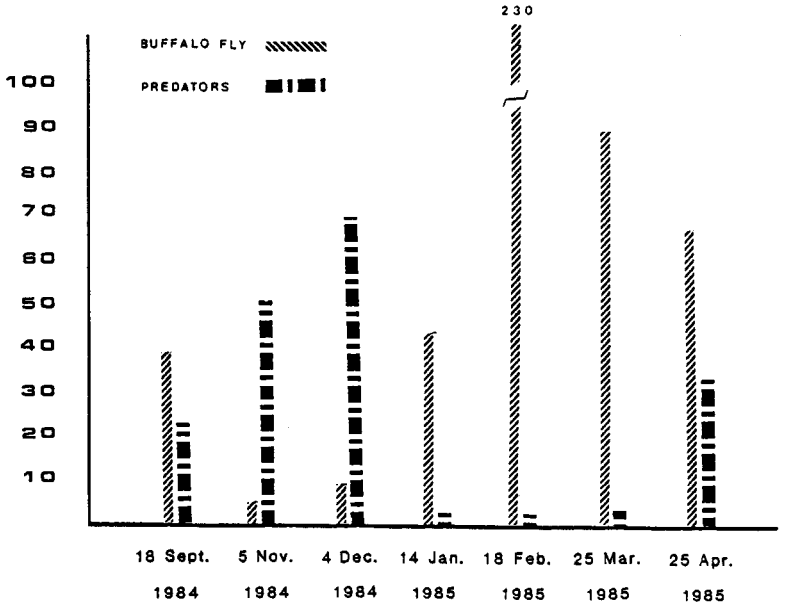

FIG. 2. Relationship between the mean number of buffalo flies emerging from cattle dung pats from which scarabs were excluded and the mean number of coleopterous predators collected in pitfall traps baited with cattle dung.

Craighoyle field station. Lower numbers of predators were needed to control buffalo flies as compared to the number of scarabs needed; but predators reached controlling numbers in only two of the tests, while scarabs reached controlling numbers in four of the tests. Predators may be limited by the density dependent relationship with their prey. As predators decrease the number of available prey, the ability of individual predators to locate their prey may also decrease. This would probably result in the predator abandoning a dung pat when the prey density in that pat became lower than the predators searching threshold. Thus, it may be difficult for predators to completely eliminate all the prey in a dung pat. This would especially be the case if most of the predator species prey on the same life stage of the prey. Roth (1982) found that a combination of predator species which attack different life stages of the horn fly were more effective than equal numbers of either predator species alone.

Scarab activity has the potential to completely eliminate emergence of Haematobia species from dung pats through the complete burial or desiccation of the dung pat, but this requires a very high scarab population. This occurred in only one of the tests in this study when scarab numbers averaged 850/trap. We found that scarab activity at the Craighoyle location not only reduced buffalo fly survival but also reduced the suitability of dung pats as breeding sites for almost all other dung fauna including insect predators and parasitoids (Roth et al. unpublished data). Therefore, it is possible that the establishment of exotic scarabs at the Craighoyle site has reduced the importance of predators and parasitoids as mortality factors of the buffalo fly.

The fact that scarab numbers need to be high in order to control the buffalo fly has several implications as to the value of importation of exotic tropical and subtropical scarabs into the United States. The

impact of such scarab species on horn fly populations in the warm temperate regions of the United States is likely to vary with climatic cycles. During years with mild winters and high summer rainfall dung beetle populations could reach levels high enough to have a suppressing effect on horn fly numbers, but such high dung beetle populations are not likely to be maintained in years when winters are more severe or when summer droughts occur. Under the latter conditions low to moderate levels of scarab activity could reduce the numbers of other beneficial dung fauna while having little or no effect on horn fly numbers.

ACKNOWLEDGEMENT

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LITERATURE CITED

Blume, R. R., S. E. Kunz, B. F. Hogan, and J. J. Matter. 1970. Biological and ecological investigations of horn flies in central Texas: Influence of other insects in cattle manure. J. Econ. Entomol. 63: 1121-1123.

Bornemissza, G. F. 1976. The Australian dung beetle project 1965-1975. Aust. Meat Res. Comm. Rev. 30: 1-30.

Macqueen, A., and B. P. Beirne. 1975. Influence of other insects on production of the horn fly, Haematobia irritans (Diptera: Muscidae) from cattle dung in south-central British Columbia. Can. Entomol. 107: 1255-1264.

Macqueen, A., M. M. H. Wallace, and B. M. Doube. 1986. Seasonal changes in favorability of cattle dung in central Queensland for three species of dung-breeding insects. J. Aust. Entomol. Soc. 25: 23-29.

Roth, J. P. 1982. Predation of the horn fly, Haematobia irritans (L.), by three Philonthus species. Southwest. Entomol. 7: 26-30.

Roth, J. P., G. T. Fincher, and J. W. Summerlin. 1983. Competition and predation as mortality factors of the horn fly, Haematobia irritans (L.) (Diptera: Muscidae), in a central Texas pasture habitat. Environ. Entomol. 12: 106-109.

Thomas, G. D., and C. E. Morgan. 1972. Field mortality studies on the immature stages of the horn fly in Missouri. Environ. Entomol. 1: 453-368.

Thomas, G. D., R. D. Hall, C. W. Wingo, D. B. Smith, and C. E. Morgan. 1983. Field mortality of the face fly (Diptera: Muscidae) in Missouri. Environ. Entomol. 12: 823-830.

Valiela, I. 1969. An experimental study of the mortality factors of larval Musca autumnalis DeGeer. Ecol. Monogr. 39: 199-222.

Waterhouse, D. F. 1974. The biological control of dung. Sci. Am. 230: 101-108.

Wingo, C. W., G. D. Thomas, G. N. Clark, and C. E. Morgan. 1974. Succession and abundance of insects in pasture manure: Relationship to face fly survival. Ann. Entomol. Soc. Am. 67: 386-390.

DENSITY AND DISTRIBUTION OF THREE SPECIES OF LICE ON CALVES IN CENTRAL TEXAS

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ABSTRACT

The development and distribution of populations of Haematopinus eurysternus (Nitzsch), Linognathus vituli (L.), and Bovicola bovis (L.) were determined on six young calves held under natural environmental conditions in a barn in central Texas. Each predominantly-white Holstein bull calf (2.5 months old) was infested with 150 female H. eurysternus and 175 female L. vituli on 2 February 1987 and with 100 female B. bovis on 24 March 1987. Observations of lice at 122 sites on each animal for 16 consecutive weeks revealed that the largest numbers of H. eurysternus were found between the 4th and 7th wk postinfestation, while the largest numbers of L. vituli were found between the 3rd and 7th wk. Following infestation, B. bovis increased on all calves for 6 wk and then declined rapidly. During the study, 94% of H. eurysternus were found on the ears, base of the horns, crest of the neck, and dewlap; 79% of L. vituli were found on the shoulders, dewlap, and side of the neck; and 91% of B. bovis were found on the crest of the neck, the side of the neck, and the shoulders.

INTRODUCTION

Populations of lice on cattle fluctuate seasonally with moderate to heavy populations occurring in winter and spring. Usually few, if any, lice are apparent on cattle during summer. Both biting and sucking lice are obligate, host-specific parasites unable to live away from the host for more than a few hours or days; therefore, cattle most commonly become infested with lice by direct body contact with other louse infested animals. Mild to severe loss of blood can result from feeding by sucking lice, and both biting and sucking lice may cause skin irritation that induces self-damaging grooming activity (rubbing, licking, kicking, etc.) by the host. The resulting skin abrasions may become secondarily infected, and depilation, if sufficiently great, can compromise the host's ability to regulate heat exchange with attendant detrimental effects on productivity. Significant weight loss in heifers infested with heavy populations of Bovicola bovis (L.), Linognathus vituli (L.), and Solenopotes capillatus Enderlein was reported by Gibney et al. (1985).

Kennedy and Kralka (1986) checked six sites per animal and found B. bovis infesting 36.3 and L. vituli 37.2 % of all cattle brought to a veterinary diagnostic laboratory in central Alberta, Canada, between November 1984 and July 1985. These authors also found that calves were more frequently infested with lice than were cattle over one year of age. Mock (1974) noted that extremely large louse populations of B.

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bovis and L. vituli are sometimes observed on young dairy calves less than 2 wk of age. Since the life cycle of both louse species is about one month (Matthysse 1946), and dairy calves are removed from their dams within three days, the source of the infestation most likely was the dam.

Because lice are small and live deep within the haircoat, ranchers and dairymen sometimes do not realize that these pests are present on their cattle until the animals look unthrifty or lose hair. If, however, there are preferred body sites that could be easily checked for the presence of lice during routine handling of cattle, infestations could be more readily detected and accompanying problems could be diminished or prevented. This study was conducted to obtain density and distribution estimates over time for Haematopinus eurysternus (Nitzsch), L. vituli, and B. bovis. Such information could be useful in the design of experiments to investigate the preferred site concept.

MATERIALS AND METHODS

Six predominantly white Holstein bull calves ca. 2.5 months old were obtained and placed in individual pens (1.8 X 3.4 m) within a barn having no environmental controls. Manure was removed and the concrete floors of the pens were washed daily. Calves were fed a ration consisting of alfalfa hay, coastal bermudagrass hay, and a 14% protein creep feed, and adequate water was provided. Temperature and relative humidity in the barn were recorded with a hygrothermograph. All calves were weighed weekly.

Lice used to infest the calves were collected individually from carrier cattle and transferred to the recipient calf along the dorsal mid line within 5-30 minutes. On 2 February 1987, each calf was infested with 150 female H. eurysternus and 175 female L. vituli. On 24 March 1987, each calf received 100 female B. bovis . Weekly louse counts were made at 4-6 randomly selected sites within 22 arbitrarily designated body areas (total = 122 sites) on each animal for 16 consecutive weeks (Fig. 1a). At each site, the hair was parted and the numbers of individuals of each louse species were counted in an area about 0.5 cm X 5 cm (2.5 sq cm). Comparable body areas were sampled on each side of the calf; however, areas on the crest of the neck and the tail were not paired.

Weekly mean louse counts were calculated for each body location. A standard error (SE) for each location was calculated (SAS Institute Inc., 1982) for use in weekly comparisons of mean differences within a given sampling area.

RESULTS AND DISCUSSION

The distribution of lice found in each body area over the total time period is shown in Table 1. Largest numbers of H. eurysternus were found between the 4th and 7th wk postinfestation, while largest numbers of L. vituli were found between the 3rd and 7th wk. Prior to artificial infestation with B. bovis (wk 7), low numbers (2-5) of this species were found on one calf (wk 1 and 2), and less than 35 B. bovis/calf were found on four of the six calves (wk 5 and 6). The source of this naturally occurring infestation is unknown. Following artificial infestation, populations of B. bovis increased on all animals for 6 wk and then declined rapidly (Fig. 2).

Distribution of all three species of lice was not uniform (Fig. 1). During the course of the study, 94% of H. eurysternus were found on the ears, poll, crest of the neck, and dewlap (Fig. 1b). All mobile

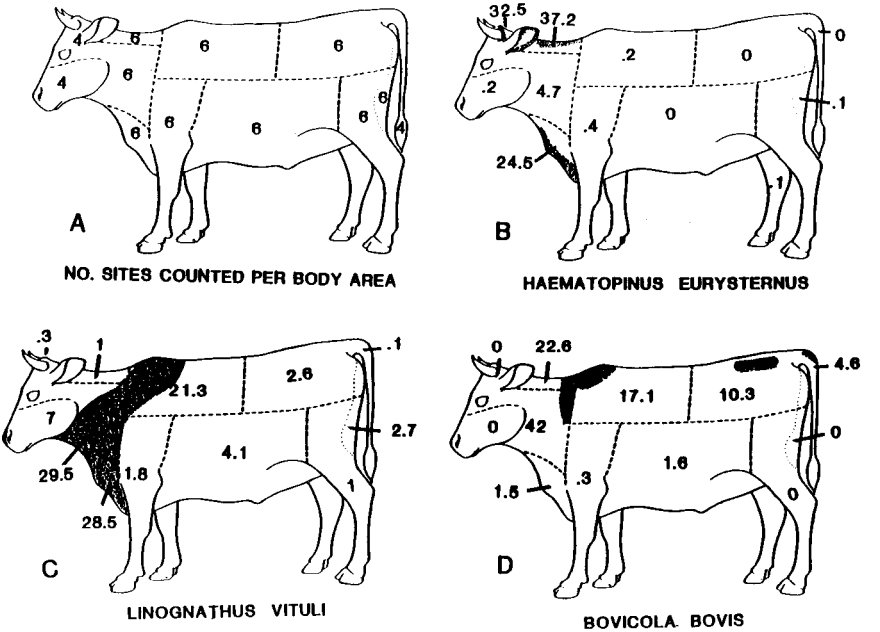

FIG. 1. Distribution of lice on cattle following artificial infestation; A - number of sites counted/wk/body area, B - % of H. eurysternus found per body area; C - % of L. vituli found per body area; D - % B. bovis found per body area.

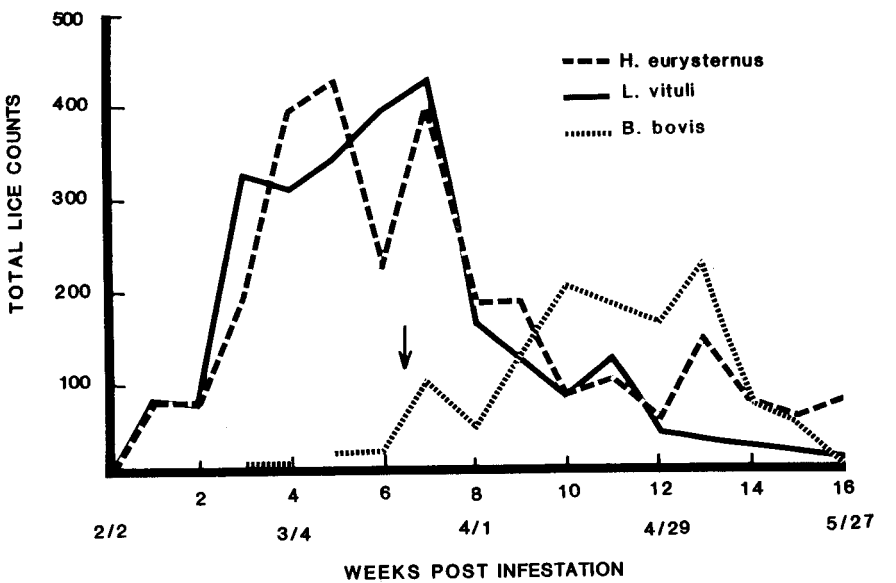

FIG 2. Total lice counts on 6 calves for 16 weeks. Arrow indicates date of artificial infestation with B. bovis.

Table 1. Mean Louse Counts for Each Body Area on Six Holstein Bull Calves.

Body Location	Weeks post infestation																SE
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
								Haematopinus eurysternus									
Jaws and nose	0	<1	1	7	0	<1	<1	0	0	<1	0	0	0	0	<1	0	1.6
Ears to poll	12	3	4	5	10	7	13	5	7	4	12	8	20	12	10	12	2.5
Crest of neck	<1	8	24	34	36	15	22	12	11	5	1	<1	1	<1	<1	1	0.3
Side of neck	0	<1	1	<1	2	2	7	5	3	1	<1	1	<1	0	0	0	1.3
Dewlap	0	<1	3	20	22	12	25	9	11	4	3	1	<1	<1	<1	1	5.7
Shoulder to cntr back	0	<1	0	<1	<1	0	0	0	<1	0	<1	0	0	0	0	0	0.1
Front leg	0	<1	0	0	<1	<1	<1	0	0	0	0	0	0	0	0	0	0.1
Side	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<1	0.1
Center of back to tail	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Hind Leg	0	0	0	0	0	<1	<1	0	<1	0	0	0	0	0	0	0	0.1
Scrotal area	0	0	0	0	0	0	<1	0	0	0	0	0	<1	0	0	0	0.1
Tail	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Weekly mean/calf	13	13	33	67	70	37	67	31	32	14	17	11	22	12	12	14	
								Linognathus vituli									
Jaws and nose	<1	<1	0	6	3	1	9	3	2	<1	3	1	<1	<1	<1	<1	0.7
Ears to poll	<1	0	0	0	<1	<1	0	0	0	0	0	0	0	0	0	0	0.2
Crest of neck	<1	0	0	0	<1	1	<1	0	0	<1	<1	0	<1	0	<1	<1	0.4
Side of neck	7	3	19	12	18	20	14	6	6	3	7	3	2	2	2	1	3.6
Dewlap	4	3	13	19	14	25	24	7	4	3	3	2	2	1	<1	<1	5.9
Shoulder to cntr back	2	6	21	14	14	10	10	5	3	2	2	<1	<1	1	<1	0	2.8
Front leg	0	0	0	0	<1	<1	2	1	<1	2	<1	<1	<1	<1	0	0	0.4
Side	0	<1	0	<1	3	2	5	3	3	1	<1	<1	<1	<1	0	0	0.6
Center of back to tail	0	0	<1	0	2	2	3	0	<1	1	1	0	0	<1	0	0	0.5
Hind leg	0	0	0	0	<1	0	<1	<1	<1	<1	1	0	<1	0	0	0	0.3
Scrotal area	0	0	0	<1	<1	3	4	2	2	<1	1	<1	<1	<1	0	0	0.8
Tail	0	0	0	0	<1	0	0	0	0	0	<1	0	0	0	0	0	0.1
Weekly mean/calf	14	13	54	52	56	63	71	28	20	13	20	7	6	5	3	2	
								Bovicola bovis a/									
Jaw and nose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Ears and poll	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Crest of neck	0	0	0	0	0	<1	1	0	<1	4	5	0	9	4	5	0	2.5
Side of neck	0	0	0	0	2	<1	11	6	14	2	2	3	2	2	4	0	8.3
Dewlap	0	0	0	0	<1	<1	1	<1	0	0	0	0	0	0	0	0	0.3
Shoulder to cntr back	<1	<1	0	0	3	1	3	1	7	1	1	<1	<1	<1	0	0	1.1
Front leg	0	0	0	0	0	<1	0	<1	0	0	0	0	0	0	0	0	0.1
Side	0	0	0	0	<1	0	<1	<1	<1	<1	0	<1	<1	0	0	0	0.2
Center of back to tail	0	0	0	0	4	<1	<1	<1	<1	<1	4	0	<1	<1	0	0	1.1
Hind leg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Scrotal area	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Tail	0	0	0	0	1	<1	<1	0	<1	1	<1	0	<1	<1	0	0	0.3
Weekly mean/calf	<1	1	0	0	11	3	17	8	23	9	12	4	13	2	9	0	

a/Animals artificially infested on week 7

stages of this louse were found in clusters in folds of skin along the crest of the neck, along the caudoventral aspect of the dewlap, around the edge of the ears, or the base of the horns. Largest numbers of H. eurysternus eggs were found on long hairs in the inner upper edge of the ears or on hairs around the base of the horns. L. vituli (79%) were found primarily on the shoulders, dewlap, and side of the neck (Fig. 1c). Members of this species were usually found as individuals distributed throughout those areas that extend from the top of the shoulders along the side of the neck and the dewlap. B. bovis (91%) was found predominantly on the crest of the neck, the side of the neck, and the shoulders (Fig. 1d). B. bovis tended to cluster but remained in smaller groups than H. eurysternus. The greatest concentrations of B. bovis were found along the side of the neck just anterior to the shoulder blade. Toward the end of the study (wk 11) increased numbers of B. bovis were observed posterior to the hip bone and at the tail head.

Calves gained an average of 0.68 kg/day during the study. Other than increased rubbing, particularly the neck, from the 4th to 8th wk of the study, there was no other observable adverse reaction to the louse infestation. Many H. eurysternus were removed by rubbing, leaving reddened abraded skin. This was particularly evident where clusters of lice had been observed.

Mean high and low monthly temperatures (°C) were 17.8 and 12.5; 19.9 and 12.0; 25.5 and 14.8; and 27.7 and 20.7 for the months of February, March, April, and May, respectively. Relative humidity varied from 30 to 100%. As temperatures and day length increased, the calves began shedding; and by the end of the study, most had completely shed their winter coats.

The cause of the population decline among all three species of lice was not determined. A fungus similar in appearance to a pathogenic fungus reported (Meola and DeVaney 1976) on three species of chicken lice was observed on both sucking and biting lice in this study. Increasing temperature, shedding of the winter hair coat, grooming activity, host immunity, or fungal infection could have individually or collectively caused the population decline.

These results agree with those of Craufurd-Benson (1941a,b) in Great Britain; Matthysse (1946), in New York; Chalmers and Charleston (1980), in New Zealand; and Watson (1984) in Wyoming in that distribution of both biting and sucking lice on cattle is not random but involves concentrations of lice in particular areas. These areas of concentration appear to differ according to the species of louse involved. More critical studies are needed to evaluate the "preferred site" concept. If this concept is valid, then studies to define the limits of such sites are needed. Studies are also needed to determine whether differences in the density and distribution patterns are related to age, genetics, nutrition, hair coat, environmental conditions, or other factors.

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LITERATURE CITED

Chalmers, K., and W. A. G. Charleston. 1980. Cattle lice in New Zealand: Observations on the biology and ecology of Damalinia bovis and Linognathus vituli. N.Z. Vet. J. 28: 214-216.

Craufurd-Benson, H. J. 1941a. The cattle lice of Great Britain Part I. Biology, with special reference to Haematopinus eurysternus. J. Parasitol. 33: 331-342.

Craufurd-Benson, H. J. 1941b. The cattle lice of Great Britain. Part II. Lice populations. J. Parasitol. 33: 343-358.

Gibney, V. J., J. B. Campbell, D. J. Boxler, D. C. Clanton, and G. H. Deutscher. 1985. Effects of various infestation levels of cattle lice (Mallophaga: Trichodectidae and Anoplura: Haematopinidae) on feed efficiency and weight gains of beef heifers. J. Econ. Entomol. 78: 1304-1307.

Kennedy, M. J., and R. A. Kralka. 1986. A survey of ectoparasites on cattle in Central Alberta, November 1984 - July 1985. Can. Vet. J. 27: 459-460.

Matthysse, J. G. 1946. Cattle lice: their biology and control. Cornell Univ. Agri. Expt. Sta. Bull. 832. Ithaca, NY.

Meola, S., and J. DeVaney. 1976. Parasitism of Mallophaga by Trenomyces histophtorus. J. Invert. Pathol. 28: 195-201.

Mock, D. E. 1974. The cattle biting louse, Bovicola bovis (Linn.) I. In vitro culturing seasonal populations, and role of the male II. Immune response of cattle. M.S. Thesis. Cornell Univ., Ithaca, NY.

Sas Institute Inc. SAS User's Guide: Statistics, 1982 Edition. Cary, NC. Sas Institute Inc, 1982.

Watson, D. W. 1984. The dynamics and distribution of cattle lice populations on naturally infested steers. M.S. Thesis. Univ. Wyoming, Laramie.

BLOW FLY[1] BAIT PREFERENCES AND SEASONAL ACTIVITY IN BEXAR COUNTY, TEXAS[2]

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ABSTRACT

Bait preferences and seasonal activity of blow flies were assessed in Bexar County, Texas from 14 September 1986 through 18 August 1987. Flies were hand netted biweekly from bait stations set 20-m apart containing fresh liver and rotting fruit. A total of 602 blow flies was collected from both baits during the 1-yr study period. Phaenicia cuprina (Wiedemann) comprised 95% of the total collected flies. Three calliphorid species were taken from fruit, whereas six species were collected from liver. There were no obvious differences in bait attractiveness; however, 3 species were collected only from liver bait indicating a possible preference. A breakdown of species and numbers collected per bait, as well as seasonal fly activity patterns at both baits, are presented and discussed.

INTRODUCTION

Many blow fly species cause losses in the animal industry worldwide through various forms of myiasis and mechanical disease transmission. Other species, while not significant in their disease transmitting capacity, are considerable nuisance pests. On the beneficial side, developing blow fly maggots, occurring by the thousands in a carcass, can rapidly dispose of a dead animal thereby rendering a valuable service to the environment. In addition, knowledge of blow fly species present in an area and their succession patterns on carrion can be a useful tool in forensic entomology (Meek et al. 1983, Keh 1985).

Numerous surveys and studies concerning the Calliphoridae have been conducted using meats as attractants (Lindquist 1954, Roberts 1933, Cushing and Parish 1938); whole mammals are often used in forensic studies (Payne 1965, Deonier 1940, Fuller 1934, Bornemissza 1957, Goddard and Lago 1985). However, little information is known about relative attractiveness of different baits or baits of varying ages (see discussion in Norris 1965). This study was initiated to investigate attractiveness patterns between two baits: fresh beef liver and a rotting banana-apple mixture.

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[1]Diptera: Calliphoridae

[2]The opinions and assertions contained herein are those of the author and are not to be construed as views, either official or unofficial, of the U.S. Air Force or the Department of Defense.

MATERIALS AND METHODS

Description of the Study Area. Blow flies were collected in this study from 14 September 1986 through 18 August 1987 in the housing area at Brooks Air Force Base (AFB), TX (suburban San Antonio). Brooks AFB comprises about 1300 acres and is bordered on the north by a mixed urban environment along Military Drive. The east and south sides of the base are bordered by pasture land and major highways. Between the west side of the base and the nearby San Antonio River is a mixed commercial/industrial/residential area. Because the base is located on the edge of the Gulf Coastal Plains, a modified subtropical climate, predominantly continental during the winter months and marine during the summer months, occurs. Normal mean monthly temperatures range from 50.7°F in January to a high of 84.7°F in July. Mild weather prevails during much of the winter months, with below-freezing temperatures occurring only on an average of about 20 days per year (Anonymous 1987).

Collection Methods. Flies were collected biweekly from liver and fruit in the following manner. Once in every 2-wk period, one-half pound of fresh beef liver and one-half pound of a 7-10 day old mixture of apples and bananas were placed in the study area, and visiting flies were hand netted (as many as possible) for 1 h. Obviously, not all attempts to collect flies were successful, but any biases inherent in the hand netting technique would have an equal chance of occurring over either bait. All sampling was conducted in the same 200 meter^2 area between 1000-1400 hours on clear or partly cloudy days (with one exception) with an ambient temperature of at least 58°F. The two baits were placed directly on the ground approximately 20-m apart. Relative positions of the baits in the study area (north end, south end, etc.) were altered each 2-wk period to negate any effects of prevailing winds. After netting, flies were killed with synergized pyrethrins, counted, and returned to the laboratory for identification. Keys used for the identifications were primarily those contained in Hall (1948), and Hall and Townsend (1977). Voucher specimens were sent to Dr. N. E. Woodley (Systematic Entomology Laboratory, USDA) for confirmation, and are deposited in the Insect Collection of the Entomology Department, Texas A & M University, College Station.

RESULTS AND DISCUSSION

A total of 602 blow flies (all species combined) was collected from both baits during the 1-yr study period. Total fly numbers were similar for both baits with 300 collected from liver and 302 collected from fruit (Table 1). Phaenicia cuprina (Wiedemann) was the most commonly collected species from both baits and accounted for over 95% of all flies collected. Three calliphorid species were taken from fruit (number collected and percent of total given in parentheses): P. cuprina (298, 98.7%), Cynomyopsis cadaverina (Robineau-Desvoidy) (3, 1.0%), and P. sericata (Meigen) (1, 0.3%). On the other hand, six species were collected from liver bait: P. cuprina (275, 91.7%), P. sericata (9, 3.0%), C. cadaverina (9, 3.0%), Phaenicia mexicana[3] (Macquart) (5, 1.7%), Cochliomyia macellaria (Fabricius) (1, 0.3%), and P. eximia (Wiedemann) (1, 0.3%). There were no obvious differences in bait attractiveness; however, P. mexicana, C. macellaria, and P. eximia were collected only from liver bait even though the fruit bait station was only 20-m away.

[3]Comprises those identified as Phaenicia sp. (near mexicana) also.

During fall, P. cuprina was abundant on both baits whereas P. mexicana was occasionally collected from liver. Some P. cuprina and P. sericata were collected in winter from both baits, but the most commonly collected species (both baits) in January and February was C. cadaverina. Phaenicia cuprina was frequently collected from both baits during spring; however, C. cadaverina, P. sericata, and C. macellaria were collected from liver during that season. In the summer months, P. cuprina was again the most abundant species collected with one P. eximia taken from liver bait.

Peak numbers of P. cuprina (both baits) and P. mexicana were recorded in October, whereas most P. sericata were collected in May. Peak numbers of C. cadaverina occurred in March. The single specimens of C. macellaria and P. eximia were taken in June and July, respectively.

Results of this study indicate that P. cuprina and C. cadaverina are readily attracted to both fresh liver and rotting fruit with no apparent bait preferences. On the other hand, P. mexicana was collected on three occasions from liver only, and this pattern may indicate a preference. In addition, only one P. sericata was collected from fruit with nine collected from liver at different sampling dates.

The collections of P. cuprina in this study are not unusual considering its known biology. Numerous studies have demonstrated that this species is commonly found on decaying meat and fruits, especially garbage (Goddard and Lago 1983, Hall and Townsend 1977). Cynomyopsis cadaverina has been previously taken from various forms of decaying meats and carrion (Goddard and Lago 1983, Hall 1948, Hall and Townsend 1977); however, this study indicates that it has an affinity for decaying fruit also. Phaenicia sericata was collected in this study from liver, which is consistent with other studies that reported the species from varying types and ages of meat or carrion (Cushing and Parish 1938, Roberts 1933, Goddard and Lago 1983). Little information is known about P. mexicana and its carrion associations because it is rare in North America; however, in this study, P. mexicana seemed to prefer liver over fruit. Unfortunately, specimen numbers of this species, and even more so with C. macellaria and P. eximia, were too low to assess bait preferences patterns.

Seasonal activity patterns reported herein are not unlike those previously reported. Phaenicia cuprina specimens are numerous in the warm months throughout the southern U.S. with peak population numbers occurring in the summer (Hall 1948). This study showed that P. cuprina is active almost all year in south Texas. Cynomyopsis cadaverina was most abundant during the winter; this is the case in many geographic locations throughout its range (Hall and Townsend 1977, Goddard and Lago 1983). Phaenicia sericata was collected most often in May. Cushing and Parish (1938) collected P. sericata from raw beef most often in June in Menard Co, Texas. Most P. mexicana specimens were collected in October. This finding is in contrast to Cushing and Parish (1938) who reported a peak in June; however, total numbers of P. mexicana in this study were probably too low to determine its seasonal distribution. The one C. macellaria collected in this study was taken in June; Cushing and Parish (1938) reported peak populations of the species in July.

Studies of blow fly bait preferences should be pursued. Theoretically, if certain target pest species prefer particular baits or particular ages of baits then synthetic chemical attractants could be produced. These chemical attractants tagged with chemosterilants or other insecticides could provide highly specific pest control with minimal effects on nontarget organisms.

Table 1. Blow Fly Species and Number of Adult Specimens Collected from Liver and Fruit at Brooks AFB TX, September 1986 - August 1987.

Collection Date	Ambient Temp	Sky Condition	Wind[3]	Liver[1]						Fruit[2]		
				PC[4]	CC	PS	PM	CM	PE	PC	CC	PS
14 Sep 86	90°F	Ptly Cldy	SW 8	22	-	-	-	-	-	2	-	-
20 Sep 86	90°F	Clear	S 10	25	-	-	-	-	-	27	-	-
4 Oct 86	90°F	Ptly Cldy	SE 10	9	-	-	1	-	-	72	-	-
25 Oct 86	80°F	Ptly Cldy	S 8	54	-	-	3	-	-	12	-	-
5 Nov 86	64°F	Clear	NW 5	13	-	-	1	-	-	21	-	-
15 Nov 86	58°F	Cloudy	Calm	7	-	-	-	-	-	4	-	-
13 Dec 86	58°F	Clear	N 3	4	-	-	-	-	-	6	-	-
30 Dec 86	60°F	Clear	N 3	-	-	-	-	-	-	-	-	-
15 Jan 87	65°F	Ptly Cldy	W 4	1	2	-	-	-	-	-	1	-
25 Jan 87	68°F	Clear	S 7	-	-	-	-	-	-	-	1	-
12 Feb 87	75°F	Ptly Cldy	S 8	-	1	-	-	-	-	-	1	-
28 Feb 87	68°F	Clear	Calm	-	-	-	-	-	-	-	-	1
13 Mar 87	70°F	Ptly Cldy	S 10	2	5	-	-	-	-	3	-	-
27 Mar 87	70°F	Clear	S 10	1	1	-	-	-	-	1	-	-
14 Apr 87	70°F	Clear	W 15	-	-	-	-	-	-	3	-	-
26 Apr 87	75°F	Clear	S 5	1	-	1	-	-	-	1	-	-
15 May 87	80°F	Ptly Cldy	E 8	2	-	4	-	-	-	3	-	-
28 May 87	80°F	Ptly Cldy	S 15	19	-	2	-	-	-	2	-	-
14 Jun 87	85°F	Ptly Cldy	S 8	15	-	2	-	1	-	17	-	-
30 Jun 87	95°F	Ptly Cldy	S 5	11	-	-	-	-	-	23	-	-
14 Jul 87	90°F	Ptly Cldy	S 3	43	-	-	-	-	-	46	-	-
31 Jul 87	90°F	Clear	Calm	21	-	-	-	-	1	35	-	-
11 Aug 87	90°F	Clear	S 10	16	-	-	-	-	-	14	-	-
18 Aug 87	95°F	Clear	S 8	9	-	-	-	-	-	6	-	-
			Total	275	9	9	5	1	1	298	3	1

[1]One-half pound fresh beef liver.
[2]One-half pound mixture, 7-10 day old banana and apple.
[3]Mph.
[4]Blow fly species collected: PC = Phaenicia cuprina, CC = Cynomyopsis cadaverina, PS = Phaenicia sericata, PM = Phaenicia mexicana, CM = Cochliomyia macellaria, PE = Phaenicia eximia.

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LITERATURE CITED

Anonymous. 1987. Meteorological data: Texas. pp. 110-124. IN "Texas Almanac." A. H. Belo Co, Dallas.

Bornemissza, G. F. 1957. An analysis of arthropod succession in carrion and the effect of its decomposition on the soil fauna. Australian J. Zool. 5: 1-12.

Cushing, E. C., and H. E. Parish. 1938. Seasonal variations in abundance of Cochliomyia spp., Phormia spp., and other flies in Menard County Texas. J. Econ. Entomol. 31: 764-69.

Deonier, C. C. 1940. Carcass temperatures and their relation to winter blow fly populations and activity in the southwest. J. Econ. Entomol. 33: 166-170.

Fuller, M. E. 1934. The insect inhabitants of carrion, a study in ecology. Bull. Aust. Counc. Sci. Ind. Res. 82: 5-62.

Goddard, J., and P. K. Lago. 1983. An annotated list of the Calliphoridae (Diptera) of Mississippi. J. Georgia Entomol. Soc. 18: 481-484.

Goddard, J., and P. K. Lago. 1985. Notes on blow fly succession on carrion in northern Mississippi. J. Entomol. Sci. 20: 312-317.

Hall, D. G. 1948. The blow flies of North America. Thomas Say Found. Washington.

Hall, R. D., and L. H. Townsend, Jr. 1977. The blow flies of Virginia. The Insects of Virginia No. 11, Res. Div. Bull. 123, Virginia Poly. Inst. and State Univ.

Keh, B. 1985. Scope and applications of forensic entomology. Ann. Rev. Entomol. 30: 137-154.

Lindquist, A. W. 1954. Flies attracted to decomposing liver in Lake County, California. Pan-Pacific Entomol. 30: 147-152.

Meek, C. L., M. D. Andis, and C. S. Andrews. 1983. Role of the entomologist in forensic pathology, including a selected bibliography. Bibliogr. Entomol. Soc. Amer. 1: 1-10.

Norris, K. R. 1965. The bionomics of blow flies. Ann. Rev. Entomol. 10: 47-68.

Payne, J. A. 1965. A summer carrion study of the baby pig Sus scrofa Linnaeus. Ecology 46: 592-602.

Roberts, R. A. 1933. Activity of blow flies and associated insects at various heights above the ground. Ecology 14: 306-314.

COMPARATIVE HOST SUITABILITY OF BELL PEPPER AND SELECTED WEED SPECIES FOR LIRIOMYZA TRIFOLII (BURGESS)[1/][2/]

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ABSTRACT

Two common weed species, ragweed parthenium, Parthenium hysterophorus L., and Palmer amaranth, Amaranthus palmeri S. Wats., were significantly more attractive than bell pepper, Capsicum annuum L., to Liriomyza trifolii (Burgess) for feeding and oviposition, and larger numbers of larvae developed in the two weeds per cm^2 leaf area. Common sunflower, Helianthus annuus L., was similar to bell pepper in leafminer preference. Common purslane, Portulaca oleracea L., was not a host for L. trifolii. Total mean development time of L. trifolii from oviposition to pupation was shortest on ragweed parthenium but was similar on bell peppers, common sunflower and Palmer amaranth. Management of weed hosts may aid in reduction and subsequent control of L. trifolii on bell peppers.

INTRODUCTION

Fresh market green peppers are an important crop throughout the United States and in particular the Lower Rio Grande Valley of Texas (LRGV). Texas bell pepper production was valued at $23.8 million in 1985 (U.S.D.A. 1986). Agromyzid leafminers are among the most damaging of the many insects associated with this crop (Longbrake et al. 1976), and Liriomyza trifolii (Burgess) is the most common species reported on peppers in the LRGV (Chandler 1985). Adult female leafminers puncture leaves to feed and oviposit. The punctures injure the leaf tissue which reduce photosynthetic capacity (Johnson et al. 1983, Parrella et al. 1985). The characteristic mining of the upper leaf mesophyll by the larvae also reduces photosynthesis and can adversely affect vegetable yields (Johnson et al. 1983, Schuster and Everett 1983).

1/Diptera: Agromyzidae.
2/Mention of a proprietary product does not constitute endorsement or a recommendation for its use by the USDA or Texas A&M University. Approved by the director of the Tex. Agric. Exp. Stn. as Technical Article No. TA-23554.
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Understanding the role of alternate host plants in leafminer population dynamics is important for development of pest management schemes. Alternate hosts may serve as sources for pest epidemics and may provide reservoirs for indigenous natural enemies. Little is currently known concerning the ecological relationships of L. trifolii and weed hosts. The host range of the insect has been summarized by Stegmaier (1966), Spencer (1973), and Spencer and Stegmaier (1973). Zoebisch et al. (1984) recently determined that L. trifolii in Florida can ovposit successfully in laboratory environments in common nightshade, Solanum nodiflorum Jacq., common beggar-tick, Bidens alba (L.) DC., and downy groundcherry, Physalis pubescens L. Pigweed, Amaranthus viridis L., was not a preferred host. Sixteen weed species were found to be hosts of L. trifolii in laboratory tests conducted in Nova Scotia (Smith and Hardman 1986). Of the sixteen, only creeping Charlie, Glechoma hederalea L., was an unsuitable host.

Due to the lack of information on L. trifolii host preference in Texas, studies were designed to evaluate the role of four common south Texas weed species in the leafminer-pepper ecosystem. One objective was to determine L. trifolii preference between weeds and cultivated bell pepper in field and laboratory settings. Another objective was to evaluate the effects of various host plants on leafminer larval developmental time and mortality. No information is currently available for L. trifolii host preference for the four selected weed species that are commonly found adjacent to pepper growing areas.

MATERIALS AND METHODS

Field Studies. Four species of weeds and 'Grande Rio 66' bell pepper (Capsicum annuum L.) were seeded 20 February 1985 in a field on U.S.D.A. facilities at Weslaco, TX. Weed species planted were: Palmer amaranth, Amaranthus palmeri S. Wats.; ragweed parthenium, Parthenium hysterophorus L.; common sunflower, Helianthus annuus L.; and common purslane, Portulaca oleracea L. Each plant species was planted in plots 1 row (102 cm) wide by 7.6 m long replicated four times in a randomized complete block design. Plants were grown using normal horticultural practices. No pesticides were applied to the plots.

Beginning at seedling emergence and continuing at three week intervals through plant maturity, three plants per plot were selected at random, bagged and removed from the field and brought to the laboratory for analysis. The following data were recorded for each plant: number of leaves (cotyledons, mature, and newly emerged), leaf area (cm^2), number of L. trifolii feeding-oviposition punctures and larvae, and total number of mines (empty or containing larvae). Leaf area was obtained using a Zeiss MOP-30 digital image analyzer.

Laboratory Studies. The four weed species and bell pepper were seeded in the greenhouse into 7.6 cm plastic pots containing Baccto pre-mixed potting soil. When plants had developed a minimum of three primary leaves they were removed from the greenhouse, brought to the laboratory, and choice bioassays of L. trifolii host preference were initiated. The laboratory was maintained at 24+2°C and 50+5% relative humidity. A series of plants (one plant per species) was placed into a 30.5 x 30.5 x 30.5 cm insect rearing cage containing 50 three-day-old adult female L. trifolii. Leafminers were obtained from established laboratory cultures reared on peppers for several generations. After

24 h plants were removed from the cage, and the numbers of leaves (cotyledon, mature, and newly emerged) and leafminer feeding-oviposition punctures per plant were recorded. No attempt was made to document the number of eggs deposited per plant. Plants were then monitored daily for egg hatch, larval development, and pupation. Leafminer larval mortality was recorded also. At the conclusion of leafminer larval development within the plant, leaves were removed and total leaf area (cm^2) per plant was recorded. Fourteen choice bioassay series were completed.

Statistical Analyses. Means and standard deviations were computed for all data. An analysis of variance procedure was conducted for all data, with means separated using Duncan's multiple range test (Duncan 1955). Data were transformed to Log_{10} $(x + 1)$ to stabilize the variance between replications (Snedecor and Cochran 1980). Total numbers of mines, feeding-oviposition punctures, and larvae per plant were converted to numbers per cm^2 leaf area to provide a standardized measure of host preference among plant species.

RESULTS AND DISCUSSION

Field Studies. Primary growth statistics (leaves per plant and total leaf area) are presented in Table 1. Peak plant growth for each species occurred within the period from 23 April to 5 June. Palmer amaranth had significantly more leaves per plant than the other tested species on 4 April, 15 May and 5 June. Common sunflower had the greatest amount of leaf surface area during 15 May to 5 June. In general, bell peppers had fewer leaves and leaf surface area than Palmer amaranth and sunflower on most dates during the study. The decline in numbers of leaves per plant exhibited by Palmer amaranth and common sunflower on 5 June can be attributed to plant senescence. A similar decline in numbers of leaves on common purslane was caused by a sawfly, Schizocerus pilicornis (Holmgren) (Hymenoptera: Argidae). The larvae of these insects were observed mining the leaves resulting in defoliation of the plant (Chandler, unpublished data).

The mean number of L. trifolii inflicted feeding-oviposition punctures per cm^2 leaf surface area was similar among all plant species on the first two sample occasions (Table 2). Plants on 14 March were similar in total leaf surface area available with the exception of bell pepper which had the least amount present (Table 1). During the period of peak plant growth (15 May and 5 June), female L. trifolii punctured ragweed parthenium significantly more than any other plant species. Common purslane was not punctured by females at any time and did not serve as a field host.

The greatest number of live L. trifolii larvae per bell pepper plant occurred on 5 June (13.3 ± 1.9, $\bar{x} \pm SD$). Palmer amaranth had 47.3 $\pm$ 5.7 larvae per plant on 15 May. No other plant species had more than ten live larvae per plant at any time during the study. Economic threshold levels for L. trifolii larvae on bell peppers currently do not exist. The number of live larvae encountered on peppers during this study is typical of that encountered during most growing seasons in the LRGV. The number of leafminer larvae per cm^2 leaf area was similar among all tested plant species. All species had 0.02 or fewer larvae per cm^2 leaf area. Variable lengths of life cycle and mortality differences per plant species may aid in creating the equitable

TABLE 1. Mean Number of Leaves and Leaf Area (cm^2) per Plant in a Field Study. Weslaco, Texas, 1985.

Plant Species	$\bar{x}$ No. Of Leaves/Plant ($\pm$ SD) 1/				
	14 March	4 April	23 April	15 May	5 June
Bell Pepper	3.5 $\pm$ 0.9 c	5.3 $\pm$ 1.2 c	12.5 $\pm$ 1.0 b	55.1 $\pm$ 4.2 d	75.8 $\pm$ 5.3 c
Palmer Amaranth	6.4 $\pm$ 1.4 ab	25.5 $\pm$ 18.4 a	185.0 $\pm$ 89.4 a	3348.2 $\pm$ 185.6 a	323.3 $\pm$ 35.2 a
Ragweed Parthenium	7.2 $\pm$ 1.2 a	6.4 $\pm$ 2.5 c	41.3 $\pm$ 10.7 b	68.8 $\pm$ 8.1 d	131.8 $\pm$ 15.4 b
Sunflower	5.8 $\pm$ 1.2 b	9.6 $\pm$ 2.5 bc	31.0 $\pm$ 12.7 b	228.3 $\pm$ 26.2 c	141.3 $\pm$ 10.2 b
Purslane	6.8 $\pm$ 1.0 ab	16.7 $\pm$ 12.3 b	121.8 $\pm$ 12.8 a	592.5 $\pm$ 29.7 b	11.5 $\pm$ 2.4 d
	Leaf Area (cm^2)/Plant ($\pm$ SD) 1/				
Bell Pepper	2.8 $\pm$ 1.1 b	11.7 $\pm$ 4.4 c	135.7 $\pm$ 46.8 b	897.7 $\pm$ 18.8 c	2006.3 $\pm$ 94.2 b
Palmer Amaranth	5.1 $\pm$ 2.8 a	56.1 $\pm$ 49.8 a	814.8 $\pm$ 282.2 a	7292.6 $\pm$ 332.0 b	955.5 $\pm$ 41.4 c
Ragweed Parthenium	4.0 $\pm$ 1.3 ab	41.0 $\pm$ 31.6 ab	772.7 $\pm$ 128.6 a	441.3 $\pm$ 43.0 d	548.4 $\pm$ 33.8 d
Sunflower	5.3 $\pm$ 3.0 a	68.6 $\pm$ 44.6 a	834.0 $\pm$ 359.5 a	9017.8 $\pm$ 249.9 a	2207.1 $\pm$ 238.8 a
Purslane	4.9 $\pm$ 1.6 a	23.4 $\pm$ 22.3 bc	176.0 $\pm$ 32.2 b	279.7 $\pm$ 18.3 d	4.8 $\pm$ 2.4 e

1/Means followed by the same letter in a column are not significantly different ($P > 0.05$, Duncan's Multiple Range Test).

TABLE 2. Mean Number of L. trifolii Feeding-Oviposition Punctures per cm^2 Leaf Area per Plant in a Field Study. Weslaco, Texas, 1985

Plant Species	$\bar{x}$ No. of Punctures/cm^2 Leaf Surface (± SD) 1/				
	14 March	4 April	23 April	15 May	5 June
Bell Pepper	0.06 ± 0.22	0.25 ± 0.72	0.44 ± 0.54 a	0.07 ± 0.01 c	0.17 ± 0.01 b
Palmer Amaranth	0.00	0.07 ± 0.15	0.08 ± 0.07 ab	0.69 ± 0.03 b	0.17 ± 0.01 b
Ragweed Parthenium	0.00	0.14 ± 0.22	0.14 ± 0.11 ab	1.17 ± 0.08 a	0.33 ± 0.03 a
Sunflower	0.03 ± 0.11	0.02 ± 0.04	0.04 ± 0.05 ab	0.04 ± 0.01 cd	0.10 ± 0.01 c
Purslane	0.00	0.00	0.00 b	0.00	0.00 d
	N.S.	N.S.			

1/Means followed by the same letter in a column are not significantly different ($P > 0.05$, Duncan's Multiple Range Test). N.S. indicates non-significant.

appearance among plants. Total mines, therefore, present a better estimation of L. trifolii preference in field settings.

The mean number of L. trifolii mines (empty or containing larvae) per cm^2 leaf area per plant is presented in Table 3. No differences among plant species in mines per cm^2 leaf area were noted on 14 March or 4 April, though bell peppers were the only plant species with mines on 14 March. On 23 April bell peppers had significantly more mines than other tested plant species. Conversely, ragweed parthenium had significantly more mines per cm^2 leaf area on 15 May and 5 June, with Palmer amaranth similar to ragweed parthenium on 15 May. These latter results are similar to those on the number of punctures per cm^2 leaf area. Ragweed parthenium appears to be most preferred for feeding-oviposition and mining during times of peak plant growth. Additionally, Palmer amaranth may be a more preferred host compared to bell pepper later in a growing season.

Laboratory Studies. Table 4 presents the mean number of L. trifolii larvae per plant, and the number of feeding-oviposition punctures and larvae per cm^2 of leaf area for laboratory bioassays. Bell pepper had significantly fewer punctures than Palmer amaranth and ragweed parthenium and was similar in number to common sunflower and common purslane. Ragweed parthenium exhibited the greatest number of larvae per plant and per cm^2 leaf area throughout the study. Although punctures were found on common purslane, no larvae were observed. However, since oviposition rates were not documented, it is possible that eggs were placed in purslane and that these eggs did not hatch. Additionally, we cannot assume that egg eclosion rates in all tested plant species were similar. Apparently, adult female L. trifolii may use purslane as a source of food in the laboratory. This was not apparent in field situations. During these laboratory studies, bell peppers averaged 13.3 + 9 (SD) punctures per cm^2 leaf area. Peppers were statistically similar in leaf area to ragweed parthenium (6.6 $\pm$ 12.7 cm^2) and common sunflower (8.0 + 13.3 cm^2). The latter two species were also similar in leaf area to Palmer amaranth (3.2 $\pm$ 3.2 cm^2) and common purslane (3.0 + 3.2 cm^2.)

In addition to studying preference for L. trifolii punctures and larval numbers per plant species, the overall life span of the insect from oviposition to pupation was determined for individuals on all plant species except common purslane. Time required for egg hatch was significantly longer on common sunflower (4.9 + 0.6 days) and was shortest on ragweed parthenium (3.6 + 1.1 days). Incubation averaged 4.4 $\pm$ 1.0 and 4.1 $\pm$ 1.3 days on bell pepper and Palmer amaranth, respectively. Conversely, the time from hatch to pupation was longest on bell pepper (4.6 + 0.5 days) and Palmer amaranth (4.6 + 0.8 days) and shortest on sunflower (3.8 + 0.4 days). Time from hatch to pupation averaged 4.1 + 1.0 days on ragweed parthenium. Total developmental time for oviposition to pupation was 9.1 days on bell pepper, 8.7 days on common sunflower, 8.6 days on Palmer amaranth, and 7.7 days on ragweed parthenium. Additionally, 33.3% of developing larvae died on bell pepper, while 30.0, 21.4, and 3.9% died on ragweed parthenium, Palmer amaranth, and common sunflower, respectively. Sunflower was not the most preferred host for feeding and oviposition or for subsequent numbers of larvae per cm^2 leaf area. But, the minimum amount of L. trifolii larval death within the leaf tissue provided a favorable habitat for leafminer survival.

TABLE 3. Mean Number of L. trifolii Mines per cm^2 Leaf Area per Plant in a Field Study. Weslaco, Texas, 1985.

Plant Species	$\bar{x}$ No. Of Mines/cm^2 Leaf Area (± SD) 1/				
	14 March	4 April	23 April	15 May	5 June
Bell Pepper	0.02 ± 0.05	0.02 ± 0.04	0.04 ± 0.01 a	0.03 ± 0.01 b	0.05 ± 0.01 b
Palmer Amaranth	0.00	0.01 ± 0.02	0.01 ± 0.02 b	0.12 ± 0.01 a	0.03 ± 0.01 c
Ragweed Parthenium	0.00	0.01 ± 0.02	0.02 ± 0.01 b	0.12 ± 0.01 a	0.22 ± 0.01 a
Sunflower	0.00	<0.01 ± 0.01	<0.01 ± 0.01 b	0.01 ± 0.01 c	0.01 ± 0.01 c
Purslane	0.00	0.00	0.00 b	0.00 c	0.00 d
	N.S.	N.S.			

1/Means followed by the same letter in a column are not significantly different ($P > 0.05$, Duncan's Multiple Range Test). N.S. indicates non-significant.

TABLE 4. Mean Number of L. trifolii Larvae per Plant and Feeding-Oviposition Punctures and Larvae per cm^2 Leaf Area per Plant in a Laboratory Study. Weslaco, Texas, 1985.

Plant Species	N[1]	Punctures/cm^2 $\bar{x} \pm$ SD [2]	Larvae/plant $\bar{x} \pm$ SD [2]	Larvae/cm^2 $\bar{x} \pm$ SD [2]
Bell Pepper	14	0.4 ± 0.3 b	0.9 ± 1.0 b	0.1 ± 0.1 b
Palmer Amaranth	14	5.5 ± 10.0 a	1.0 ± 2.1 b	0.5 ± 1.1 b
Ragweed Parthenium	14	5.7 ± 4.9 a	3.6 ± 3.9 a	2.4 ± 2.1 a
Sunflower	14	4.0 ± 5.5 ab	1.8 ± 3.1 b	1.0 ± 2.3 b
Purslane	14	1.4 ± 2.4 ab	0.0 b	0.0 b

[1] Number of replicates.
[2] Means followed by the same letter in a column are not significantly different ($P > 0.05$, Duncan's Multiple Range Test).

In conclusion, this study showed that bell peppers were not the preferred host of L. trifolii if other wild plant hosts were available. Field and laboratory studies indicated that ragweed parthenium and Palmer amaranth generally were more attractive to adult female L. trifolii for feeding and oviposition. Common sunflower was a less-preferred host in field situations. Since laboratory studies conducted under intensive leafminer population pressure confirmed field study results, it is doutful if the field findings reported here would change under varying leafminer infestation levels. Ragweed parthenium, Palmer amaranth, and common sunflower may serve as sources of great numbers of L. trifolii. Management of these weeds may aid in the reduction of L. trifolii on peppers. In addition, the use of ragweed parthenium and Palmer amaranth as possible trap crops for leafminers may provide an alternative management approach for leafminer control in peppers. However, Zoebisch et al. (1984) stated that the confirmation of host-conditioning of L. trifolii reared from each plant species must be studied before these techniques can be unequivocably recommended. If leafminers on bell peppers are conditioned to oviposit only on pepper foliage, then use of other plants as trap plantings would be useless. Conversely, lack of host-conditioning would be decisive in explaining sources of leafminer outbreaks.

ACKNOWLEDGEMENT

The authors wish to thank Dr. Bob Menges for supplying the weed seeds used in this study. We also thank Dr. Bob Wharton for his identification of the sawfly infesting the common purslane.

LITERATURE CITED

Chandler, L. D. 1985. Flight activity of Liriomyza trifolii (Diptera: Agromyzidae) in relationship to placement of yellow traps in bell pepper. J. Econ. Entomol. 78: 825-828.

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

Johnson, M. W., S. C. Welter, N. C. Toscano, I. P. Ting, and J. T. Trumble. 1983. Reduction of tomato leaflet photosynthesis rates by mining activity of Liriomyza sativae (Diptera: Agromyzidae.) J. Econ. Entomol. 76: 1061-1063.

Longbrake, T., S. Cotner, R. Roberts, J. Parsons, and W. Peavy. 1976. Keys to profitable pepper production. Tex. Agr. Ext. Ser. L-966.

Parrella, M. P., V. P. Jones, R. R. Youngman, and L. M. Lebeck. 1985. Effect of leaf mining and leaf stippling of Liriomyza spp. on photosynthetic rates of chrysanthemum. Ann. Entomol. Soc. Am. 78: 90-93.

Schuster, D. J., and P. H. Everett. 1983. Response of Liriomyza trifolii (Diptera: Agromyzidae) to insecticides on tomato. J. Econ. Entomol. 76: 1170-1174.

Smith, R. F., and J. M. Hardman. 1986. Rates of feeding, oviposition, development, and survival of Liriomyza trifolii (Burgess) (Diptera: Agromyzidae) on several weeds. Can. Entomol. 118: 753-759.

Snedecor, G. W., and W. G. Cochran. 1980. Statistical Methods. 7th Ed. Iowa St. Univ. Press, Ames.
Spencer, K. A. 1973. Agromyzidae (Diptera) of economic importance. W. Junk B. V., The Hague.
Spencer, K. A., and C. E. Stegmaier, Jr. 1973. Arthropods of Florida and neighboring lands, Vol. 7. Agromyzidae of Florida with a supplement on species from the Caribbean. Fla. Dept. Agr. Consumer Serv., Div. Plant Indus., Bureau Entomol. Contribution, No. 171.
Stegmaier, C. E., Jr. 1966. Host plants and parasites of Liriomyza trifolii in Florida (Diptera: Agromyzidae). Fla. Entomol. 49: 75-80.
U.S.D.A. 1986. 1985 Texas vegetable statistics. Tex. Dept. Agr. and U.S.D.A. Bull. 238.
Zoebisch, T. G., D. J. Schuster, and J. P. Gilreath. 1984. Liriomyza trifolii: oviposition and development in foliage of tomato and common weed hosts. Fla. Entomol. 67: 250-254.

MINUTES OF THE 12TH ANNUAL MEETING OF THE SOUTHWESTERN ENTOMOLOGICAL SOCIETY

The 12th Annual Meeting of the Southwestern Entomological Society was called to order by President Bob Harris, at 7:30 P.M. February 8, 1988, in the Grand Ballroom of the Sheraton Mockingbird West Hotel, Dallas, Texas.

A motion was made to dispense with the reading of the Minutes of the 11th Annual Meeting, since those Minutes had been published in the Southwestern Entomologist (Vol. 11, No. 2).

Minutes of the Executive Committee Meeting were Read by Don Nordlund.

The Executive Committee and Editorial Board of the Southwestern Entomological Society met in the Executive Boardroom of the Sheraton Mockingbird West Hotel, Dallas, Texas on February 8, 1988. The meeting was called to order by President Harris at 4:00 P.M. Present were Executive Committee members Bob Harris, Don Rummel, Jeff Slosser, Tom Fuchs, and Don Nordlund. Editorial Committee members present included Juan Lopez, Don Bull, Ron Davey, Pat Morrison, and Knox Walker.

The reading of the Minutes of the Executive Committee Meeting held at the 11th Annual Meeting of the Society were dispensed with since they had been published in the Southwestern Entomologist (Vol. 11, No. 2).

The Committee decided that members more than six months in arrears on dues should be sent a letter informing them that they will be dropped from the rolls unless payment is received in thirty days.

Rummel moved and Bull seconded that an annual cash award be made to the Editor and Secretary-Treasurer and that the awards for 1987 be $750 and $500, respectively. The motion carried.

Walker moved and Fox seconded that each of the four previous editors (Don Rummel, Don Bull, Bob Harris and Horace Burke) be given a one-time cash award of $400 for their service to the Society. Motion carried.

Nordlund moved and Rummel seconded that we propose holding a joint meeting with the Southwestern Branch to the Executive Committee of the Southwestern Branch. Motion carried.

The committee approved seeking affiliate status with the Entomological Society of America.

Walker moved and Lopez seconded a motion to establish a policy of keeping records of manuscripts submitted to the Southwestern Entomologist for two years and that the Editor be authorized to dispose of manuscripts after that period. Motion carried.

The Committee authorized printing of bibliographic information on the edge of the binding for the Southwestern Entomologist.

The Committie authorized the Editor to include, in his letter to authors of papers accepted for publication in the Southwestern Entomologist, a paragraph informing them that the Southwestern Entomological Society urged authors to deposit voucher material (specimens, cultures, etc.) documenting their research at recognized institutions and to cite the place of deposit in the paper.

The meeting was adjourned at 5:37 P.M.

Respectfully Submitted,
Donald A. Nordlund
Secretary-Treasurer

Auditing Committee Report was Read by Bob Harris.

An Auditing Committee composed of myself and Darrell Bay met on 27 January 1988 and examined the financial records of the Southwestern Entomological Society as maintained by Secretary-Treasurer Don Nordlund for the year 1987. The committee examined the accounts, records, receipts, checks and other documents and found the books to be in order. Don has done an excellent job as Secretary-Treasurer of the Society by computerizing the bookkeeping. This system makes it simple to audit and provides a quick update on our financial situation at any time.

Respectfully Submitted,
Truman Fincher, Chairman
Auditing Committee

Secretary-Treasurer's Report for 1987 was Read by Don Nordlund.

Balance on hand as of January 1, 1987		$10578.33
Income January 1 - December 31, 1987		
Dues	$ 2590.00	
Page Charges	11759.70	
Subscriptions	2100.00	
Institute for Sci. Inf.	18.00	
Interest	626.68	
Miscellaneous Charges	4147.39	
Total Income	$21241.77	
Expenses January 1- December 31, 1987		
Journal		
Printing	$15281.78	
Secretary	1200.00	
Supplies	89.06	
Postage & Handling	806.78	

Society Operations	
Secretary	526.59
Supplies	65.76
Postage	314.80
Miscellaneous	12.00
Awards	83.07
Total Expenses	$18379.84

Balance on hand as of December 31, 1987 $13440.26

As of December 31, 1987 there were 305 members and 106 institutional subscribers in the Southwestern Entomological Society.

Respectfully submitted,
Donald A. Nordlund
Secretary-Treasurer

The Editor's Report was Read by J. E. Slosser.

Editor's Financial Report

Date	Description	Receipts	Expenditures	Balance
01/01/87	Balance Forward			64.62
02/27/87	Mailing Labels		5.05	59.57
02/27/87	Reg. Mail: Vol 12 #1		6.29	53.28
05/22/87	Reg. Mail: Vol 12 #2		5.95	47.33
06/01/87	From Treasurer	200.00		247.33
06/05/87	Purchase Stamps		129.50	117.83
06/25/87	Mailing Envelopes		40.59	77.24
08/13/87	Mailing Labels		4.33	72.91
09/04/87	Reg. Mail: Vol 12 #3		5.95	66.96
10/20/87	Mailing Labels		5.80	61.16
11/30/87	Computer Paper		38.76	22.40
12/01/87	Reg. Mail: Vol 12 #4		5.95	16.45

There were 43 manuscripts published in the four regular issues in 1987. No supplements were issued. Total number of pages was 364. This compared to 42 manuscripts and 299 pages issued in 1986.

During 1987, I received 51 manuscripts for consideration. Of these, 9 (17.6%) were rejected. This rejection rate decreased from 25% in 1986.

The significant change in format in 1987 was in the color of the cover of the journal. Each number is issued with a different color. The primary purpose was to help distinguish the volumes from each other. The first, or March, issue each year is brown.

Another accomplishment in 1987 was the publication of manuscript preparation guidelines in Spanish. Both the English and Spanish guidelines appeared in the September 1987 issue.

Minutes of the annual meetings are now published in the June issue. The minutes of the 11th Annual Meeting were published in June 1987. Also, the revised Constitution of the Southwestern Entomological Society was published in June 1987.

Supplement No. 11 was reprinted in August 1987 for distribution at an international congress on pesticide application in Malaysia. Printing costs were paid by Exxon Research. The only supplement planned, to date, for 1988 is the same supplement that was planned for 1987. I understand the Microplitis supplement is about ready for submission for review.

Respectfully Submitted,
J. E. Slosser, Editor
Southwestern Entomologist

There being no new business, Jeff Slosser, Editor of the Southwestern Entomologist, presented an informative report on the Editor's Conference held at The Southeastern Branch Meeting.

President Harris announced that Pat Morrison had been elected to the position of President-Elect. He also announced the results of the non-binding referendum on voucher specimen policy. The policy that "Authors are urged to deposit voucher materials (specimens, cultues, etc.) documenting their research at recognized insititutions and to cite the place of deposit in publications" was preferred by a wide margin.

Don Rummel was installed as the new President and he presented a plaque to out-going President Harris.

The meeting was adjourned at 8:20 P.M.

Respectfully Submitted,
Donald A. Nordlund
Secretary-Treasurer

EFFECT OF EARLY-SEASON APPLICATIONS OF ETHEPHON ON COTTON FRUITING AND PINK BOLLWORM, PECTINOPHORA GOSSYPIELLA (SAUNDERS),[1] POPULATIONS[2]

L. A. Bariola[3], T. J. Henneberry[3], J. L. McMeans[4], and C. M. Brown[5]

ABSTRACT

Ethephon applied at 1.7 kg AI/ha on 26 May or 31 May significantly delayed flowering, but plants recovered and had accumulated as many or more total flowers by mid-July. The number of pink bollworm infested flowers was significantly reduced as a result of the ethephon treatments.

INTRODUCTION

Infestations of pink bollworm, Pectinophora gossypiella (Saunders), in the current year's cotton crop are initiated in flower buds (squares) from eggs oviposited by moths emerging from larvae that overwintered in diapause. Emergence of moths that occurs before squares are available as a source of larval food is suicidal or non-reproductive (Bariola 1978). Delayed cotton planting extends the time to cotton squaring, delays the initiation of pink bollworm infestations, and reduces the early-season population increase by lengthening the suicidal emergence period (Henneberry et al. 1982).

Ethephon is a plant growth regulator that causes cotton square abscission. Ethephon-treated plants begin reflowering and may do so at a faster rate than untreated plants (Kittock et al. 1973). The use of a plant growth regulator, such as ethephon, to eliminate early-season squares appears to have potential in pink bollworm population management, if the treatment does not delay crop maturity or reduce yield. The objectives of the study reported in this paper were to determine the fruiting response of cotton plants and the effect on pink bollworm populations of early-season treatment with ethephon.

MATERIALS AND METHODS

Tests were conducted in two fields on the USDA, ARS Imperial Valley Conservation Research Center, Brawley, CA. Seeds of Deltapine 16 were planted 21 March 1973, in row spacings of 102 cm. Two ethephon treatments were applied based on stage of cotton fruiting 1) two squares/plant (26 May), and 2) four squares/plant (31 May). Plots were 16 rows wide and 21 m long in Field 1, and 8 rows wide and 18 m long in

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[1] Lepidoptera: Gelechiidae.

[2] Mention of a proprietary product in the manuscript does not constitute an endorsement by the USDA.

[3] Western Cotton Research Laboratory, U.S. Department of Agriculture, Agricultural Research Service, Phoenix, AZ.

[4] National Peanut Research Laboratory, U.S. Department of Agriculture, Agricultural Research Service, Dawson, GA.

[5] Imperial Valley Conservation Research Center, U.S. Department of Agriculture, Agricultural Research Service, Brawley, CA.

Field 2. Each treatment and the untreated control were replicated eight times in each field. Ethephon was applied with an eight-row, high clearance sprayer at 1.7 kg AI/ha. For insect control, Field 1 was treated with either chlordimeform (0.6 kg AI/ha) or monocrotophos (0.9 kg AI/ha) weekly from 15 July to 13 September for a total of eight applications. Field 2 was treated with azinphosmethyl (0.6 kg AI/ha) on 1 May, and thereafter with either chlordimiform or monocrotophos at weekly intervals from 29 May through 13 September for a total of 16 applications. Insecticides were applied with an eight-row, high clearance ground sprayer or by air when fields were wet.

The number of flowers was counted on two rows per plot from 11 June to 10 July, then one row per plot through 27 September. The number of rosetted flowers, which indicates the presence of a mature pink bollworm larva, was counted also. Counts were made daily, except for week-ends, holidays, and when fields were irrigated, until 24 August; thereafter, counts were made 2 or 3 days per week.

The number of flowers and of rosetted flowers per row were accumulated by days. Data were analyzed by analysis of variance, and means were separated with Duncan's Multiple Range Test (Duncan 1955) on selected days at 5 to 14-day intervals throughout the season. Linear regressions of the flowering rate (x = sample date, y = cumulative number of flowers) were calculated for each treatment on the combined data from both fields, and the slopes were compared.

RESULTS AND DISCUSSION

The first flowers were found in the untreated plots on 11 June and in the ethephon-treated plots on 13 June. Untreated plots accumulated more flowers than the treated plots in the early season (Table 1).

TABLE 1. Number of Flowers in Untreated and Ethephon-Treated Plots. Brawley, CA, 1973.

	Cumulative No. of Flowers/1-m row[a]					
	Field 1[b]			Field 2[c]		
	Untreated	Ethephon		Untreated	Ethephon	
Date	check	26 May	31 May	check	26 May	31 May
15 June	4 a	2 b	0.7 b	5 a	1 b	0.2 b
20	7 a	4 b	1.0 c	10 a	3 b	0.4 c
29	17 a	14 a	2.4 b	24 a	14 b	2.2 c
13 July	49 a	50 a	37.0 b	61 a	59 ab	52.0 b
19	64 a	65 a	55.0 b	74 a	82 a	82.0 a
27	76 a	78 a	76.0 a	78 b	89 ab	96.0 a
10 Aug	89 b	92 ab	98.0 a	90 b	100 a	110.0 a
24	100 a	102 a	108.0 a	113 a	113 a	117.0 a
07 Sept	110 a	110 a	111.0 a	136 a	128 a	125.0 a

[a] Data are averages of eight replications. Means in a row within a field having the same letter are not significantly different, [P > 0.05; Duncan's (1955) Multiple Range Test].

[b] Field 1 treated eight times with insecticides from 15 July to 13 September.

[c] Field 2 treated 16 times with insecticides from 1 May to 13 September.

Conversely, 31 May-treated plots had accumulated more flowers than the untreated plots by 27 July in Field 1, and by 10 August in Field 2. No differences were in cumulative number of flowers in untreated and treated plots after 10 August.

Significantly fewer rosetted flowers were observed in the 31 May ethephon-treated plots than in the untreated plots through 10 July in both fields (Table 2). Fewer rosetted flowers were observed in the 26 May ethephon-treated plots than in the untreated plots during June, but no significant differences were observed during July. The insecticide treatments beginning 1 May in Field 2 greatly reduced the number of rosetted blooms, as compared to those in Field 1 which received no insecticides until 15 July.

TABLE 2. Number of Rosetted Flowers in Untreated and Ethephon-Treated Plots, Brawley, CA, 1973.

	Cumulative No. of Rosettes/10-m row[a]					
	Field 1[b]			Field 2[c]		
	Untreated	Ethephon		Untreated	Ethephon	
Date	check	26 May	31 May	check	26 May	31 May
15 June	1.9 a	1.0 b	0.14 c	1.0 a	0.17 b	0.0 b
20	4.8 a	2.4 b	0.24 c	1.2 a	0.33 b	0.0 b
29	12.9 a	10.5 b	0.95 c	1.5 a	0.72 ab	0.6 b
05 July	18.6 a	15.7 a	5.70 b	--	--	--
10	21.0 a	18.1 a	8.60 b	1.67a	0.89 ab	0.22b

[a] Data are averages of 16 rows; 8 replications; 2 rows/replication. Means in a row within a field having the same letter are not significantly different, [P > 0.05; Duncan's (1955) Multiple Range Test].

[b] No insecticide treatments prior to 10 July.

[c] Seven insecticide treatments from 1 May to 5 July.

The slope of the regression line for the untreated check, b = 5.18, was significantly lower than for the slope of the 26 May treatment, b = 6.11 (P < 0.05) and also significantly lower than that for the 31 May treatment, b = 6.72 (P < 0.05) (Fig. 1). There were no significant differences between the slopes for the two treatment dates. These data show that ethephon removed squares on the plants at the time of treatment and delayed flowering significantly. However, the data also show that the plants recovered and began flowering at a more rapid rate than plants in the untreated plots, so that the cumulative number of flowers in the ethephon-treated plots exceeded the number of flowers in the untreated plots by early August. The reduced number of flowers in June in the treated plots reduced the number of pink bollworm larvae (= rosetted flowers) produced in the plots. Large field tests are needed to determine if this reduction would prevent buildup of pink bollworm infestations to economic levels throughout the season.

Plants in the treated plots appeared to have more lateral branching following treatment than plants in the untreated plots. This result may be due to the high rate of ethephon used (1.7 kg AI/ha). We did not determine whether the main terminal was killed. Tests need to be conducted with lower rates of ethephon to determine whether this adverse effect on the growth of the plant could be prevented with the same reduction in numbers of early-season flowers and pink bollworm larvae.

Establishment of the F_1 pink bollworm generation in the cotton crop is essential to the subsequent development of the populations of the insect. The population is particularly vulnerable during early season because of lack of host material (Bariola 1978), predation (Henneberry and Clayton 1982), high soil temperatures (Fye 1971, Butler and Henneberry 1976, Clayton and Henneberry 1982) and other adverse environmental factors. Population increases in the early season are low (0.5 to 1.5X) compared with those in late season (2.4 to 15.0X) (Graham et al. 1962, Slosser and Watson 1972, Bariola 1978). Use of a plant growth regulator to exploit the vulnerability of the insect at this critical time in its population development appears to have considerable potential as a suppression tool.

Also, infestations of early bolls by pink bollworm larvae are known to promote infection of seeds by Aspergilus flavus Link and accumulation of aflatoxin, a known carcinogen (McMeans and Brown 1975). Elimination of these early bolls may thus reduce the level of aflatoxin accumulation.

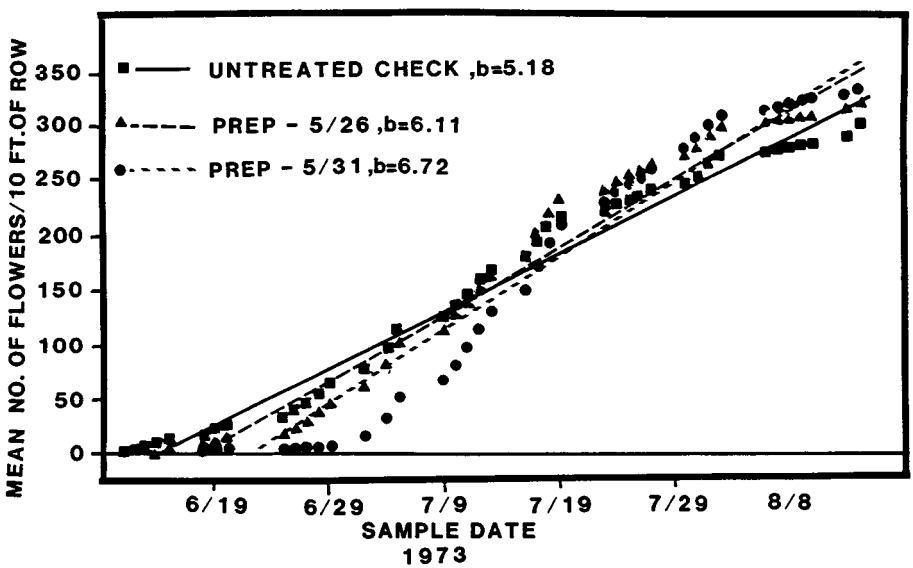

FIG. 1. Regression lines of accumulated number of flowers in untreated and ethephon-treated plots. Brawley, CA, 1973.

LITERATURE CITED

Bariola, L. A. 1978. Suicidal emergence and reproduction by overwintered pink bollworm moths. Environ. Entomol. 7: 185-192.

Butler, G. D., Jr., and T. J. Henneberry. 1976. Biology, behavior, and effects of pink bollworm larvae in cotton flowers. Environ. Entomol. 5: 970-972.

Clayton, T. E., and T. J. Henneberry. 1982. Pink bollworm: effect of soil moisture and temperature on moth emergence in field and laboratory studies. Environ. Entomol. 11: 147-149.

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

Fye, R. E. 1971. Mortality of mature larvae of the pink bollworm caused by high soil temperature. J. Econ. Entomol. 64: 1568-1569.

Graham, H. M., L. C. Fife, O. T. Robertson, and P. L. Adkisson. 1962. Pink bollworm population dynamics, p. 5-10. In D. F. Martin and R. D. Lewis, (eds.) A summary of recent research basic to the cultural control of pink bollworm. Tex. Agric. Exp. Sta., Misc. Pub. 579.

Henneberry, T. J., K. L. Kittock, and L. A. Bariola. 1982. Pink bollworm: effect of cotton types and planting date on early season infestations. Southwest. Entomol. 7: 65-69.

Henneberry, T. J., and T. E. Clayton. 1982. Pink bollworm: seasonal oviposition, egg predation, and square and boll infestations in relation to cotton plant development. Environ. Entomol. 11: 663-666.

Kittock, D. L., J. R. Mauney, H. F. Arle, and L. A. Bariola. 1973. Termination of late season cotton fruiting with growth regulators as an insect control technique. J. Environ. Qual. 2: 405-408.

McMeans, J. L., and C. M. Brown. 1975. Aflatoxins in cottonseed as affected by the pink bollworm. Crop Sci. 15: 865-866.

Slosser, J. E., and T. F. Watson. 1972. Population growth of the pink bollworm. Ariz. Agric. Exp. Sta. Bull. 195.

OVERWINTERING STRATEGIES OF BOLL WEEVIL[1/] IN SOUTHERN TEXAS: REPRODUCTION ON CULTIVATED COTTON

K. R. Summy, J. R. Cate[2/] and W. G. Hart

Subtropical Cotton Insects Research
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ABSTRACT

Cotton regrowth occurring in the subtropical Lower Rio Grande Valley of Texas may facilitate continuous and substantial reproduction by the overwintering population of boll weevil, Anthonomus grandis Boheman. Estimated adult recruitment occurring on cotton regrowth ranged from ca. 483,000 adult weevils/ha during a 25-wk postshredding period (October, 1985- March, 1986) to ca. 1.7 million adults/ha during a 31-wk period (September, 1986- March, 1987). The ecological significance of cultivated cotton as an overwintering habitat for boll weevil in southern Texas is discussed.

INTRODUCTION

Potential overwintering strategies of boll weevil, Anthonomus grandis Boheman, which have been documented in the subtropical Lower Rio Grande Valley (LRGV) of Texas include adult reproductive diapause (Keeley et al. 1977, Graham et al. 1978, 1979), probable reproduction on several malvaceous plants, particularly Cienfuegosia drummondi (Gray) Lewton (Cross et al. 1975, Burke and Clark 1976), reproduction on cultivated cotton (Summy et al. 1986) and survival in cotton residue (Summy et al. 1988). This repertoire of potential survival strategies appears similar to that documented in the southwestern United States (Fye et al. 1970, Bergmann et al. 1983), although the relative importance of the various processes has not been adequately clarified.

Cotton production regulations currently applicable to the LRGV region (Texas Pink Bollworm Quarantine; Texas Ann. Civ. Arts. 62-85, as amended) stipulate a two-zone system of legal planting dates (15 February and 31 March) and stalk destruction deadlines (31 August and 28 September), which technically provide a cotton-free period of ca. 4-5 months duration. Regulations notwithstanding, substantial amounts of volunteer and regrowth cotton detected by aerial surveillance during an intensive stalk destruction campaign (1982-1986) suggest that

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[1/] Coleoptera: Curculionidae.
[2/] Department of Entomology, Texas A&M University, College Station, TX 77843.

the overwintering LRGV weevil population has only rarely been deprived of cultivated cotton during the September-February "cotton-free" period (Summy et al. 1986, 1988). Since the population dynamics of boll weevil on volunteer and regrowth cotton has received only limited attention (Summy et al. 1986), the present research was conducted to evaluate the seasonality of cotton regrowth and the ecological significance of reproduction as an overwintering strategy of boll weevil in the subtropical LRGV environment.

MATERIALS AND METHODS

Studies were conducted in 0.5-ha plots of 'G&P 3774' cotton planted during March (1985 and 1986) on ARS facilities in Brownsville. Following shredding operations during 1985 (11 October) and 1986 (29 August), twenty 1.0 m^2 quadrats were delineated at random locations; all plant material (including root systems) within ca. 1.0 m of each quadrat was removed, and any foliage remaining on shredded stalks (within quadrats) was excised with pruning shears. Regrowth within each quadrat was monitored at weekly intervals for a period of 25 wks (1985-1986) and 31 wks (1986-1987) using methods described by Summy et al. (1986). Total numbers of fruiting structures within each quadrat were counted and categorized (squares and bolls; attached and abscised; infested and uninfested) in each census. Infested fruiting structures (attached and abscised) were placed inside screen cages (20x20x5-cm) situated under canopies of nearby plants and monitored at weekly intervals for adult emergence. Upon completion of adult emergence, fruiting structures were dissected to evaluate stage-specific mortality and causal factors. Estimates of weekly fruit production were calculated as the difference between average fruit density per quadrat (attached and abscised) and density of uninfested fruiting structures (attached) recorded during the previous census. Boll weevil oviposition and adult emergence were measured directly by removal of infested material.

RESULTS AND DISCUSSION

Following shredding operations during 1985 (11 October), the average mature cotton stalk initiated floral production within a period of ca. 6.0 wks, and produced a cumulative 22.0 floral structures during the subsequent 25-wk period (equivalent to ca. 2.1 million/ha, based on mean plant density of 9.7 plants/m^2) (Table 1). The average stalk shredded during 1986 (29 August) initiated floral production within ca. 4.0 wks, and produced a cumulative 68.7 floral structures during the subsequent 31-wk period (equivalent to ca. 4.7 million/ha, based on mean plant density of 6.3 plants/m^2). Despite differences in magnitude of plant growth rates and productivity (which presumably reflected generally higher temperatures, greater precipitation and a slightly longer study period during 1986-1987), two important similarities were evident: following shredding operations, floral initiation occurred within a period of several weeks, and the average stalk produced floral structures continuously and in abundance throughout the fall-spring period.

TABLE 1. Seasonal Reproduction by Overwintering Boll Weevils on Cotton Regrowth in the Lower Rio Grande Valley of Texas.

Year	Month	Temperature (°C) Mean	Temperature (°C) Range	Rain (cm)	No. per hectare[a] Fruit	No. per hectare[a] Eggs	No. per hectare[a] Adults
1985[b]	Oct.	24.8	11.7-32.8	10.2	0	0	0
	Nov.	22.8	7.2-30.6	2.5	73,900	36,500	1,000
	Dec.	15.8	-1.1-31.7	1.0	213,700	68,000	8,500
1986	Jan.	16.1	2.2-27.2	2.8	172,600	63,200	29,000
	Feb.	18.8	3.9-34.4	0.5	581,700	276,500	78,000
	Mar.	20.6	5.0-32.8	<0.01	1,037,100	672,100	366,000
1986[c]	Sep.	29.1	22.2-35.6	4.3	38,000	3,000	3,000
	Oct.	24.6	11.1-35.6	11.7	1,320,000	647,000	432,200
	Nov.	19.3	3.3-31.1	19.6	1,973,000	1,817,000	898,500
	Dec.	15.7	3.3-26.7	6.1	947,000	1,052,000	341,400
1987	Jan.	15.2	1.1-26.7	6.4	121,000	92,000	40,000
	Feb.	17.8	6.7-30.0	5.8	45,000	16,000	7,142
	Mar.	17.9	1.1-29.4	1.5	159,000	111,000	22,857

[a] Estimates based on 9.7 plants/m^2 (1984-1985) and 6.3 plants/m^2 (1986-1987).
[b] Stalks shredded 11 October; collections terminated 19 March (compiled from Summy et al. 1986).
[c] Stalks shredded 29 August; collections terminated 30 March.

Reproductive patterns of boll weevil on cotton regrowth also exhibited several important similarities (Table 1). Oviposition commenced with availability of large (>5mm) squares and continued throughout the fall-spring period, resulting in estimated egg production of 11.6 eggs/plant during 1985-1986 (ca. 1.1 million eggs/ha), and 59.2 eggs/plant during 1986-1987 (ca. 3.7 million eggs/ha). Mortality sustained by cohorts during 1985-1986 (45.5-97.3%) and 1986-1987 (33.2-79.4%) occurred primarily among eggs and larvae and appeared to result primarily from dessication and other abiotic factors (Table 2). Egg mortality generally increased to maximum levels during the November-January period; however, a relatively high percentage of egg hatch occurring during this interval (50.5-55.3%) failed to corroborate a previous observation of substantial infertility during the mid-winter period (Guerra et al. 1982). One factor which may have contributed to both egg mortality and reduced oviposition during the mid-winter period was extensive feeding injury inflicted by adult weevils to fruiting structures of all sizes. Representatives of at least two parasite genera (Bracon and Catolaccus) were detected; however, parasitism consistently accounted for a relatively small percentage of observed real mortality (0-1.7%) occurring among immature stages. Despite such mortality, both studies clearly indicated a generally high rate of adult recruitment throughout the fall-spring period, which ranged from 5.0 adults/plant during 1985-1986 (ca. 483,000 adults/ha) to 25.4 adults/plant during 1986-1987 (ca. 1.7 million adults/ha).

Cultivated cotton thus provides a potentially vast and nearly optimal overwintering habitat for boll weevil in southern Texas. In contrast to temperate regions, in which subfreezing temperatures typically occur as early as November, climatic patterns of the LRGV region (Orton et al. 1967) tend to facilitate perennial growth of cotton plants, which may produce fruiting structures continuously and in abundance during much or all of the fall-spring period. Moreover, fields of undestroyed cotton typically exhibit relatively high

TABLE 2. Seasonal Mortality of Boll Weevil on Cotton Regrowth in the Lower Rio Grande Valley (1986-1987).

Month	N	% Real Mortality[a/]	% Apparent Mortality[b/]			
			Eggs	Larvae	Pupae	Adults
Oct	178	33.2	26.4	29.8	0.0	0.0
Nov	418	50.6	44.7	35.9	0.0	0.0
Dec	660	67.5	49.5	27.3	0.4	0.8
Jan	65	56.5	46.2	11.4	0.0	9.6
Feb	11	55.6	18.2	33.3	0.0	16.7
Mar	58	79.4	27.6	47.6	4.3	23.8

[a/] Observed mortality/original cohort size.
[b/] Observed mortality/numbers entering particular life stage.

plant densities (75,000-125,000 plants/ha) and may comprise a substantial total area, as exemplified by results of an aerial surveillance program (Table 3).

Although previous research has documented both biochemical and behavioral evidence of adult reproductive diapause in the LRGV boll weevil population (Keeley et al. 1977, Graham et al. 1978, 1979), overwintering adults (or at least a segment thereof) clearly exhibit a propensity for continuous reproduction in the presence of fruiting cotton. In addition to a generally high rate of adult recruitment occurring on undestroyed volunteer and regrowth cotton, such habitat also appears to be essential for development of other important overwintering strategies, e.g., adult reproductive diapause and survival (of adults and immature stages) within crop residue following plant death due to subfreezing temperatures or late crop termination (Summy et al. 1988).

New stalk destruction legislation enacted by the Texas Legislature during 1987 enhanced the prospects for a substantial curtailment or elimination of boll weevil reproduction and other survival processes occurring on volunteer and regrowth cotton (Summy et al. 1988). Given the potential for substantial weevil reproduction during the fall and winter months, however, expedient postharvest destruction of cotton stalks during the late summer period, and an effective region-wide approach to stalk destruction, remain the two critical elements if such a strategy is to be successfully implemented against boll weevil in southern Texas.

TABLE 3. Cultivated Cotton Acreage in the Lower Rio Grande Valley of Texas (1982-1986) and Estimated Abundance of Undestroyed Cotton Detected by Aerial Surveillance.[a/]

Year	Cotton (ha)	
	Planted	Undestroyed[b/]
1982	91,000	11,140
1983	68,800	300
1984	97,200	>20,000
1985	120,600	>20,000
1986	101,200	>20,000[c/]

[a/] Modified from Summy et al. (1988).
[b/] Volunteer and regrowth cotton detected by aerial surveillance during October-November.
[c/] Sequential surveys detected ca. 1,620 ha of volunteer and regrowth cotton during January, 1987, much of which remained intact until April.

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LITERATURE CITED

Bergmann, D., T. J. Henneberry, and L. A. Bariola. 1983. Overwintering boll weevil populations in southwestern Arizona cultivated cotton, pp. 182-185, In Proc. Beltwide Cotton Prod. Res. Conf., San Antonio, TX.

Burke, H. R. and W. E. Clark. 1976. Cienfuegosia drummondi as a host of the boll weevil, Anthonomus grandis, in south Texas, pp. 12-21, In Boll Weevil Suppression, Management, and Elimination Technology. U. S. Dep. Agric. ARS-S-71.

Cross, W. H., M. J. Lukefahr, P. A. Fryxell, and H. R. Burke. 1975. Host plants of the boll weevil. Environ. Entomol. 4: 19-26.

Fye, R. E., J. E. Leggett, and C. D. Bonham. 1970. Winter survival of the boll weevil complex in Arizona. J. Econ. Entomol. 63: 1071-1074.

Graham, H. M., N. S. Hernandez, Jr., J. R. Llanes, and J. Tamayo. 1978. Overwintering habitats of the boll weevil in the Lower Rio Grande Valley, Texas. Environ. Entomol. 7: 345-348.

Graham, H. M., N. S. Hernandez, Jr., J. R. Llanes, and J. Tamayo. 1979. Seasonal incidence of diapause in boll weevil populations in the Lower Rio Grande Valley of Texas. Southwest. Entomol. 4: 170-175.

Guerra, A. A., R. D. Garcia, and J. A. Tamayo. 1982. Physiological activity of the boll weevil during the fall and winter in subtropical areas of the Rio Grande Valley of Texas. J. Econ. Entomol. 75: 11-15.

Keeley, L. L., D. S. Moody, D. Lynn, R. L. Joiner, and S. B. Vinson. 1977. Succinate-cytochrome c reductase activity and lipids in diapause and non-diapause Anthonomus grandis from different latitudes. J. Insect Physiol. 23: 231-234.

Orton, R., D. J. Haddock, E. G. Bice, and A. C. Webb. 1967. Climatic guide: The Lower Rio Grande Valley. Texas Agric. Exp. Stn. Misc. Publ. 841.

Summy, K. R., M. D. Heilman, L. N. Namken, and W. G. Hart. 1986. Control of boll weevils (Coleoptera: Curculionidae) through crop residue disposal: Destruction of subtropical cotton under inclement conditions. J. Econ. Entomol. 79: 1662-1665.

Summy, K. R., W. G. Hart, M. R. Davis, J. R. Cate, J. W. Norman, Jr., C. W. Wofford, Jr., M. D. Heilman, and L. N. Namken. 1988. Regionwide management of boll weevil in southern Texas. In Proc. Beltwide Cotton Prod. Res. Conf., New Orleans, LA. (In press).

LABORATORY STUDIES OF CHRYSOPERLA CARNEA [1] PREDATION ON BEMISIA TABACI [2/3]

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ABSTRACT

Common green lacewing, Chrysoperla carnea (Stephens), larvae consumed all immature stages of the sweetpotato whitefly, Bemisia tabaci (Gennadius). First stage lacewing larvae consumed sweetpotato whitefly eggs and larvae in about the same time, and second stage lacewing larvae consumed B. tabaci eggs more rapidly than did first stage lacewing larvae. Third stage lacewing larvae consumed whitefly pupae in 33 to 78 seconds.

Sweetpotato whitefly adults avoided cotton leaves when lacewing larvae were present and for several days after lacewing larvae were gone. This behavior resulted in significantly fewer whitefly larvae on cotton leaves previously frequented by lacewing larvae.

INTRODUCTION

Bemisia tabaci (Gennadius), the sweetpotato whitefly, is a serious pest of cotton, Gossypium spp., in many areas of the world. It is difficult to control with conventional insecticide application technology because immature forms are distributed on the underside of leaves on the lower portion of the plant canopy (Gerling et al. 1980), and insecticide resistance has developed (Prabhaker et al. 1985).

The role of natural enemies in regulating sweetpotato whitefly populations is not well understood. Worldwide outbreaks of the species have appeared to intensify since the introduction of synthetic organic insecticides (Anonymous 1981). A review of natural enemy records shows that a large number of parasite species, as well as chrysopid, coccinelid and several phytoseiid mite species, are known predators of the sweetpotato whitefly, which suggests that these predators may reduce population density (Butler et al. 1986). Euseuis hibisci (Chant), a phytoseiid mite, was reported to feed on and develop to the adult stage on a mixed diet of B. tabaci eggs and first- and second-instar larvae (Meyerdirk and Coudriet 1985). Several additional phytoseiid mite species have been reported to prey on B. tabaci (Teich 1966, Elbadry 1967, Swirski and Dorzia 1968, 1969, Swirski et al. 1970, and Gameel 1971) and appeared to reduce populations in the field (Teich, 1966; Gameel, 1971). Whitefly populations were observed in Israel during 1987 by the senior author. Whitefly adult populations increased slowly during August and early September in untreated cotton compared with an exponential buildup of adults in insecticide-treated cotton. On 16

1/ Neuroptera: Chrysopidae.
2/ Homoptera: Aleyrodidae.
3/ This paper presents the results of research only. Mention of a proprietary product does not constitute an endorsement by the USDA.

September there were 3.5 ± 2.0 whitefly pupae per leaf and 5.6 ± 3.5 Phytoseiulus persimilis Athias-Henriot adults and immatures per leaf on untreated cotton, but in insecticide-treated cotton there were 23.8 ± 4.0 whitefly pupae per leaf and no predaceous mites. Thus, the potential impact of predation on sweetpotato whitefly populations needs to be determined.

Detailed studies on the common green lacewing, Chrysoperla carnea (Stephens), have been conducted in Arizona on development at constant and fluctuating temperatures (Butler and Ritchie 1970), on the searching capacity of larvae for Heliothis spp. eggs in laboratory studies (Butler and May 1971), on timing of field releases of eggs and larvae (Butler and Hungerford 1971), and on Feed Wheast applications to increase abundance and fecundity (Butler and Ritchie 1971). Or and Gerling (1985) studied the common green lacewing in relation to sweetpotato whitefly populations on cotton in Israel. They found that lacewings already present in the cotton habitat develop and reproduce in whitefly-infested cotton fields. Development of lacewing larvae fed whitefly eggs and larvae was approximately 2 days slower than when fed other hosts. The authors concluded that adult lacewings were not attracted to whitefly-infested fields and that lacewing population buildup was slowed by low oviposition and slow immature developmental rates. During whitefly studies in Managua, Nicaragua, the senior author observed many adults of a green lacewing (species not determined) around weeds infested with whitefly adults. In preliminary studies in small cages in the insectary, two lacewing adults per cage consumed an average of 35 adult whiteflies, and a single adult per cage consumed about half that number. Those results prompted us to conduct laboratory and greenhouse studies at Phoenix, Arizona in 1987 to more fully define C. carnea predation on sweetpotato whitefly life forms. The present paper is a report of these studies.

MATERIALS AND METHODS

Several hundred sweetpotato whitefly adults were collected with a vacuum cleaner aspirator from cotton plants growing in a greenhouse. The insects were introduced into 105 x 68 x 105-cm screen cages containing 'Stoneville 825' cotton plants growing in plastic pots to obtain plants infested with various whitefly stages. The C. carnea used in these studies were obtained as eggs and pupae from Vitova Insectaries, Inc., Oak View, CA. Eggs were held at 25°C in the containers with Sitotroga cerealella (Oliver) eggs and rice hulls in which they were received until used in the studies.

Newly emerged adult lacewings were placed on whitefly-infested leaves and observed to determine their ability to attack whitefly immature stages. The time required for 1st, 2nd, and 3rd stage lacewing larvae to consume the various life stages of the whitefly was determined by placing the appropriate lacewing stage on cotton leaves with whitefly eggs, 1st or 2nd stage larvae or pupae. A cotton leaf infested with the appropriate whitefly stage and lacewing larva was observed under a microscope. The time of initial contact of the lacewing larva with the whitefly life stage and the time when consumption of the stage occurred or the lacewing larva left the host was recorded.

The effect of the presence of lacewing larvae on cotton leaves on subsequent whitefly adult visitation and population development was determined. Ten lacewing larvae were placed on each of 3 leaves of 10 cotton plants having 3-4 leaves and on each of 3 leaves of 8 cotton plants having 6 leaves. Plants with lacewing larvae were placed in cloth screen cages, and adult whiteflies were then introduced as previously described. One or 2 days later, and for 4 to 6 days thereafter, the average number of whitefly adults per three cotton

leaves was counted on lacewing-treated plants and on an equal number of untreated plants. In one experiment, leaves were cut from the lacewing-treated and untreated plants and taken to the laboratory; and the number of whitefly larvae were counted with the aid of a microscope.

The data were analyzed using Student's "t" test for paired mean difference comparisons.

RESULTS AND DISCUSSION

The adult C. carnea in our study did not feed on sweetpotato whitefly adults, in contrast to the behavior of the lacewing adults observed in Nicaragua, suggesting another species occurs there. Also, lacewing adults in our study did not feed on whitefly eggs. C. carnea has been reported not to be entomophagous in the adult stage (Toschi 1965).

Lacewing larvae of all stages voraciously attacked the various whitefly stages presented on the cotton leaves (Table 1). First-stage lacewing larvae took about the same amount of time to consume both whitefly eggs and 1st-stage larvae. The time lacewing larvae took to consume 2nd-stage whitefly larvae varied greatly as indicated in the two series of observations, probably because of different ages of the lacewing larvae and the amount of prior feeding. Several 1st stage lacewing larvae were observed to have their mandibles positioned to feed on whitefly pupae, but they were unsuccessful in penetrating the sclerotized pupal case. One 1st-stage larva was successful and fed for 4.3 minutes. Second stage lacewing larvae consumed whitefly eggs in about 15 sec. as compared to 28 sec. for 1st-stage lacewing larvae. One 2nd-stage lacewing larva consumed a whitefly adult in almost 4 min. Generally a 3rd-stage lacewing larva would begin feeding on a pupa and then reposition itself to continue feeding until all the body contents were totally consumed. One individual partially consumed the whitefly pupa first attacked and then moved on to feed on other pupae, thus killing several of them.

TABLE 1. Mean Time in Seconds for C. carnea Larvae to Consume Sweetpotato Whitefly Eggs, Larvae and Pupae.

	Whitefly			
			Time consumed	
Lacewing Larval Stage	Stage	No.	$\bar{x}$	± S.D.
1st	Egg	25	28.0	9.6
	Larval (1st)	38	28.0	12.9
	Larval (2nd)	22	16.7	5.8
		20	48.2	16.5
	Pupal	1	260.0	
2nd	Egg	25	15.0	5.7
	Adult	1	238.0	
3rd	Pupal	8	78.0	20.5
		17	33.2	10.5

When 10 1st-stage lacewing larvae were placed on each of 3 leaves on a cotton plant having either 3-4 or 6 leaves, there was a significant reduction in the number of adult whiteflies present on the leaves 2 days later (Table 2). This reduction continued for at least five days, even

though the lacewing larvae had died or moved off the cotton leaves 2 days after placement on them. Similar results were obtained in another test, and the reduced adult whitefly visitations and oviposition activity on the plants in the presence of lacewing larvae resulted in significantly fewer 1st stage whitefly larvae present 6 days after the lacewing larvae had been placed on the plants (Table 3).

TABLE 2. Mean[a] Number of Sweetpotato Whitefly Adults Per Three Cotton Leaves on Different Dates Following the Placement of Ten Lacewing Larvae On Each of Three Leaves.

Days following lacewing introduction	No. Whitefly Adults On Lacewing-treated	Untreated	t[b]
	3-4 leaf plants		
2	7	65	9.88 **
3	10	67	9.16 **
4	12	61	8.52 **
5	18	47	4.01 **
	6-leaf plants		
2	8	34	4.40 **
3	11	37	3.62 **
4	10	37	3.65 **

[a] Means of 10 and 8 replicates from 3-4 and 6-leaf plants, respectively.
[b] Double asterisks (**) indicate that means are significantly different ($P \leq 0.01$).

TABLE 3. Mean[a] Number of Sweetpotato Whitefly Adults Per Three Cotton Leaves on Different Dates, and Number of First-Stage Larvae After Ten Lacewing Larvae Were Put on Each Leaf.

Days following lacewing introduction	Lacewing-treated	Untreated	t[b]
	No. Whitefly Adults		
1	16	59	5.22 **
2	56	161	4.78 **
3	55	153	3.97 **
6	62	103	1.53 NS
	No. Whitefly Larvae		
6	194	1322	5.27 **

[a] Means of 8 replicates.
[b] Double asterisks (**) indicate that means are significantly different ($P \leq 0.01$).

Common green lacewings are prevalent in cotton habitats in the arid southwestern desert cotton growing areas, and they are considered part of the predator species complex that regulates populations of several important pest species (Telford and Hopkins 1957, van den Bosch and Hagen 1966).

Although a number of reports of whitefly predation by green lacewing species have been recorded worldwide (Anonymous 1981), little effort has been made to establish the importance of the predator in whitefly population dynamics. Or and Gerling (1985) found that C. carnea developed more slowly on whitefly immature stages than on other reported hosts, and adults were not attracted to cotton plants with whitefly honeydew. The authors suggested that lacewings present in the cotton habitat may continue to develop in whitefly-infested cotton fields; but since additional adults are not attracted, lacewing population increase will be slowed by low oviposition and immature development rates, limiting their potential to regulate whitefly populations. Another possible host interaction of C. carnea populations is with populations of the cotton aphid, Aphis gossypii Glover. Cotton aphids increase the supply of suitable lacewing hosts throughout the growing season, which may result in higher lacewing populations that could reduce whitefly populations. These prey-predator interactions are virtually uninvestigated and should be studied carefully.

Augmenting the lacewing population in cotton by inundative releases, as suggested by Ridgway and Jones (1968), should be considered, particularly since insecticide-resistant lacewing strains are being used to establish commercial cultures. Tauber and Tauber (1983) suggested that Chrysopa rufilabris Burmeister should be utilized in augmentation systems. The authors found that C. rufilabris was better adapted for humid regions. However, in desert areas such as the Imperial Valley, CA, dense cotton growth under flood irrigation could provide a suitable habitat for that species.

The results of our studies show that immature stages of the common green lacewing feed on the whitefly in all stages of development except third stage whitefly larvae, which were not evaluated. Our studies also indicate that the presence of green lacewing larvae on cotton leaves inhibited adult whitefly visitation and oviposition on those leaves. Although this result may have occurred because of visual or olfactory detection of the predator by whitefly adults, the effect appeared to persist even after the lacewing larvae had left the leaves. Semiochemicals that influence spacing patterns and overcrowding of phytophagous insects have been discovered (Prokopy 1981), and similar phenomena may occur in the common green lacewing to reduce competition for hosts. The results suggest some olfactory or other avoidance mechanism that is operative as a whitefly survival mechanism. Further investigation of this phenomenon might lead to the identification of a volatile chemical that could be developed to repel whitefly adults.

LITERATURE CITED

Anonymous. 1981. Possibilities for the use of biotic agents in the control of the whitefly, Bemisia tabaci. Biocontrol News and Information, Commonwealth Institute of Biological Control. 2: 1-7.

Butler, G. D., Jr., and P. L. Ritchie, Jr. 1970. Development of Chrysopa carnea at constant and fluctuating temperatures. J. Econ. Entomol. 63: 1028-1030.

Butler, G. D., Jr., and C. M. Hungerford. 1971. Timing field releases of eggs and larvae of Chrysopa carnea to insure survival. J. Econ. Entomol. 64: 311-312.

Butler, G. D., Jr., and C. J. May. 1971. Laboratory studies of the searching capacity of larvae of Chrysopa carnea for eggs of Heliothis spp. J. Econ. Entomol. 64: 1459-1461.

Butler, G. D., Jr., and P. L. Ritchie, Jr. 1971. Feed wheast and the abundance and fecundity of Chrysopa carnea. J. Econ. Entomol. 64: 933-934.

Butler, G. D., Jr., T. J. Henneberry, and W. D. Hutchison. 1986. Biology, sampling and population dynamics of Bemisia tabaci. pp. 167-195. In G. E. Russell (ed.), Agricultural Zoology Reviews. Intercept. Ponteland, Newcastle Upon Tyne, England.

Elbadry, E. A. 1967. Three new species of phytoseiid mites preying on the cotton whitefly, Bemisia tabaci, in the Sudan (Acarina: Phytoseiidae). Entomologist. 100: 106-111.

Gameel, O. I. 1971. The whitefly eggs and first larval stages as prey for certain phytoseiid mites. Rev. Zool. Bot. Afr. 84: 79-82.

Gerling, D., U. Motro, and R. Horowitz. 1980. Dynamics of Bemisia tabaci (Gennadius) (Homoptera: Aleyrodidae) attacking cotton in the coastal plain of Israel. Bull. Entomol. Res. 70: 213-219.

Meyerdirk, D. E., and D. L. Coudriet. 1985. Predation and developmental studies of Euseius hibisci (Chant) (Acarina: Phytoseiidae) feeding on Bemisia tabaci (Gennadius) (Homoptera: Aleyrodidae). Environ. Entomol. 14: 24-27.

Or, R., and D. Gerling. 1985. The green lacewing, Chrysoperla carnea, as a predator of Bemisia tabaci. Phytoparasitica. 13: 75.

Prabhaker, N., D. L. Coudriet, and D. E. Meyerdirk. 1985. Insecticide resistance in the sweetpotato whitefly, Bemisia tabaci (Homoptera: Aleyrodidae). J. Econ. Entomol. 78: 387-409.

Prokopy, R. J. 1981. Epideictic pheromones that influence spacing patterns of phytophagous insects. pp. 181-213 In D. A. Nordlund, R. L. Jones and W. J. Lewis (Eds). Semiochemicals: Their Role in Pest Control. John Wiley and Sons, Inc., New York, NY, 306 pp.

Ridgway, R. L., and S. L. Jones. 1968. Field-cage releases of Chrysopa carnea for suppression of populations of the bollworm and tobacco budworm on cotton. J. Econ. Entomol. 61: 892-898.

Swirski, E., and N. Dorzia. 1968. Studies on the feeding, development and oviposition of the predacious mite Amblyseius limonicus Garman and McGregor (Acarina: Phytoseiidae) on various kinds of food substances. Isr. J. Agr. Res. 18: 71-75.

Swirski, E., and N. Dorzia. 1969. Laboratory studies on the feeding, development and fecundity of the predacious mite Typhlodromus occidentalis Nesbitt (Acarina: Phytoseiidae) on various kinds of food substances. Isr. J. Agr. Res. 19: 143-145.

Swirski, E., S. Amitai, and N. Dorzia. 1970. Laboratory studies on the feeding habits, post-embryonic survival and oviposition of the predacious mites, Amblyseius chilenensis Dosse and Amblyseius hibisci Chant (Acarina: Phytoseiidae) on various kinds of food substances. Entomophaga. 15: 93-106.

Tauber, M. J., and C. A. Tauber. 1983. Life history traits of Chrysopa carnea and Chrysopa rufilabris (Neuroptera: Chrysopidae): Influence of humidity. Ann. Entomol. Soc. Am. 76: 283-285.

Teich, Y. 1966. Mites of the family Phytoseiidae as predators of the tobacco whitefly, Bemisia tabaci Gennadius. Isr. J. Agr. Res. 16: 141-142.

Telford, A. D., and L. Hopkins. 1957. Arizona cotton insects. Ariz. Agr. Expt. Sta. Bull. 286.

Toschi, C. A. 1965. The taxonomy, life histories, and mating behavior of the green lacewings (Neuroptera: Chrysopidae) of Strawberry Canyon. Hilgardia. 36: 391-433.

van den Bosch, R., and K. S. Hagen. 1966. Predacious and parasitic arthropods in California cotton fields. Calif. Agric. Exp. Sta. Bull. 820.

DEVELOPMENT OF ONION THRIPS, THRIPS TABACI[1] LINDEMAN, AS A FUNCTION OF TEMPERATURE

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ABSTRACT

Developmental rate of onion thrips, Thrips tabaci Lindeman, was determined under constant and fluctuating temperature conditions. A degree-day (DD) model for predicting development in the field was developed from these data. An estimated 191.1 DD were required for thrips to develop from egg to ovipositing adult female (base temperature = 11.5°C). Under fluctuating temperature conditions in the greenhouse, development from egg to mature female took 228.2 DD (base temperature = 11.5° C) which differed from the predicted estimate by 37 DD. Cool weather conditions as experienced in south Texas during December, January and February approximate the lower developmental thresholds for onion thrips and may explain lack of large populations in onion fields during these months.

INTRODUCTION

Onion thrips, Thrips tabaci Lindeman, is the major arthropod pest of onions grown in south Texas and has previously been shown to cause onion bulb yield reductions (Edelson et al. 1986). Therefore, pest management programs are being developed to aid producers in optimizing control programs. Essential to the development of an integrated pest management program for thrips is a knowledge base of the general biology of the species.

A major need is a method of predicting population development in the field. Previous research has shown that temperature determines the growth and development rate of insects and insect populations (Sharpe and DeMichele 1977), although development is often mediated by additional factors (Taylor 1981). A systems approach to managing agroecosystems, such as the onion production system in south Texas, is dependent upon development of a plant model and models of factors that influence plant growth.

Various researchers have evaluated onion thrips development (Lall and Singh 1968, Quartey 1982, Sakimura 1932) but either did not use onions as food sources, did not develop rate models or verify models under fluctuating

[1] Thysanoptera: Thripidae

temperature conditions. Research reported herein was conducted to develop a degree-day model describing the development rate of onion thrips feeding on onion. This model was subsequently verified under fluctuating greenhouse temperature conditions.

MATERIALS AND METHODS

A culture of onion thrips was established from specimens removed from onions grown in a field at the Texas Agricultural Research and Extension Center, Weslaco in 1987. Thrips were maintained on whole green onions in covered plastic containers provided with screened openings for ventilation. Pupating thrips were removed from the bottom of the container and placed individually in 30 ml creamer cups and held in chambers at 25° C. Cups were monitored at 24-h intervals for adult eclosion. Date of eclosion was noted, and a 3 - 4 cm section of onion leaf was placed in each cup with the adult thrips. A circular piece of filter paper was placed in each cup to absorb excess moisture.

One hundred twenty adult thrips were isolated in containers and 20 randomly assigned to be held at each of six constant temperatures - 10, 15, 17.5, 20, 25, and 27.5° C. The onion leaf tissue in each cup was replaced with new tissue at 24-h intervals. The tissue removed from the cups was labeled with date of exposure to adult thrips and held at the same constant temperature as the adult from which it was removed. Tissue was then monitored at 24-h intervals to determine when adults first laid eggs (preoviposition period) and the length of the incubation period, as indicated by subsequent egg eclosion. Twenty neonate larvae from each temperature were individually isolated in creamer cups with onion leaf tissue and held at the same constant temperature as the parental adult.

Larval thrips were monitored at 24-h intervals, and fresh onion leaf tissue supplied as necessary. Pupation and adult eclosion were noted at 24-h intervals.

Onion leaf tissue of the same size and origin was held in creamer cups without being exposed to thrips. This tissue was held for 10 days at 25°C. These were monitored throughout the experiments as a check to be certain that no thrips or eggs were being introduced from outside the experimental constraints.

Twenty thrips were isolated in a duplicate series of creamer cups and placed in a greenhouse under fluctuating temperatures. The same protocol was followed as in the constant temperature experiments. A hygrothermograph placed next to the cups in the greenhouse recorded temperatures.

Days to first oviposition (preoviposition period), egg eclosion (incubation period), and larval eclosion to development of adult (immature period) were recorded for each thrips at each temperature in the laboratory and greenhouse. Mean development time for each life stage was determined for each temperature.

The reciprocal of mean number of days for each stage was regressed on temperature, and results were used to determine lower development thresholds. Lower development thresholds were then used as base temperatures in calculation of degree-days (Arnold 1960) for development of each life stage and for the total life cycle. Degree-days calculated under constant temperature conditions were then compared to degree-days calculated from data collected under fluctuating temperature conditions in the greenhouse.

RESULTS AND DISCUSSION

Preoviposition period, egg incubation period, duration of larval stages and therefore total life cycle decreased as temperatures increased from 17.5 to 27.5° C (Table 1). No development was noted at 10 or 15° C, and experiments were terminated at these temperatures after 21 days. No thrips developed from onion tissue held as checks without being exposed to adult thrips.

Preoviposition periods varied from 5.7 days at 17.5° to 1 day at 27.5° C. Egg incubation period varied from 15.1 to 4.3 days at 17.5 and 27.5° C, respectively. Larval emergence from egg to adult eclosion varied from 15.3 to 6.8 days at 17.5 and 27.5° C, respectively. Total life cycle from oviposition of an egg to oviposition by the adult from that egg ranged from 30.4 days at 17.5° to 11.1 days at 27.5° C (Table 1).

TABLE 1. Mean Number of Days and Associated Standard Deviations (sd) for Developmental Periods at Constant and Fluctuating Temperatures.

Temperature °C	Pre-oviposition $\bar{x}$	Pre-oviposition sd	Egg Incubation $\bar{x}$	Egg Incubation sd	Larva to Adult $\bar{x}$	Larva to Adult sd	Total Life Cycle $\bar{x}$
27.5	1.0	0	4.3	0.48	6.8	0.63	11.1
25.0	1.1	0.32	6.0	0.94	7.3	1.06	13.3
20.0	3.2	0.42	8.4	0.84	11.9	0.57	20.3
17.5	5.7	0.67	15.1	0.88	15.3	1.34	30.4
FT[a]	1.0	0.52	4.6	0	8.6	0.52	14.4

[a]FT = fluctuating temperature conditions as recorded in a greenhouse (maximum = 39°C, minimum = 18.9°C, mean = 26.7°C).

Lall and Singh (1968) reported that the onion thrips' life cycle on onion took an average of 17.5 days at an average temperature of 22° C over a 4-mon period. Sakimura (1932) reported that onion thrips were polyphagous in Hawaii, and that the life cycle on various host plants in the field averaged 18.5 days at a mean monthly temperature of 24° C. Quartey (1982) conducted laboratory rearing experiments with onion thrips on onions at constant temperatures and reported

development time for the immature stage to adult was 13.2 (± 2.3) days at 20° C. We found that the mean development time at 20° C was 11.9 (± 0.6) days which does not vary significantly from Quartey's (1982) results.

Quartey (1982) reported the lower developmental threshold for the total life cycle (defined as egg hatch to adult) was 7.4° C. Our determination of the lower developmental threshold indicated a threshold of 11.5° C (Table 2) which differs considerably from Quartey (1982). However, our calculations include development of the egg and preoviposition period which were not included in Quartey's (1982) calculations.

TABLE 2. Regression Equations (P = 0.01) Describing Development Rate of Thrips tabaci Growth Stages as a Function of Temperature.

Stage	Regression Equation	r^2	Lower Threshold Temperature (°C)
Pre oviposition	y = -1.4255 + 0.0906(x)	0.95	15.7
Egg	y = -0.2005 + 0.0155(x)	0.96	12.9
Larva to Adult	y = -0.0923 + 0.0090(x)	0.98	10.2
Total Life Cycle	y = -0.0644 + 0.0056(x)	0.99	11.5

Significant linear relations (P = 0.05) were indicated for the regressions of the reciprocals of development periods on temperatures for each life stage period (Table 2). Extrapolation of the regression lines allowed us to estimate lower development thresholds of 10.2° for the larval stages, 12.9° for egg incubation period, 15.7° for adult preoviposition period and 11.5° for the total life cycle. Degree-days determined using the lower development thresholds as base temperatures for the different life stages are shown in Table 3.

Mean number of days for development of eggs (egg incubation period), larvae to adults, and adult preoviposition period under greenhouse (fluctuating temperature) conditions are shown in Table 1. The maximum temperature recorded was 39°C, the minimum was 18.9°C and mean temperature over the entire experimental period was 26.7°C. Eggs hatched in 4.6 days; larvae developed to adults in 8.6 days, and adults began ovipositing at 1.0 days. Total life cycle from egg hatch to an ovipositing adult was 14.4 days.

Development of an ovipositing adult female thrips took a mean (± sd) of 191 (±0.9) degree-days as calculated from constant temperature data from laboratory experiments (Table 3). Results of studies conducted in the greenhouse yielded

an estimated mean development period of 228 degree-days or 37 degree-days slower than indicated in the laboratory. Logan et al. (1985) suggested possible sources of variability that may account for differences in development using constant versus fluctuating temperature experimental conditions. Error, for example, may result from lack of compensation with constant temperature in allowing for changes from one rate-controlling mechanism to another at extreme temperatures. Variability in data, and thus possible sources of error, are introduced through the temperature cabinets ($\pm 1^{o}C$) and through methods of recording and reading of temperatures (hygrothermograph in the greenhouse).

TABLE 3. Degree-Days (DD) and Standard Deviations (sd) for each Developmental Stage for the Onion Thrips under Constant and Fluctuating Temperatures (FT) in a Greenhouse.

Temp. ^{o}C	Pre-Oviposition DD	sd	Egg Incubation DD	sd	Larva To Adult DD	sd	Total Life Cycle DD	
27.5	11.8	0	62.8	7.0	117.6	10.9	192.2	
25.0	10.3	3.1	72.6	11.4	108.0	15.7	190.9	
20.0	13.6	1.7	59.6	6.0	116.6	5.6	190.0	
17.5	10.2	1.2	69.5	4.0	111.6	9.8	191.4	
$\bar{x}$	11.5	1.6	66.1	6.0	113.4	4.5	191.1	± 0.9
FT[a]	12.8	0.3	82.6	8.8	132.8	8.2	228.2	

[a]FT = fluctuating temperature conditions as recorded in a greenhouse (maximum=$39^{o}C$, mininum=$18.9^{o}C$, mean=$26.7^{o}C$).

Onions are grown from October through April in south Texas. Average monthly temperatures in south Texas during December, January, and February are 17, 18 and 18^{o} C, respectively, and thus approach the predicted lower developmental thresholds (Table 2) for onion thrips. The predicted periods for development from oviposition of an egg to subsequent ovipositing adult female were 35, 29 and 29 days for December, January and February, respectively. Predicted periods for the same development in March and April were 23 and 15 days, respectively. Therefore, thrips populations should not build rapidly during December, January and February in comparison to development in March and April.

Resources expended on pest management efforts, such as time spent in scouting fields or applying pesticides, should be concentrated during the last months of the growing season (March and April, 20 and 24^{o} C mean monthly temperatures) as temperatures begin increasing. Edelson et al. (1986) indicated that significant populations of thrips (> 1 per plant for more than 2 consecutive weeks) did not occur until late March.

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LITERATURE CITED

Arnold, C. T. 1960. Maximum-minimum temperature as a basis for computing heat units. J. Am. Soc. Hort. Sci. 76: 682-692.

Edelson, J. V., B. Cartwright and T. A. Royer. 1986. Distribution and impact of Thrips tabaci (Thysanoptera: Thripidae) on onion. J. Econ. Entomol. 79: 502-505.

Lall, B. S., and Singh, L. M. 1968. Biology and control of the onion thrips in India. J. Econ. Entomol. 61: 676-679.

Logan, P. A., R. A. Casagrande, H. H. Faubert and F. A. Drummond. 1985. Temperature-dependent development and feeding of immature Colorado potato beetles, Leptintarsa decemlineata (Say) (Coleoptera: Chrysomelidae). Environ. Entomol. 14: 275-283.

Quartey, S. 1982. Population dynamics of the onion thrips, Thrips tabaci Lindeman, on onions. Ph.D. Dissertation. Michigan State University. East Lansing, Michigan.

Sharpe, P. J. H. and DeMichele, D. W. 1977. Reaction kinetics of poikilothermic development. J. Theor. Biol. 64: 649-670.

Sakimura, K. 1932. Life history of Thrips tabaci L. on Emilia sagittata and its host plant range in Hawaii. J. Econ. Entomol. 25: 884-891.

Taylor, F. 1981. Ecology and evolution of physiological time in insects. Am. Nat. 117: 1-23.

SPIDER[1/] AND ANT[2/] PREDATORS OF THE COTTON FLEAHOPPER[3/] ON WOOLLY CROTON

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ABSTRACT

A field release radiotracer method was used to identify the predators of third to fifth instar cotton fleahopper, Pseudatomoscelis seriatus (Reuter), on dense stands of woolly croton in east central Texas. Estimated consumption rates of fleahopper nymphs by the predators was based on the presence of phosphorus-32 transferred from the radiolabeled fleahoppers to their predators. Ten species of spiders and one species of ant preyed upon fleahoppers on woolly croton. Five radioactive fleahopper releases in 1986 and five in 1987 yielded 146 labeled predators. The spider species, in order of decreasing numbers of individuals detected, were Misumenops celer (Hentz), Phidippus audax (Hentz), Oxyopes salticus Hentz, Metaphidippus galathea (Walckenaer), Grammonota texana (Banks), Aysha gracilis (Hentz), Cheiracanthium inclusum (Hentz), Peucetia viridans (Hentz), Hentzia palmarum (Hentz), and Tetragnatha laboriosa Hentz. The ant species was Solenopsis invicta Buren. The abundance of these and other arthropods on woolly croton for 1986 and 1987 is presented.

INTRODUCTION

The cotton fleahopper, Pseudatomoscelis seriatus (Reuter), is currently considered the major pest of cotton in Texas, producing more yield loss than either Heliothis spp. or the boll weevil in 1987, and is ranked as the third most damaging cotton insect pest in the U.S. (King et al. 1988). Although the cotton fleahopper has many host plants, its preferred overwintering host is woolly croton, Croton capitatus (Michaux) (Almand et al. 1976, Gaylor and Sterling 1977, Holtzer and Sterling 1980). From September to November, fleahopper adults congregate on woolly croton plants and insert overwintering eggs into the stems. In the spring, the eggs hatch and the nymphs grow to adults that migrate to evening primrose (Oenothera spp.), horsemint (Monarda spp.) and an assortment of other species before moving to cotton (Almand et al. 1976).

Parasites of fleahopper nymphs and adults are not common, although overwintering egg parasites may occasionally have a significant effect on egg mortality (Ewing and Crawford 1939).

1/ Araneae
2/ Hymenoptera: Formicidae
3/ Hemiptera: Miridae

However, several predators of fleahopper nymphs and adults are known (Dean et al. 1987). Without a knowledge of the species of predators that consume fleahoppers, we are unlikely to reliably predict the effect of predators on the population dynamics of fleahoppers using TEXCIM (Texas cotton insect model), and hence their economic effect (Hartstack and Sterling 1988).

In cotton production, applying pesticides for early-season control of the fleahopper greatly reduces or destroys natural enemies of fleahoppers and other pests (Shepard and Sterling 1972). These applications can lead to further spraying to avoid economic damage by other cotton pests that later invade the fields, which are by then likely to be unoccupied by natural enemies. Knowledge of the predator complex of the fleahopper on the overwintering host plants will contribute to our understanding of fleahopper population regulation mechanisms. This information may lead to nonchemical, natural control methods, thereby preserving the beneficial arthropod populations in the cotton fields for the control of other cotton pests.

MATERIALS AND METHODS

The methods and materials used to irradiate and release immature cotton fleahoppers and the algorithms to transform counts or disintegrations per minute (CPM) data to estimate predation rates were discussed by Breene and Sterling (1988). The basic method consists of irradiating a cohort of immature fleahoppers by exposing the insects to 100 to 500 µCi phosphorus-32 (as H_3PO_4,in a 5% sucrose solution) for 1-3 h. After determining the mean CPM of the cohort of fleahoppers by measuring individuals after irradiation with liquid scintillation techniques (n=20 or more), the insects are field released on host plants. After 24 h, the host plants were sampled for labeled predators. The CPM of the radioactive predators is determined by liquid scintillation counting and an algorithm is used to calculate the number of individual prey items consumed by field captured predators (Breene and Sterling 1988). The algorithm requires species specific assimilation indices for both the prey and predator involved in the analysis. The rate of isotope loss by fleahoppers and the rate of decay was determined and used in the algorithm. The algorithm uses the CPM of the predator multiplied by the amount the predator species usually wastes from its feeding behavior in the numerator (values usually range from 1 to 2.5). The value of the numerator is divided by the average CPM of the released cohort of fleahoppers after the amount of radioisotope lost from the insect plus the decay after a specific period of time is taken into account.

In order to release radioactive biological material in Texas, a license must be granted to the principle investigator by the university radiological safety office. Each member of the research team handling radioisotopes must take a multi-week course for certification on radiation safety techniques.

The methods used for the mass rearing P. seriatus were described by Gaylor and Sterling (1977).

In 1986, 6,175 radiolabeled third to fifth instar fleahopper nymphs were released onto woolly croton in five releases during the period of 12 August to 23 September. In 1987, 4,710 labeled fleahopper nymphs were released five times from 2 Sep-

tember to 30 September. Experiments were conducted on land in which the top few cm of soil had been disturbed by heavy construction equipment during the previous midwinter, providing nearly ideal conditions for the growth of woolly croton. Land overgrazed by cattle and other poor ranch management tactics also provide situations conducive to the dense growth of woolly croton. In many patches of the research area, the woolly croton growth was nearly solid. In other patches on the site, woolly croton plants were separated by ten or more m. In 1986, the site was approximately 150 m wide by 0.75 km in length along a portion of route 6 approximately 4 km south of College Station, Texas. In 1987, the site had been reduced by road construction activity to approximately 200 by 150 m.

Two to fifteen radiolabeled fleahoppers were placed on each woolly croton plant (depending upon the size of the plant), and a string was used to mark the plant. The number of host plants used in each release was dependant on the varying size of the release cohort of fleahoppers. The marked host plants were cut at the base after 24 h and placed on a beat sheet in the field where all arthropods were inspected with a Geiger tube. Predators exhibiting evidence of radioactivity were captured and placed into 7 ml liquid scintillation vials and macerated, then counted using a Beckman 6800 liquid scintillation counter (Breene and Sterling 1988). A variation in capture methods was used for the red imported fire ant, Solenopsis invicta Buren, in 1987. Unlike 1986, all ants found on the release plants were placed in vials and taken through the liquid scintillation procedure without first checking for radiation with a Geiger tube. The technique was used since the radioactive ants generally had a CPM too low to register clearly on the Geiger tube.

The woolly croton was sampled to identify the arthropod complex inhabiting the plants. In 1986, the woolly croton was sampled nine times between 20 August and 20 October. In 1987, sampling was completed eight times between 7 September and 29 October at approximately weekly intervals. In 1986, an X pattern transecting the field was followed with 25 samples taken with a beat bucket (Pyke et al. 1980) from plant terminals every ten paces on each line of the X. These terminals (1 to 8, depending on plant growth patterns and size) were gathered in a handful and beat five times into the beat bucket.

In 1987, the existing woolly croton field had been reduced to a size too small for sampling with the technique used in 1986. A method was implemented where a starting point would be chosen in the southwestern corner of the field, and the 50 sampling points from there on were chosen at random from a two digit random number table. The first digit represented the number of paces north, the second east.

Voucher specimens reside in the insect collection of the Department of Entomology, Texas A&M University.

RESULTS AND DISCUSSION

The results of both years of sampling are shown in Table 1. The arthropod fauna on woolly croton was consistently dominated by spider species, fleahoppers and ants during both years. The spider species commonly found both years were Misumenops celer (Hentz), Metaphidippus galathea (Walckenaer), Phidippus audax (Hentz), Hentzia palmarum (Hentz),

TABLE 1. Total Numbers of Arthropods Collected from Sampling the Terminals of Woolly Croton During 1986-1987 Near College Station, Texas.

Arthropod	1986	1987
Araneae		
Theridiidae		
Theridion australe Banks	0	1
Linyphiidae		
Grammonota texana (Banks)	125	6
Unidentified	4	0
Araneidae		
Argiope trifasciata (Forskal)	1	0
Unidentified	0	2
Tetragnathidae		
Tetragnatha laboriosa Hentz	0	1
Oxyopidae		
Peucetia viridans (Hentz)	1	17
Oxyopes salticus Hentz	8	2
Clubionidae		
Cheiracanthium inclusum (Hentz)	21	8
Anyphaenidae		
Aysha gracilis (Hentz)	10	7
Thomisidae		
Misumenops celer (Hentz)	30	30
Xysticus sp.	1	0
Unidentified	0	1
Salticidae		
Hentzia palmarum (Hentz)	12	4
Phidippus audax (Hentz)	12	9
Metaphidippus galathea (Walckenaer)	10	22
Unidentified	3	1
Hemiptera		
Pentatomidae		
Nezara sp.	2	0
Anthocoridae		
Orius insidiosus (Say)	0	1
Miridae		
Pseudatomoscelis seriatus (Reuter)	1221	512
Neuroptera		
Hemerobiidae	0	1
Chrysopidae	1	0
Coleoptera		
Curculionidae	1	0
Hymenoptera		
Formicidae		
Solenopsis invicta Buren	22	26

Cheiracanthium inclusum (Hentz), *Aysha gracilis* (Hentz), and *S. invicta*. *Peucetia viridans* (Hentz) was more numerous in 1987 than in 1986, while the reverse was true of *Grammonota texana* (Banks). Compared with sampling data from cotton, *Oxyopes salticus* Hentz was not common on woolly croton both years (unpublished data). Cotton fleahoppers were observed

less often in 1987 than 1986. Arthropods found only once or twice during both years were the spiders Theridion australe Banks, Argiope trifasciata (Forskal), Tetragnatha laboriosa Hentz, and Xysticus sp., the stink bug Nezara sp., the minute pirate bug Orius insidiosus (Say), a brown lacewing, a green lacewing, and a weevil.

The list of predators and an estimate of their field consumption of cotton fleahoppers in 1986 and 1987 is shown in Table 2. Of the spider species, M. celer was the most frequently captured predator, closely followed by P. audax. Similar numbers of M. galathea, O. salticus, and G. texana were found, and smaller but comparable numbers of C. inclusum and A. gracilis were found radioactive. Thirty four S. invicta were captured with low to trace amounts of radioactivity, but all had significantly higher CPM than the background CPM ($P < 0.01$).

TABLE 2. Predators of the Cotton Fleahopper on Woolly Croton and Estimates of Numbers Consumed in the Field per 24 h in 1986-1987, Near College Station, Texas.

Predator Species	Predators Labeled		P. seriatus Consumed
	Adults	Immatures	$\bar{x} \pm SE$
Araneae			
Linyphiidae			
Grammonota texana (Banks)	8	2	0.67 ± 0.34
Tetragnathidae			
Tetragnatha laboriosa Hentz	1	0	0.04 *[a]
Oxyopidae			
Peucetia viridans (Hentz)	3	0	4.14 *[a]
Oxyopes salticus Hentz	7	8	1.38 ± 0.46
Clubionidae			
Cheiracanthium inclusum (Hentz)	2	3	3.69 ± 1.66
Anyphaenidae			
Aysha gracilis (Hentz)	0	6	2.49 ± 1.26
Thomisidae			
Misumenops celer (Hentz)	2	31	2.03 ± 0.47
Salticidae			
Phidippus audax (Hentz)	0	25	3.44 ± 2.35
Metaphidippus galathea (Walckenaer)	1	12	2.06 ± 0.42
Hentzia palmarum (Hentz)	1	0	4.48 *[a]
Hymenoptera			
Formicidae			
Solenopsis invicta Buren	34	0	Trace[b]

a/ * = sample size too small for meaningful comparison.

b/ see text for discussion.

There is strong evidence of immature fleahopper consump-

tion by the five most frequently captured spider predators including M. celer, P. audax, O. salticus, M. galathea, and G. texana. All the arthropod species found radiolabeled have also been reported to prey upon fleahoppers based on field observational techniques (Dean et al. 1987, unpublished data).

Radiolabeled predator species captured less frequently probably provide weaker evidence of fleahopper predation than frequently captured, radiolabeled predators. Secondary predation, the consumption of one predator by another that has consumed radiolabeled fleahoppers, has a chance of being misidentified as predation because of the small numbers labeled. This smaller group contains H. palmarum, T. laboriosa, P. viridans and to a lesser extent, C. inclusum, and A. gracilis.

Red imported fire ants are predators of fleahoppers (Breene and Sterling, unpublished data). However, the rate and extent of such predation cannot be reliably estimated using ^{32}P. The fire ant workers cannot consume fleahoppers directly (Lofgren et al. 1975). The forager ants capture prey and bring it to the fourth instar larvae in the colony. The larvae partially digest the prey and redistribute the material to the colony via nurse ants. In this manner, the entire colony can acquire a measurable dose of radioactivity shortly after only a few workers have captured radioactive fleahoppers, or have scavenged upon their carcasses. In 1987, 65 red imported fire ants found on the woolly croton were taken through liquid scintillation procedure. Of this number, 30 (46%) were found to contain significant amounts of ^{32}P. If more time than the 24 h after a release of radioactive fleahoppers was allowed, it is possible that all foraging ants captured from a colony near the release site would be radioactive, as has been observed in cotton fields (Breene and Sterling, unpublished data).

The sampling methods used for woolly croton favor the habitat of the fleahopper (terminals), resulting in some predators not being adequately represented, especially araneids (orb-weavers) which often reside either lower on the plant or on webs hung between plants. Due to the patchy nature of woolly croton, more data are needed to make an accurate assessment of the effect of predators on the cotton fleahopper relative to other mortality factors such as seasonal plant hardening and weather. However, these data provide supporting evidence for the observational data of Dean et al. (1987), which listed 22 species of spiders representing nine families that have been observed to feed on fleahoppers. It is obvious that spiders constitute the majority of arthropod predators of the cotton fleahopper on woolly croton. Many of these spiders are highly mobile species that also readily colonize agricultural crops such as cotton (Dean and Sterling 1987).

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LITERATURE CITED

Almand, L. K., W. L. Sterling, and C. L. Green. 1976. Seasonal abundance and dispersal of the cotton fleahopper as related to host plant phenology. Tex. Agric. Exp. Sta. Bull. 1170.

Breene, R. G., and W. L. Sterling. 1988. Quantitative Phosphorus-32 labeling method for analysis of predators of the cotton fleahopper (Hemiptera: Miridae). J. Econ. Entomol. 81: (In Press).

Dean, D. A., M. Nyffeler, W. L. Sterling, and R. G. Breene. 1987. Foraging by selected spider predators on the cotton fleahopper and other prey. Southwest. Entomol. 12: 263-270.

Dean, D. A., and W. L. Sterling. 1987. Distribution and abundance patterns of spiders inhabiting cotton in Texas. Tex. Agric. Exp. Sta. Bull. 1566.

Ewing, K. P., and H. J. Crawford. 1939. Egg parasites of the cotton flea hopper. J. Econ. Entomol. 32: 303-305.

Gaylor, M. J., and W. L. Sterling. 1977. Photoperiodic induction and seasonal incidence of embryonic diapause in the cotton fleahopper, Pseudatomoscelis seriatus. Ann. Entomol. Soc. Am. 70: 893-897.

Hartstack, A. W., and W. L. Sterling. 1988. The Texas cotton-insect model-TEXCIM. Tex. Agric. Exp. Sta. Misc. Publ. 1646.

Holtzer, T. O., and W. L. Sterling. 1980. Ovipositional preference of the cotton fleahopper, Pseudatomoscelis seriatus, and distribution of eggs among host plant species. Environ. Entomol. 9: 236-240.

King, E. G., J. R. Phillips, and R. B. Head. 1988. 41st annual conference report on cotton insect research and control. In Beltwide Cotton Prod. Res. Conf. (J. M. Brown, ed.) Nat. Cotton Council of America. Memphis, TN. pp. 188-202.

Lofgren, C. S., W. A. Banks, and B. M. Glancey. 1975. Biology and control of imported fire ants. Annu. Rev. Entomol. 20: 1-30.

Pyke, B., W. L. Sterling, and A. W. Hartstack. 1980. Beat and shake bucket sampling of cotton terminals for cotton fleahoppers, other pests and predators. Environ. Entomol. 9: 572-576.

Shepard, B. M., and W. L. Sterling. 1972. Effects of early season applications of insecticides on beneficial insects and spiders in cotton. Tex. Agric. Exp. Sta. Misc. Publ. 1045.

EFFECT OF COTTON BOLL TEMPERATURES ON LARVAL MORTALITY OF PINK BOLLWORM PECTINOPHORA GOSSYPIELLA (SAUNDERS)[1/], [2/]

Chang-chi Chu[3/] and Louis A. Bariola[4/]

ABSTRACT

Mortality of pink bollworm, Pectinophora gossypiella (Saunders), larvae in green cotton bolls was studied under different temperature exposures. All larvae were killed when bolls were incubated at 60°C for 3 h, and high mortality occurred at 55°C after 8 h. At 50°C for 8 h, larval mortality of 67% was obtained in one study and 85-99% in another study. At 50°C for 8 h, mature larvae exited incubated bolls. Burning green bolls in the field with other raked cotton trash resulted in more than 80% larval mortality. The possible role of boll moisture in the survival of PBW larvae in bolls at high temperature is discussed.

INTRODUCTION

The pink bollworm (PBW), Pectinophora gossypiella (Saunders), is a major pest of cotton, Gossypium spp. in the southwestern United States. The intensity of the problem in southern California has stimulated Imperial Valley cotton growers to adopt short-season components of an integrated management system to reduce insect control costs (Henneberry 1986, Henneberry et al. 1980). There is a continuing need to develop additional methods of pink bollworm population suppression.

The effect of temperature on PBW development has been studied extensively (Henneberry et al. 1977, Hutchison et al. 1986), but little research has been conducted to determine the effect of high temperature on mortality of PBW larvae within green bolls. We recently reported that temperatures of 50°C proved fatal to nearly all PBW larvae outside green bolls, but this temperature killed only 67% of the larvae within green bolls (Chu and Bariola 1987). The present study was conducted to further investigate the effects of various temperatures on the mortality of PBW larvae within green bolls.

MATERIALS AND METHODS

Immature green cotton bolls, (G. hirsutum L., 'Deltapine 61'), from cotton planted in late March 1986 and 1987 on the USDA Desert Irrigated Research Station, Brawley, CA, were harvested during the fall of each year for the study. Sets of 20 PBW-infested bolls were placed in clear plastic shoe boxes (31 x 17 x 8 cm). The boxes had a 40-mm diam. screen-covered hole on each side and two in the lid for ventilation. Each box was considered one replicate in the experimental design. The boxes with

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1/ Lepidoptera: Gelechiidae

2/ Mention of a proprietary product does not constitute an endorsement by the U. S. Department of Agriculture.

3/ Irrigated Desert Research Station, Agricultural Research Service, U. S. Department of Agriculture, Brawley, CA.

4/ Western Cotton Research Laboratory, Agricultural Research Service, U. S. Department of Agriculture, Phoenix, AZ.

bolls were placed in incubators (modified household freezers) maintained at the desired temperatures. In 1987 only, the bolls were trimmed of bracts, but the calyx was kept intact. Bolls with calyces were weighed before and after incubation of 8 h. Water loss due to incubation was expressed as a percentage of the boll weight before incubation. The temperatures in the incubator were standardized against a certified mercury thermometer (Princo Instruments, Inc., South Hampton, PA). All experiments were conducted in replicated randomized complete block designs. In all laboratory studies, bolls were dissected 5 h or more after temperature exposure and larval mortality was recorded. All studies were replicated 3 to 9 times.

In 1986 and 1987, a series of studies were conducted to determine the effect of boll incubation at different temperatures on PBW larval mortality. PBW-infested bolls were incubated at 30, 40 and 50°C for 8 h per day and 25°C for 16 h each night for 1, 2, 3, or 4 days. In another test, infested bolls were incubated at 40, 55 and 60°C for 8 h. The developmental stages of larvae within the bolls, and of larvae which had exited the bolls during incubation, and their mortality were recorded. In a third test, bolls were incubated at 60°C for 1, 1.5, 2, 2.5, and 3 h and mortality of PBW larvae recorded.

The relationship of larval exit holes in bolls to larval mortality in incubated bolls was also studied. Infested bolls were grouped according to the number of exit holes (0, 1, 2, 3, and 4 or more). Bolls were incubated at 50°C for 8 h and mortality recorded after 5 h. PBW larvae that exited the bolls during the 8 h exposure period were also recorded.

The effect of high temperature on larval mortality, induced through burning of cotton trash and bolls in the field, was determined after cotton harvest and shredding. In 1986, trash was raked into the furrow. Green bolls (20) were placed singly 0.83 m apart on each of 2 rows either (1) on top, or (2) under raked cotton trash in rows 1-m wide by 15.2-m long; or (3) 10 green bolls in each case were placed 1.85 m apart in the furrow on unraked trash, and another 10 were placed singly 1.85 m apart on top of the bed close to cut cotton stalks. Trash and bolls were sprayed with diesel oil (0.72 L per row) and burned. The burned bolls were collected 5 h after burning and examined to determine PBW larval mortality. The use of diesel oil was based on a preliminary test which indicated that diesel oil was more effective than a herbicidal weed oil, kerosene, or gasoline. The burning of trash was not complete without an oil spray. The study was replicated 10 times. The experiment began 10 October and was completed 1 December 1986. The 1986 test has been published (Chu and Bariola 1987), and the results are included here for comparison and to supplement the 1987 test.

In 1987, trash was raked to the top of the bed close to the cut cotton stalks. The experimental design was identical to the first except that diesel oil was sprayed at 0.64 L per row. This experiment was conducted from 5 to 6 October.

Cotton bolls collected from unburned areas at the same time as the burned bolls served as controls for each burning experiment. The controls and treated bolls were dissected and larval mortality recorded.

Data from each experiment were subjected to analysis of variance for randomized complete block designs. Duncan's (1955) multiple range test was used to separate means at the 5% probability level.

RESULTS AND DISCUSSION

Differences in larval mortality after 1 to 4 days of exposure were not significantly different, and there was no significant interaction between days of temperature exposure and temperature in the 1986 experiment. Thus, the data for mortality after 1 to 4 days of exposure

are combined. All PBW larvae in the bolls were killed at 60°C; 86% were killed at 55°C; 67% were killed at 50°C; but only 3 and 4% were killed at 30°C and 40°C, respectively (Table 1). All stages of PBW larvae were killed, including 3rd or 4th instar larvae that exited the bolls during temperature exposure. The 1987 results confirmed the results of our earlier report (Chu and Bariola 1987).

TABLE 1. Mortality of Pink Bollworm Larvae and Percent Water Loss From Green Cotton Bolls Incubated for 8 H Under Different Temperatures[a/].

Temperature °C	% Mortality 1986[b/]	% Mortality 1987	% Water loss from green bolls in 1987
30	3 b		
40	4 b	0 b	5.0 c
50	67 a		
55		86 a	11.5 b
60		100 a	22.8 a

a/ Means of 12 replicates (n = 240 bolls) for 1986 and 9 replicates (n = 180 bolls) for 1987. Values in a column not followed by the same letter are different based on Duncans multiple range test, P > 0.05.
b/ From Chu and Bariola 1987.

The loss of moisture from the green bolls was related to the incubation temperatures. After 8 h incubation, the loss of moisture from the green bolls was 5.0% at 40°C; moisture loss increased to 11.5% at 55°C and to 22.8% at 60°C (Table 1). The moisture content of green bolls may protect PBW larvae from dehydration and lower the internal boll temperature slightly through transpiration. However, when the ambient temperature is raised to higher than 40°C, the temperature in the boll is raised as well, which may be detrimental to larval survival.

At temperature exposure of 60°C, over 90% of the larvae in green bolls were killed after 2 h or more (Table 2). Moisture loss from the green bolls increased as the hours of incubation were increased.

TABLE 2. Mortality of Pink Bollworm Larvae in Green Cotton Bolls Incubated at 60°C for Different Durations[a/].

Hours of incubation	% Mortality	% Water loss from the incubated green bolls
1.0	36 c	4.1 c
1.5	68 b	5.4 b
2.0	92 a	6.2 ab
2.5	98 a	6.5 ab
3.0	100 a	7.2 a

a/ Means of 9 replicates (n = 180 bolls). Values in a column not followed by the same letter are different (P > 0.05, Duncans Multiple range test).

The numbers of pink bollworm exit holes had no effect on larval mortality when green bolls were exposed to 50°C for 8 h (Table 3). The number of larvae that exited bolls during the temperature exposure period appeared to be related to the number of exit holes that were in the bolls prior to the exposure period; that is, more larvae exited the bolls that had 2 or more exit holes than from bolls with no exit holes. Although most larvae exited the bolls by way of existing holes, in a few cases they emerged through cracks in the carpel wall. A few 4th instar larvae also tunneled new holes in the carpel wall.

TABLE 3. Mortality of Pink Bollworm Larvae in Relation to Number of Exit Holes in Green Cotton Bolls Incubated at 50°C for 8 H.

Number of exit holes	% Mortality	Percentage of pink bollworm larvae having exited incubated bolls
0	99 a[a/]	14 c
1	92 a	26 bc
2	92 a	31 ab
3	89 a	30 ab
4 or more	85 a	37 a

a/ Means of 3 replicates (n = 60 bolls). Values in a column not followed by the same letter are different (P > 0.05, Duncan's multiple range test).

When cotton trash was raked into the furrow, sprayed with diesel oil, and burned, about 80% of the larvae in the bolls were killed, whether the bolls were on top or under the trash (Table 4). Larval mortality in bolls was higher (89%) when trash was raked to the top of the bed close to the cut cotton stalks. During trash burning the internal boll temperatures were shown to increase to higher than 50°C in a minimum of 17 min. with the maximum internal boll temperature reaching 106°C (Chu and Bariola 1987). Larval mortality was 44% in each year when green bolls were on top of unraked trash and burned, and no mortality occurred in control bolls which were not burned.

Another approach to raise internal boll temperature would be defoliation by the end of August, when the air temperature and solar radiation are high. The internal boll temperatures of exposed bolls may be raised to over 40°C for several hours a day, and these temperatures become about 5°C higher than those under the shade of the plant canopy (Chu and Bariola 1987). High internal boll temperatures may reduce the fecundity of adults from exposed larvae, but this effect was not determined in the present study. Fye and Poole (1971) reported the occurrence of deformed pupae when laboratory-reared larvae were subjected to 40°C for 8 h. In laboratory tests, Henneberry et al. (1977) also reported that constant temperatures between 32 and 35°C or higher during the larval development period generally resulted in reproductive failure of adults from the exposed larvae. Thus, larvae not killed after temperature exposure of 50°C or higher in this study may not reproduce.

In conclusion, all PBW larvae in bolls exposed to 60°C for 3 h were killed, and high percentages of larvae died after exposure at 55°C for 8 h. Larval mortality in bolls ranged from 67 to 99% when bolls were exposed to temperatures of 50°C for 8 h. PBW larvae in bolls exposed to 50°C tended to exit the bolls to avoid the detrimental effects. Burning cotton trash to raise internal green boll temperatures resulted in over 80% larval mortality and may be a potential cultural control method under some circumstances.

TABLE 4. Mortality[a] of Pink Bollworm Larvae in Green Cotton Bolls Burned with Trash in the Field.

Location and treatment of green bolls	% Mortality 1986[b]	% Mortality 1987[c]
On top of raked trash and burned	80 a	89 a
Under raked trash and burned	82 a	87 a
On top of unraked trashed and burned	44 b	44 b
Control-unraked trash and not burned	0 c	0 c

[a] Means of 10 replicates (n = 200 bolls). Values in a column not followed by the same letter are different (P > 0.05, Duncan's multiple range test).
[b] Trash raked into furrow. (From Chu and Bariola 1987).
[c] Trash raked to top of bed.

LITERATURE CITED

Chu, Chang-chi, and L. A. Bariola. 1987. Survival of pink bollworm, Pectinophora gossypiella (Saunders), larvae in green bolls at high internal boll temperatures. Southwestern Entomol. 12: 271-277.

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

Fye, R. E., and H. K. Poole. 1971. Effect of high temperatures on fecundity and fertility of six Lepidopterous pests of cotton in Arizona. U.S. Dept. Agric. Prod. Res. Report No. 131.

Henneberry, T. J. 1986. Pink bollworm management in cotton in the southwestern United States. U.S. Dept. Agric., Agric. Res. Serv., ARS-51. 45 pp.

Henneberry, T. J., L. A. Bariola, and D. L. Kittock. 1980. Integrating methods for control of the pink bollworm and other cotton insects in the southwestern United States. U.S. Dept. Agric. Tech. Bull. 1610.

Henneberry, T. J., H. M. Flint, and L. A. Bariola. 1977. Temperature effects on mating, sperm transfer, oviposition, and egg viability of pink bollworm. Environ. Entomol. 6: 513-517.

Hutchison, W. D., G. D. Butler, Jr., and J. M. Martin. 1986. Age-specific developmental times for pink bollworm (Lepidoptera: Gelechiidae): three egg classes of eggs, five larval instars, and pupae. Ann. Entomol. Soc. Am. 79: 482-487.

DEVELOPMENT OF THE SOUTHWESTERN CORN BORER[1], *DIATRAEA GRANDIOSELLA* DYAR, ON CORN AND JOHNSONGRASS[2]

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ABSTRACT

Studies were conducted to compare southwestern corn borer, *Diatraea grandiosella* Dyar, developmental rate, fecundity, and fertility when reared on johnsongrass as compared with corn. Development was faster from 3rd through 5th instars on corn than on johnsongrass. Survival in 1st and 5th instars and the pupal stage was different on the two host plants. Pupal weight, fecundity, and fertility were significantly ($P<0.05$) lower on johnsongrass than on corn.

INTRODUCTION

The southwestern corn borer (SWCB), *Diatraea grandiosella* Dyar, first described in 1911 from Mexico (Dyar 1911), was reported from New Mexico in the United States in 1913 (Davis et al. 1933). Since its introduction into the United States it has spread generally eastward and is now established in 14 states of the U.S. cornbelt (Kikukama and Chippendale 1983). The SWCB mainly infests corn, *Zea mays* L. (Davis and Williams 1983), and damage may be caused by larvae feeding in the whorl causing "dead heart", stalk tunneling, and stalk girdling (Henderson and Davis 1969). Corn losses in the U.S. have been estimated at about 1 percent annually (Wiseman and Morrison 1981), but losses in individual fields may reach 100 percent (Walton and Bieberdorf 1948). The SWCB may also feed on sorghum, *Sorghum bicolor*; sugarcane, *Saccharum officinarum*; sudan grass, *Sorghum bicolor* var. *sudanese*; and pearl millet, *Pennisetum americanum* (Todd and Thomas 1930, Burton et al. 1982).

Johnsongrass, *Sorghum halepense*, is one of the most important weeds in the southern United States (McWhorter and Jordan 1976) and has been reported as a host of SWCB (Wilbur et al. 1950). Based upon a single individual, Rolston (1955) reported slower larval development and reduced pupal weight for SWCB on this secondary host; however, no information regarding fecundity and fertility are available. Since this information could be of importance in making management decisions in johnsongrass and SWCB infested areas, studies were initiated to determine if differences existed in SWCB reared on corn and on johnsongrass.

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[1] Lepidoptera: Pyralidae

[2] Contribution No. 88-431-J from the Kansas Agricultural Experiment Station.

METHODS AND MATERIALS

One-day old SWCB larvae, obtained from Funk Seed Company, were fed on excised portions of field-grown corn (Funk G4507) or field-collected johnsongrass leaf and stalk tissue in 100 x 15 mm Petri dishes, with one larva per dish, in the laboratory. Laboratory environmental conditions were 16:8 (L:D) photoperiod, 25.3°C and 65% ± 5% RH. A completely randomized design was used with seven replications of 40 larvae per replication per host. Fresh corn or johnsongrass tissue, as appropriate, was provided to the larvae as needed (every 4-6 days through 1st instar and alternate days thereafter). All corn plants utilized for food were in growth stage 1.5 to 2 (Hanway 1971), and johnsongrass was in early to full bloom stage. SWCB instar determinations were made based on head capsule widths, according to Rolston (1955). Instar developmental times were recorded on both host plants, and thermal units were calculated using the equation of Whitworth and Poston (1979). A Mettler® unipan electric balance was used to weigh SWCB pupae 24 h after pupation. The pupae were maintained in cages (49.0 x 30.0 x 34.0 cm) at 25.3°C with 65% ± 5% RH. Wax paper strips were suspended in each cage (pupae from corn were caged separately from those reared on johnsongrass) and egression recorded. The wax paper strips were removed periodically, and eggs were counted and placed in 3.5 L glass containers at 26.5°C and 65% ± 5% RH. Fertility was recorded by counting the number of larvae eclosing from each treatment. Percent survival of each instar was calculated on the basis of live larvae in the preceding instar. Data were analyzed using Duncan's Multiple Range Test for comparison of development, survival, fecundity, and fertility between the two hosts.

RESULTS AND DISCUSSION

SWCB developmental time for 1st and 2nd instars was not significantly ($P>0.05$) different on corn as compared with johnsongrass (Table 1). However, developmental times for instars 3-5 were significantly longer ($P<0.05$) and increased progressively for each instar on johnsongrass as compared with corn. Thus, total larval developmental time from 1st through 5th instar and to adult emergence was significantly ($P<0.05$) shorter on corn. Pupal stage duration was not significantly ($P>0.05$) different for the two hosts. Developmental time in thermal units on corn for this study were in agreement with those reported by Whitworth and Poston (1979).

Food quantity was assumed to not be a limiting factor since plant material was changed regularly. Although not quantified, less feeding was observed (as evidenced by less frass and shorter tunnel lengths) on johnsongrass than on corn. Thus, slower development may have been due simply to less larval feeding or other chemically induced growth-limiting factors. Johnsongrass may serve as a "marginal" host (which can support the insect's development) but may not be preferred. Longer SWCB development time has already been documented on less-preferred corn plant parts by Loera et al. (1980) and other hosts by Rolston (1955) and Burton et al. (1982).

In addition to quantity, food quality also influences the development and other life processes of insects. A good food plant must contain essential nutrients for normal insect growth (Soo Hoo and Fraenkel 1966). According to Jangaard (1974), johnsongrass contains less protein than corn, which may be a contributing factor to poor larval development. Physical characters of plants also adversely affect feeding and utilization by insects resulting in slower growth rates (Bernays 1985). The smaller stem diameter of johnsongrass may contribute to the

TABLE 1. Mean Developmental Time of Southwestern Corn Borer Reared on Corn and Johnsongrass at 25.3°C.

Host Plant	Instar[a] 1st	2nd	3rd	4th	5th	Total larval	Pupal	Eclosion to adult
Corn								
Thermal units[b]	119.5a	71.2a	85.6b	75.4b	109.7b	461.6b	174.0a	635.7b
(Days)	(7.8)	(4.6)	(5.6)	(4.9)	(7.1)	(30.1)	(11.3)	(41.5)
Johnsongrass								
Thermal units	121.8a	80.7a	105.4a	144.3a	198.5a	644.0a	171.3a	814.4a
(Days)	(7.9)	(5.2)	(6.8)	(9.4)	(12.9)	(42.1)	(11.1)	(53.2)

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

[b] Using 10°C as base temperature.

TABLE 2. Mean Percent Survival of Southwestern Corn Borer Larvae on Corn and Johnsongrass.

Host Plant	Instar[a/] 1st	2nd	3rd	4th	5th	Pupal
Corn	75.3a[b/]	94.2a	94.2a	94.5a	91.5a	89.9a
	(75.3a)[c/]	(70.7a)	(65.7a)	(63.2a)	(57.5a)	(48.5a)
Johnsongrass	46.4b	75.7a	87.9a	73.0a	70.7b	64.1b
	(46.4b)	(32.5b)	(26.4b)	(17.8b)	(11.8b)	(8.0b)

[a/] Means in same column followed by the same letter are not significantly (P>0.05) different using Duncan's Multiple Range Test.
[b/] Based on number of live larvae in the preceding instar.
[c/] Based on initial number of larvae, i.e. 40/rep. (accumulative survival).

slower SWCB developmental rate by limiting space available for the larvae. Burton et al. (1982) speculated that reduced SWCB development on millet as compared with corn was caused by the smaller diameter of the stalk. Percent survival (Table 2) for 1st and 5th larval instars and pupae was significantly ($P \leq 0.05$) greater on corn than on johnsongrass. Survival of 2nd to 4th instars was not significantly ($P > 0.05$) different for the two host plants. Accumulative survival to the adult stage (calculated on the basis of initial number of larvae) was 40% lower on johnsongrass than on corn.

First instar larval survival was significantly ($P \leq 0.05$) less than that of other instars irrespective of host. Although all possible care was taken, handling of newly eclosed larvae may have contributed to the reduced survival rate.

SWCB pupal weight and mean fecundity for those reared on johnsongrass was 53.3% and 21.5%, respectively, of those reared on corn (Table 3). These results are in agreement with findings of earlier workers who reported reduction in SWCB pupal weight on alternate hosts (Burton et al. 1982, Rolston 1955) and even on less preferred plant parts, i.e., corn tassels (Loera et al. 1980). This may be attributed to the poorer nutritional quality of johnsongrass compared with corn.

TABLE 3. Pupal Weight, Fecundity and Fertility of Southwestern Corn Borer on Corn and Johnsongrass[a/].

Host plant	Pupal weight (gm)	Fecundity[b/]	Fertility[c/]
Corn	0.15a	148.4a	47.2a
Johnsongrass	0.08b	31.9b	0.00b

[a/] Means in same column followed by the same letter are not significantly ($P > 0.05$) different with Duncan's Multiple Range Test.
[b/] Mean number of eggs oviposited per female.
[c/] Mean percent eclosion.

Lighter or smaller pupae result in reduced fecundity in the SWCB (Loera et al. 1980) and in other insects (Fenemore 1979). Reduced pupal weight of johnsongrass-fed SWCB resulted in reduced fecundity also. Feeding on johnsongrass may have caused the larvae to expend more energy on food consumption and digestion than on conversion of nutrients to body substances. According to Englemann (1970), egg production in insects is influenced by both quality and quantity of food consumed, and a small nutrient deficiency and imbalance in johnsongrass may have caused the reduced fecundity.

Egg viability also was significantly ($P \leq 0.05$) different for both host plants. None of the eggs produced by the johnsongrass-fed SWCB eclosed, whereas 47.1% eclosion was recorded from the corn-fed SWCB. Again, certain nutrients are essential for insect fecundity and fertility and even a small change will reduce both in the SWCB, according to Chippendale (1975). Thus, johnsongrass may not have a proper balance or

sufficient amount of these essential nutrients for normal SWCB fertility and fecundity.

These results indicate that johnsongrass is an inferior host for the SWCB. Therefore, observations of SWCB eggs oviposited on johnsongrass throughout those overlapping SWCB and johnsongrass ranges need cause little alarm. The SWCB may feed and develop to the adult stage on johnsongrass; however, if there are no viable eggs produced then those SWCB issuing from johnsongrass will not affect the SWCB potential for infesting corn.

LITERATURE CITED

Bernays, E. A. 1985. Regulation of feeding behavior, pp. 1-32. In Comprehensive Insect Physiology, Biochemistry, and Pharmacology. Vol. 4.

Burton, R. L., K. J. Starks, and J. A. Webster. 1982. Corn, sorghum, and millet as hosts for the southwestern corn borer. Southwest. Entomol. 7: 1-3.

Chippendale, G. M. 1975. Ascorbic acid: An essential nutrient for a plant-feeding insect, Diatraea grandiosella. J. Nut. 105: 449-507.

Davis, E. G., Jr., C. H. Horton, C. H. Gable, E. V. Walter, R. A. Blanchard, and C. Heinrich. 1933. The southwestern corn borer. USDA Tech. Bull. 388.

Davis, F. M., and W. P. Williams. 1983. Second generation southwestern corn borer (Lepidoptera: Pyrahidae): Ear and stalk damage to susceptible and resistant maize. J. Econ. Entomol. 76: 507-509.

Dyar, H. G. 1911. The American species of Diatraea (Lepidoptera: Pyrahidae). Entomol. News 22: 199-207.

Englemann, F. 1970. Factors that affect egg production and fecundity, pp. 107-142. In The Physiology of Insect Reproduction. Vol. 44.

Fenemore, P. G. 1979. Oviposition of potato tubermoth, Phthorimaea operculella Zell. (Lepidoptera: Gelechnidae): The influence of adult food, pupal weight, and host-plant tissue on fecundity. New Zealand J. Zool. 6: 389-395.

Hanway, J. J. 1971. How a corn plant develops. Iowa State Univ. of Sci. and Tech., Coop. Ext. Ser. Spec. Rep. 48.

Henderson, C. A., and F. M. Davis. 1969. The southwestern corn borer and its control. Miss. Exp. Sta. Bull. 773.

Jangaard, N. A. 1974. The characterization of phenylaline amonia-lyase from several plant species. Phytochemistry 13: 1765-1768.

Kikukama, S., and G. M. Chippendale. 1983. Seasonal adaptations of populations of the southwestern corn borer, Diatraea grandiosella, from tropical and temperate regions. J. Insect Physiol. 29: 561-567.

Loera, J., F. L. Poston, and R. J. Whitworth. 1980. Development of southwestern corn borer as affected by a diet of selected corn plant tissue. Ann. Entomol. Soc. Am. 73: 24-27.

McWhorter, C. G., and T. N. Jordan. 1976. The effect of light and temperature on the growth and development of johnsongrass. Weed Sci. 24: 88-91.

Rolston, L. H. 1955. The southwestern corn borer in Arkansas. Ark. Exp. Sta. Bull. 553.

Soo Hoo, C. F., and G. Fraenkel. 1966. The selection of food plants in a polyphagous insect, Prodemia eridania (Cramer). J. Insect Physiol. 12: 693-709.

Todd, C. T., and F. L. Thomas. 1930. Notes on southwestern corn borer, Diatraea grandiosella Dyar. J. Econ. Entomol. 23: 118-121.

Walton, R. R., and G. A. Bieberdorf. 1948. Seasonal history of the southwestern corn borer, Diatraea grandiosella Dyar in Oklahoma; and experiments on methods of control. Okla. Agric. Exp. Sta. Tech. Bull. T-32.

Whitworth, R. J., and F. L. Poston. 1979. A thermal unit accumulation system for the southwestern corn borer. Ann. Entomol. Soc. Am. 72: 253-255.

Wilbur, D. A., H. R. Byron, and R. H. Painter. 1950. Southwestern corn borer in Kansas. Kans. Agric. Exp. Sta. Bull. 339.

Wiseman, B. R., and W. P. Morrison. 1981. Components for management of field corn and sorghum insects and mites in the United States. ARS Agric. Reviews and Man. ARM-5-18.

POPULATION DYNAMICS OF STALK BORERS [1] ATTACKING CORN AND SORGHUM IN THE TEXAS RIO GRANDE VALLEY [2]

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ABSTRACT

Studies were conducted in the Texas Lower Rio Grande Valley (LRGV) from 1982 to 1985 to describe the population dynamics and relative abundance of stem borers associated with corn, Zea mays (L.), and sweet, forage and grain sorghums Sorghum bicolor (L.) Moench. Four species of stem borers were collected, including Diatraea lineolata Walker, Diatraea saccharalis (Fabricius), Eoreuma loftini (Dyar), and Elasmopalpus lignosellus (Zeller). E. loftini was the most abundant stem borer collected from the four host plants studied. The second most common borer was D. saccharalis, followed by D. lineolata, and E. lignosellus. Results indicate that stem borers readily move from early-planted crops to later crops when the former are no longer suitable.

INTRODUCTION

Corn, Zea mays (L.), and sweet, forage and grain sorghums Sorghum bicolor (L.) Moench are important crops in the Texas Lower Rio Grande Valley (LRGV). Pyralid stem borers attacking these crops in the LRGV include the neotropical cornstalk borer (NCB), Diatraea lineolata Walker; sugarcane borer (SCB), Diatraea saccharalis (F.); Mexican rice borer (MRB), Eoreuma loftini (Dyar); and lesser cornstalk borer (LCB), Elasmopalpus lignosellus (Zeller). Extensive damage by MRB has been observed since 1980 in LRGV sugarcane, with up to 50% bored internodes reported on some varieties (Johnson 1981). Corn and sorghum support stem borer populations in the LRGV as does sugarcane (Fuchs 1977), but comparative information is not available for stem borer infestations of corn and sorghums. These studies were conducted to establish population phenologies and dynamics of stem borers on forage sorghum, hybrid grain sorghum, sweet sorghum, and field corn.

METHODS AND MATERIALS

Study fields were established in three successive years, 1982-84, at the Texas Agricultural Research and Extension

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1/ Lepidoptera: Pyralidae

2/ Approved by the director of the Tex. Agric. Exp. Stn. as Technical Article No. 23675.

3/ Present address: Agricultural Research and Education Center, University of Florida, Lake Alfred FL 32792.

Center at Weslaco. The 1982 field was planted on 20 April and was 80 m long by 42 rows wide (14, three-row blocks) consisting of a single row each of hybrid field corn (variety SX351), hybrid grain sorghum (variety FUNKS-G-1701), and commercial forage sorghum (variety SWEET CHEW) in each block; the 1983 field was planted on 24 March and was 80 m long by 44 rows wide (22, two-row blocks) with each block consisting of a row of hybrid grain sorghum (variety ORO-G-EXTRA) and a row of hybrid field corn (variety PIONEER 3160); and the 1984 field was planted on 9 March and was 80 m long by 48 rows wide (12, four-row blocks) with each block consisting of a single row each of sweet sorghum (variety MN-1500), grain sorghum (variety ORO-G-EXTRA), and white corn (variety FUNKS-G-4507A). The 1984 corn and grain sorghum plantings were destroyed in early August, and the sorghum was replanted on 20 August. A buffer row of corn or sorghum was planted each year on the study field perimeter.

Sampling in 1982 was conducted weekly from June through August and once per month during September, October, and November. Sampling in 1983 was weekly from May through August and once per month during September, October, November, and December. In 1984-85, sampling was in alternate weeks from May 1984 through January 1985. A single whole stalk and associated foliage served as the sample unit in all studies. In 1982, five stalks were examined in each of the three rows (= 15 stalks per block for a total of 210 stalks per sample date). In 1983, stalks were examined in the first row of each of the 22 blocks (= 110 stalks per sample date). In 1984-85, 20 stalks were examined from the two middle rows of each block (= 10 stalks per row and 240 stalks per sample date). All examined stalks were selected using a random numbers table to determine the number of paces taken down the row, and the plant immediately to the right of the last pace was examined. Each selected stalk and associated foliage was thoroughly examined in the field for stem borer eggs, larvae, and pupae. Sampled stalks were split and dissected to remove stem borer stages. Collected stem borer eggs and larvae were individually isolated in 15 ml plastic cups previously provisioned with ca. 10 ml of soybean-wheat germ media prepared as described by Shaver and Raulston (1971). Pupae were placed in empty 15 ml plastic cups. All collected stem borer stages were held in the laboratory for emergence of adult moths or parasites. Laboratory conditions were maintained at 27 $\pm$ 2^{o}C and 14 hours photophase.

Mean larval densities of stem borers were computed and plotted using a SAS Means Procedure. Calculated means for each stem borer species were then separated between plant types and within plant types using Duncan's multiple range test or a SAS t-TEST (SAS Institute Inc. 1982 a,b).

RESULTS AND DISCUSSION

Samples from corn, sweet sorghum, forage sorghum, and hybrid grain sorghum resulted in collection of the NCB, SCB, MRB and LCB. The MRB was the most abundant of stem borers collected from the four types of host plants. The second most common borer was usually SCB; NCB was usually 3rd most common, and LCB was consistently least common.

Neotropical Cornstalk Borer. Populations levels of NCB were higher in 1982 than in 1983 and 1984-85 (Fig. 1). NCB

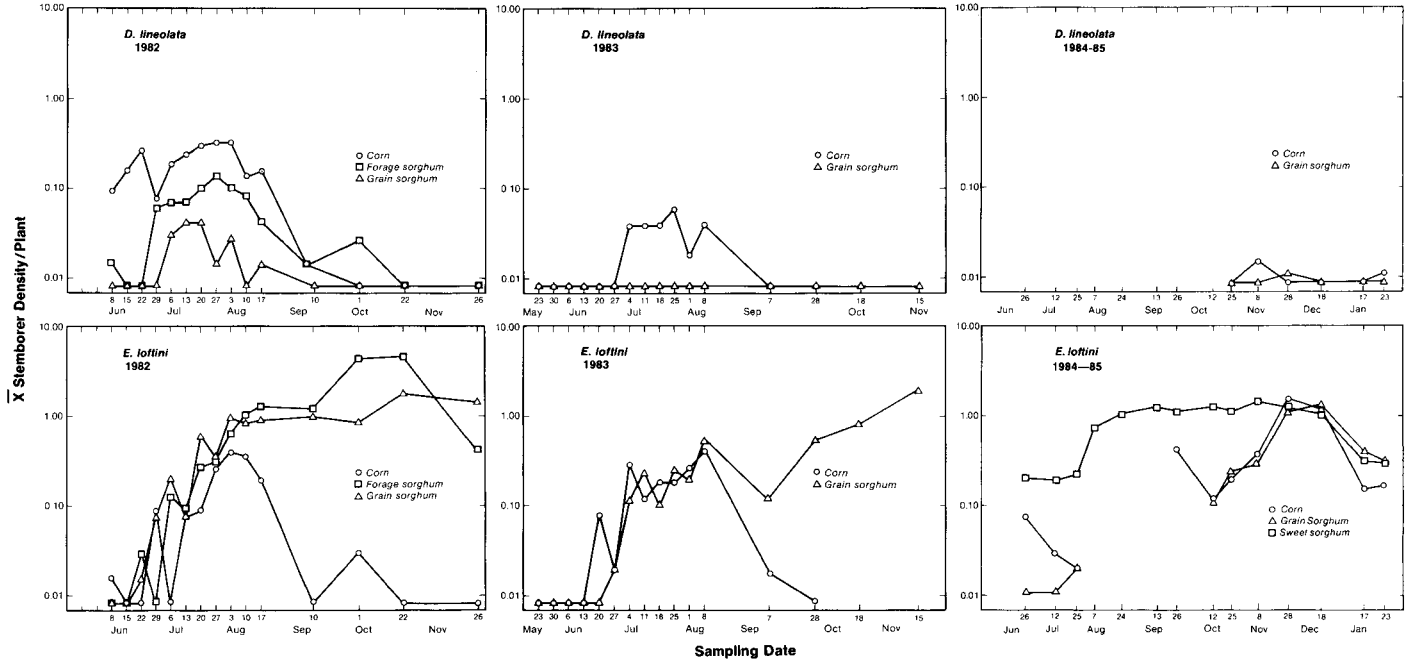

FIG. 1. Population dynamics of D. lineolata and E. loftini attacking corn, grain sorghum, and forage or sweet sorghum in the Texas Lower Rio Grande Valley during 1982-85.

occurred earlier in 1982 samples than other borer species, and each year corn developed the largest of NCB populations. Few NCB were collected from grain sorghum in 1982, and the borer was nearly absent from grain sorghum in 1983-85.

Mexican rice Borer. MRB generally occurred at low population levels in early crop phenologies, but density increased as plants advanced from vegetative to reproductive stages (Fig. 1). Infestations of MRB consistently developed in all three sorghum types, exceeding a mean 1.0 larva/plant in forage sorghum in 1982. MRB larvae were occasionally associated with dead or folded sorghum leaves which they tied together with silk. MRB pupae were collected in folded dry leaves of broken stalks. Such situations partially explain MRB increases during and after senescence of forage sorghum, a result of MRB tolerating conditions unfavorable to the other species of stem borers.

Densities of MRB on sorghums were high beginning with the first week of August of each year, and they remained high until the onset of cooler temperatures in early winter. Continued tiller production in sorghum species provided a source of new stalks until stalks were terminated by the onset of senescence coincident with near-freezing temperatures. Suitability of corn as a host declined earlier than that of sorghum species, because corn does not produce tillers. However, MRB attacked all four species of host plants for a longer duration than did the three other borer species, indicating an ability of MRB to infest host plants over a broad range of plant conditions.

Sugarcane Borer. Densities of SCB were greater in 1982 than in 1983-85, and peaked during July in 1982 and 1983 (Fig. 2). Corn and sorghum produced similar densities of SCB in 1982, but corn supported greater densities than sorghum in 1983 and 1984-85. SCB populations in 1983 were more or less restricted to spring and early summer; whereas, SCB in 1984-85 was sampled for but not collected until late fall on either sorghum or corn. The apparent erratic changes in populations of SCB may have been due in part to different overwintering SCB survival in crop residues and alternate hosts, and in part to low levels of parasitism (seasonal total < 5.0%) by the braconid parasite, Cotesia flavipes (Cameron). Additional and more intensive studies are needed to explain the changes in SCB populations.

Lesser Cornstalk Borer. LCB was present in corn and grain sorghum in 1982, but was absent from samples of forage sorghum (Fig. 2). In subsequent years, LCB was inexplicably absent from all samples despite the continued presence of MRB, SCB, and NCB.

Corn, forage sorghum, sweet sorghum and grain sorghum are excellent hosts for MRB and SCB, and these crops can harbor large numbers of both borers. Given a choice, NCB apparently favors corn over sorghum. All host plants studied can maintain stem borer infestations in the absence of other nearby host crops such as sugarcane. Increased MRB densities on 1982-83 grain and forage sorghum and on 1984-85 corn and grain and sweet sorghums apparently were due to movement from less suitable to more suitable plants within the same field. The 1982 forage sorghum and 1983 grain sorghum continuously produced tillers, and thus were reservoirs of MRB and SCB. Apparently, sorghum can be heavily infested with MRB when corn is no longer suitable as a host. Greatest numbers of stem

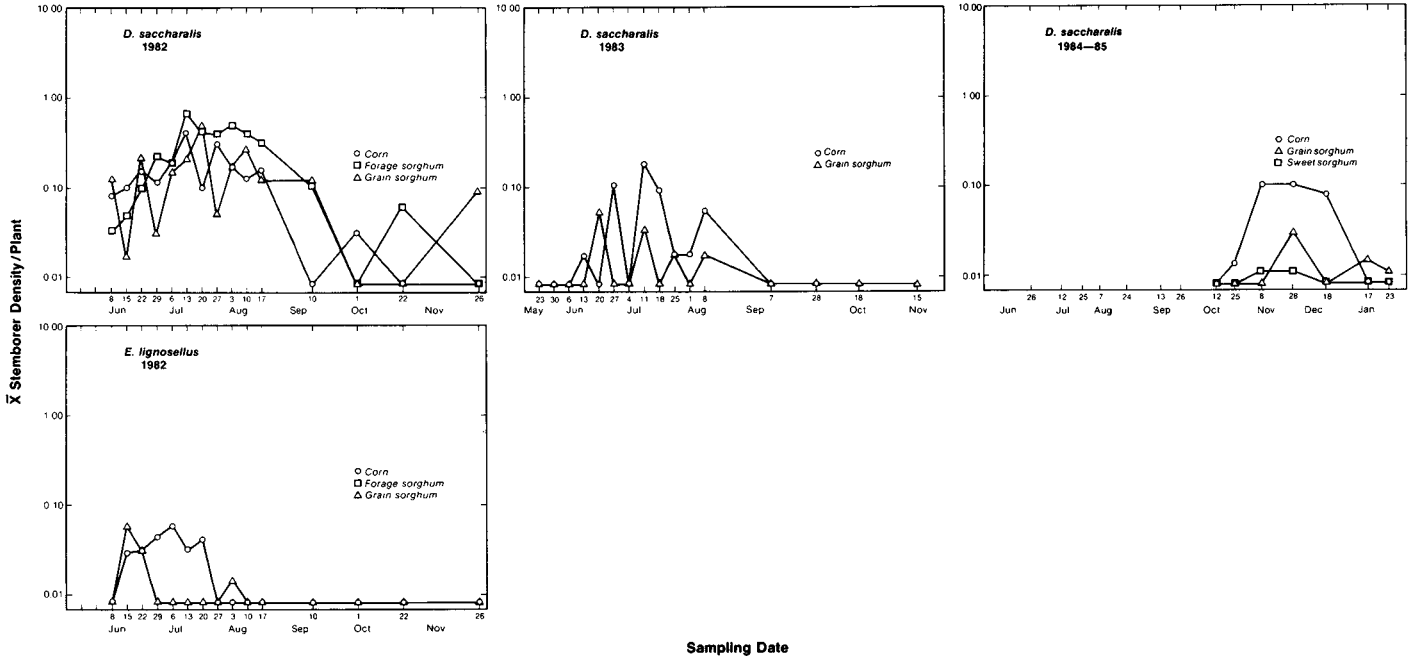

FIG. 2. Population dynamics of D. saccharalis and E. lignosellus attacking corn, grain sorghum, and forage or sweet sorghum in the Texas Lower Rio Grande Valley during 1982-85.

borers were collected in corn each year from late July to mid-August, and a precipitous population decline occurred thereafter. These studies demonstrate the flexibility of stem borers in moving from one host to another and the capability of each studied crop as a host. Results also suggest that movement of stem borers from one crop to another is strongly influenced by host plant phenology. A management strategy to suppress stem borers in the LRGV should consider the four host plants studied because they are commonly sources of stem borer infestation.

ACKNOWLEDGMENT

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LITERATURE CITED

Fuchs, T. W. 1977. Biology, ecology, and control of the sugarcane borer, Diatraea saccharalis (F.) (Lepidoptera: Pyralidae). Ph.D. dissertation, Texas A&M University, College Station.

Johnson, K. J. R. 1981. Acigona loftini (Lepidoptera: Pyralidae) in Lower Rio Grande of Texas, 1980-1981. Proc. Second Inter-American Sugarcane Seminar on Insect and Rodent Pests 2: 166-171.

SAS Institute Inc. 1982a. SAS User's Guide: Statistics. SAS Institute Inc. Cary NC.

SAS Institute Inc. 1982b. SAS User's Guide: Basics. SAS Institute Inc. Cary NC.

Shaver, T. N., and J. R. Raulston. 1971. A soybean-wheat germ diet for rearing the tobacco budworm. Ann. Entomol. Soc. Am. 64: 1077-1079.

SUPPRESSING LOW LEVEL BOLL WEEVIL[1/] POPULATIONS WITH TRAPS: INFLUENCE OF TRAP PLACEMENT, GRANDLURE CONCENTRATION AND POPULATION LEVEL[2/,3/]

J. E. Leggett[4/], W. A. Dickerson[5/], and E. P. Lloyd[6/]

ABSTRACT

Marked overwintered boll weevils, Anthonomus grandis Boheman, were released in 2 ha plots of squaring cotton to determine the efficiency of traps at a density of 2.5 per ha. The traps were baited bi-weekly with 10 mg. grandlure dispensers. The traps were 100% efficient in capturing females in plots with 2 ♀ plus 1 ♂ or 4 ♀ plus 2 ♂ and 63% efficient in capturing females in plot with 8 ♀ plus 3 ♂. The use of traps baited weekly with 3 mg of grandlure to suppress low level native boll weevil populations was determined to be effective when the estimated seasonal population was <0.3 boll weevils per trap (estimated 0.93/ha). With estimated seasonal populations of .04 to .13 boll weevils per trap (estimated 0.10-0.36/ha), the traps (baited bi-weekly with 10 mg of grandlure) eliminated reproduction in 80% of the producer fields. Boll weevil (BW) capture was influenced by trap placement at an estimated seasonal populations 0.3 Boll weevils/trap in 1982, but trap placement was not a factor in weevil capture with higher or lower populations in 1983 and 1984.

INTRODUCTION

A number of researchers have attempted to suppress boll weevil populations, Anthonomus grandis Boheman, with pheromone-baited traps. Hardee et al. (1971) conducted a study in an area that had 1.58 boll weevils/ha as measured by one Stikem coated trap per 0.4-0.8 ha. The degree of suppression was expressed as a ratio of the number trapped to the number found manually plus the number trapped. Assuming 50% manual efficiency, he reported 35-45% suppression; however, the male baited traps were effective <50% of the time due to male mortality and food deterioration. This small degree of suppression would not reduce future population levels.

The first successful suppression test was conducted in small, isolated plots of cotton with a known population of boll weevils that emerged from infested squares placed in the field. Cotton was not grown in the area prior to the test. Leggett et al. (1981) placed 20 infested squares in a clumped pattern in each plot and compared the suppression

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1/ Coleoptera: Curculionidae

2/ In cooperation with the South Carolina Agricultural Experiment Station.

3/ Mention of a proprietary product does not constitute endorsement by the USDA.

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with 2.5 and 10 infield traps per ha. The traps, assembled by Animal and Plant Health Inspection Service (APHIS) personnel, were re-baited weekly with 3 mg of grandlure that was dispensed from a cigarette filter wrapped in polyester or placed in a glass vial. The ten infield traps/ha captured five of the seven females for a 71% suppression of the female boll weevils assuming a 1:1 sex ratio. This population level is equivalent to 2.5 female boll weevils/ha or 0.25 female weevils/trap. With 2.5 traps/ha only 14% of available females were captured.

Lloyd et al. (1981) determined the suppression effect of trap densities that ranged from 4.8 to 14 infield traps/ha in 1.28 ha cotton plots artificially infested with 11.4 boll weevils/ha. The degree of suppression was manifested in the F_2 population when traps in plots with 14 infield traps/ha caught 67% fewer weevils than traps in plots with 4.8 infield traps/ha. The infield traps were assembled by Boll Weevil Eradication Trial (BWET) personnel and baited with 3 mg grandlure that was dispensed from a polyester-wrapped cigarette filter (McKibben et al. 1980).

Leggett (1984) compared trap placement in an area that had an estimated population of <1.0 normally distributed overwintered boll weevil per ha (0.3/trap) in the buffer zone of the Boll Weevil Eradication Trial. The infield and border traps used in this test were assembled by BWET personnel and baited weekly with 3 mg of grandlure that was dispensed from a polyester wrapped cigarette filter. A uniform distribution of 2.5 infield traps/ha suppressed the population 61% more than border traps at the same density based on the number of F_1 and F_2 weevils captured in traps for each treatment. No insecticide was applied during the test period.

Thus, previous research has indicated that high numbers of traps were needed to suppress artificially produced infestations. There was a need to know how effective traps would be for suppressing naturally occurring low level populations of boll weevils. An area wide control program, or severe winter resulting in high boll weevil mortality, is necessary to reduce weevil numbers to the point that a suppression test with traps could be conducted. The BWET and the Southeastern Boll Weevil Eradication (SBWE) programs were being conducted in North Carolina and Virginia; therefore, the following tests were conducted in 1984 in the buffer zone of those programs because low level native populations were maintained in those areas. Traps were required for all fields due to the mandatory programs and control fields were not available. A test was also conducted in 1984 to determine the degree of suppression that could be obtained with a low population of marked overwintered weevils in squaring cotton.

MATERIALS AND METHODS

Three 2-ha plots of cotton with 0.8 km separation were planted in Hampton County, SC on 16 May 1984. Pinhead squares were present by 19 June. The Hercon Scout® traps were placed in fields in a uniform pattern at a density of 2.5/ha and baited with a 10-mg grandlure dispenser (Hercon) on 27 June.

Overwintered weevils were collected in traps at Midville, GA, uniquely marked with spots of Testors® gloss enamel, and placed at random locations in the test plots on 26 June. Two females and one male weevil were placed in field 1; field 2 had four females and two males, and field 3 had eight females and three males. The weevils were caged individually on a cotton square until they entered the bracts, and then the cage was removed. Traps were checked daily Monday through Friday. Trapped weevils were re-released by placing them in a paper bag containing a plant terminal. The bag was then placed one-half the

distance to the next trap to allow the weevil to acclimate after being handled.

Several tests were conducted from 1982 to 1984 to determine the influence of trap placement and grandlure concentration per trap for detecting and predicting low level boll weevil populations under producers' field conditions. The data also is used in this paper to show the suppression effect of traps. In the 3 yrs of testing, four trap distributions were compared: (1) border, (2) uniform-infield, (3) peripheral, and (4) "2-row." Border traps were placed at equal intervals around the cotton field on fence rows, ditches, edge of woods, etc. with traps being placed on the first row of cotton when another crop was planted adjacent to the cotton field. A uniform-infield distribution of traps was obtained by beginning on the south or west side of the field due to prevailing southwest wind and placing traps on the fifth row from the edge, then placing traps 64 m apart down every 66th row resulting in 2.5 traps per ha (or one trap per 0.4 ha). Peripheral traps were placed 5 m inside field borders at equal intervals around the field. The "2-row" infield traps were placed down two rows. Individual rows were located on opposite sides of the field so that approximately 25% of the field was between the trap row and field edge.

The four tests comparing trap placement and lure concentration were: (1) border traps and a uniform distribution of infield traps were compared near Dunn, NC in 1982 (Leggett 1984), (2) uniform infield and peripheral infield traps were compared near Wade, NC in 1983, (3) border, uniform-infield, and 2-row infield traps were compared in Marlboro County, SC in 1984, and (4) border traps with one 10-mg grandlure wick per trap and a uniform distribution of infield traps with one, two, or three 10-mg grandlure wicks per trap were compared in Orangeburg County, SC in 1984. Treatments were compared by analysis of variance using $\sqrt{x + 0.5}$ transformed data.

Application of ULV malathion was scheduled by the SBWE Program personnel for any field with one or more boll weevils captured within 2 wks of pinhead square stage. Adjacent fields were treated in some cases depending on where, when, and how many weevils were captured. Initially all fields in the four tests had 2.5 traps per ha with ten replicates (separate fields) for each treatment. A randomized-block design was used for all 3 yrs. Trap density was increased to approximately 7.4 infield traps per ha in all fields after F_1 weevils emerged in 1982 and 1983, but trap density was not changed in 1984. Field size ranged from 6 to 22 ha per field with most fields being in the 8-10/ha range. The BWET trap (Dickerson 1983) assembled by APHIS personnel were used in 1982-1983. The Hercon Scout® trap was used in 1984. Traps in 1982 and 1983 were baited weekly with a polyester-wrapped cigarette filter containing 3-mg of grandlure (McKibben et al. 1980). The traps in 1984 were baited biweekly with a polyester wrapped cigarette filter or a Hercon dispenser containing 10-mg grandlure. The early-season infield traps were placed on 45-cm bamboo canes in the drill of the row and placed on taller canes as the cotton grew. Traps at other locations were placed on canes that were 1.2 to 1.5 m tall. All traps in a field were individually numbered and a map was drawn to show surrounding habitat. The sex of all trapped weevils was determined for each trap location. All 40 fields in test 4 were sampled for boll weevil damage by collecting 1,000 squares from each field from 6 August to 9 August 1984.

A total overwintered boll weevil emergence curve was developed by placing traps around previous year's North and South Carolina cotton fields that had been rotated out of cotton in 1983. These traps were not competing with cotton plants or males and provided the estimated total overwintering emergence. The estimated seasonal boll weevil populations were determined by comparing the weevils captured in the four tests to the overwintered boll weevil emergence curve (Leggett et al. 1988).

RESULTS AND DISCUSSION

Traps caught 100% of the released weevils in two of three isolated plots of squaring cotton in Hampton County where marked, overwintered weevils were released. Three females were captured four times each with one female responding 17 days after the release date. Three females were captured three times each and five females were recaptured once. The average recapture rate for the females was 2.5 times. The average number of days to first response was four days with a range of 3 to 9 days. The recapture records are summarized in Table 1. Only one male was recaptured after release (on day 30). Some workers (Hollingsworth et al. 1978, Snodgrass et al. 1979) have claimed that grandlure-baited traps were only 50% efficient in capturing boll weevils. The main factors they failed to consider were that the weevils will make multiple responses to traps and that weevils that fail to be captured on the first day may be captured on a later date. The traps in Hampton County test were placed within the field, but trap position was found to have no effect on weevil capture at the low populations similar to those of this test. McGovern et al. (1976) found that overwintered boll weevil pheromone production didn't reach a peak as determined by frass analysis until the 2nd week of feeding on squares, however, (in personal communication) he stated that a male that had fed on a square for 3 days was competitive with a grandlure baited trap.

TABLE 1. Recapture Record of Overwintered Weevils Placed on Squares Located at Random Points in 2-ha Cotton Fields. Hampton County, South Carolina, 1984.

Field	No. weevils released ♂	♀	Weevil no. for females	No. times recaptured	Days from release to recapture [a]	No. per trap	Percent recaptured
1	1	2	1	3	3,7,9	0.4	100
			2	1	6		
2	2	4	3	1	3	0.8	100
			4	2	3,6		
			5	4	3,6,7,9		
			6	1	9		
3	3	8	7	4	3,6,15,17	1.0	63
			8	4	3,6,9,13		
			9	1	6		
			10	3	3,6,13		
			11	3	3,6,9		
Mean				2.45	4		

[a] one male captured in field 2, 30 days after release.

In the trap placement test at Dunn, NC in 1982 (Leggett 1984), traps located in a uniform pattern in the field captured significantly more weevils and suppressed the population 61% more than traps placed on the field border. The estimated seasonal boll weevil population for this test was 0.3 boll weevils/trap. The estimated number of boll weevils per ha that corresponds to the number of boll weevils per trap is given in Table 2.

TABLE 2. Estimated Boll Weevils per ha, 1982-84, at four locations in North and South Carolina.

Location	Estimated seasonal boll weevils/ trap	Assumed percent trap efficiency	Boll weevils/ ha
Wade 1983	3.30	70	1.60
Dunn 1982	0.30	80	0.93
Orangeburg 1984	0.13	90	0.36
Marlboro 1984	0.04	100	0.10

Trap Placement Test 1983. The peripheral-infield and the uniform-infield traps at the density of 2.5/ha captured 1.4 and 2.1 cumulative overwintered boll weevils per trap, respectively, in the Wade, NC test. There was no significant difference between treatments during the 6 wks of trapping. This test was evaluated by placing 7.4 uniformly-spaced infield traps per ha in all test fields to capture F_1 and F_2 weevils. These traps captured 4.6 and 5.7 cumulative boll weevils per trap in the former peripheral-infield and the former uniform-infield test fields, respectively. There was no significant difference between treatments during the 5-wk evaluation time. The estimated seasonal population was 3.3 boll weevils per peripheral trap or an estimated 12/ha. With this higher population, weevils were detected in all fields of each treatment, but the degree of suppression between the two treatments was not evident because competition from the additional males reduced trap efficiency. The percent of females captured in pheromone-baited traps changes on a seasonal basis (Fig. 1), and the use of trap captures to estimate number of weevils per ha would not be consistent throughout the growing season.

Trap placement test, 1984. There was no significant difference in the cumulative boll weevils captured per functional trap with border, uniform-infield and 2-row infield traps (Table 3). The test in Orangeburg County, which consisted of border traps with one 10-mg grandlure wick and the uniform distribution of infield traps with 1, 2, or 3, 10-mg wicks/trap, did not have a significant difference among treatments (Table 4).

TABLE 3. Influence of Trap Placement on Boll Weevil Capture with Seasonal Population Estimated to be 0.04 Boll Weevil/Trap. Marlboro Co., SC, 1984.

Cumulative overwintered boll weevils per functional trap, and trap location [a]		
Border	Uniform infield	2-row infield
0.02 a	0.04 a	0.02 a

[a] A nonsignificant F valve was obtained by analysis of variance.

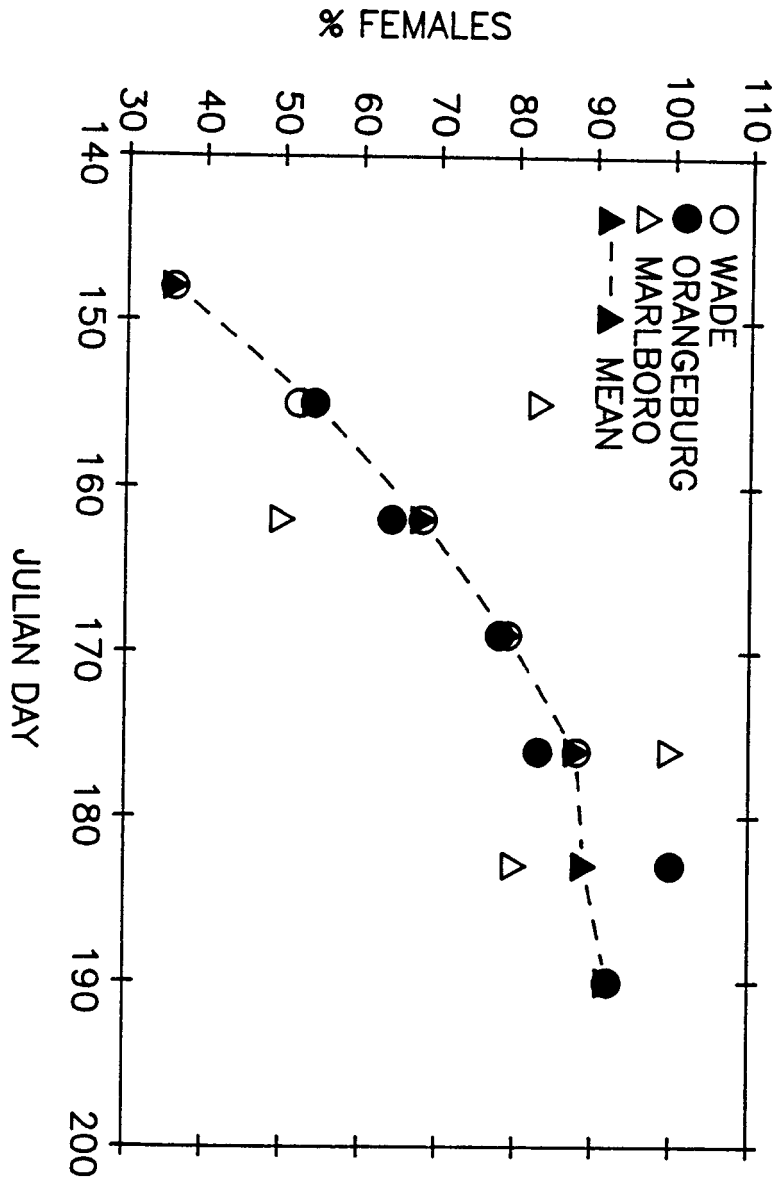

FIG. 1. Seasonal change in sex ratio of trap-captured boll weevils, 1983-84.

TABLE 4. The Influence of Trap Placement and Grandlure Concentration Per Trap on Boll Weevil Capture with a Seasonal Population Estimated to be 0.13 Boll Weevil/Trap, Orangeburg Co., SC, 1984.

Cumulative overwintered boll weevils per functional trap, trap location and number of 10 mg dispensers[a]			
Border	Uniform infield		
1 disp.	1 disp.	2 disp.	3 disp.
0.06 a	0.085 a	0.08 a	0.06 a

[a] A nonsignificant F valve was obtained by Analysis of Variance.

At a population density of 0.93 boll weevil/ha in 1982, trap efficiency was < 100% and differences in trap placement between infield and border traps were a significant factor in weevil suppression. However, when the population level was 12 weevils/ha in 1983, both treatments detected weevils; but trap efficiency was reduced, and sufficient weevils were not captured so that infestations developed equally in both treatments. With the lowest population density of 0.10-0.36 boll weevil/ha in 1984, trap efficiency was near 100% and differences between trap placement were not evident due to the low numbers of weevils present. Trap placement and grandlure concentration have previously been shown to influence the percent of weevils captured (Leggett et al. 1981, Leggett and Taft 1979, Johnson et al. 1982). However, if there are only two weevils in a cotton field and the trap density is sufficient to capture those two weevils, then increasing the amount of grandlure/trap or changing trap placement is not going to result in additional captures after the population has been depleted, which is what happened in 1984.

Therefore, the three treatments in Marlboro County were combined and the four treatments in Orangeburg County were combined to show the population suppression that may be obtained with grandlure baited traps deployed at the density of 2.5 per ha alone and in combination with 2-4 applications of malathion.

The test in Marlboro County was judged to have the lowest population because overwintered weevils were captured in only 11 of the 30 fields, and the seasonal population was estimated to be .04 boll weevil/border trap (0.1/ha). Only three fields were treated with malathion. Replicate 10 and 11, which had no reproduction, received two insecticide applications, but the degree of suppression by traps alone could not be determined. It is highly probable that 100% of the overwintered boll weevils present in the field were trapped or killed with insecticide in nine or 82% of the fields because six to fourteen weeks passed when no weevils were captured. Traps alone were 100% effective in seven or 88% of the eight insecticide-free fields. Seven weeks would be enough time for at least two generations to develop, and data from past tests (Leggett et al. 1981, Lloyd et al. 1981) verify that there is a 100% probability of detecting weevils in the second generation with 2.5 traps per ha. Seven of the 11 positive-capture fields had only one weevil, and it is highly probable that no reproduction occurred in these fields. More than one weevil was captured in four fields, and it is possible that reproduction occurred in fields 8 and 9 (Table 5).

Overwintered or curent season boll weevils were not captured from 7 April to 13 August in 19 of the 30 test fields in Marlboro County. The numbers of weevils captured in traps around the fields in August and September and the total number of weevils captured in traps are given in Table 6. Five of the fields continued to have zero capture through September.

TABLE 5. Trap Placement Test, Marlboro, South Carolina in 1984 Summarized to Show Suppression of Boll Weevil Reproduction with Grandlure-Baited Traps Deployed at the Rate of 2.5 per ha.

Fields detecting weevils	No. ha/ field	Boll weevils[cd] No. captured	Boll weevils[cd] No./ ha	Cumulative boll weevils per trap	No. weeks without additional capture	Date of first migrant capture	Probable reproduction by overwintered boll weevils
1	7.7	1	0.13	0.053	12	8/20	No
2	8.5	1	0.12	0.050	14[b]		No
3	14.6	1	0.07	0.028	12	9/10	No
4	8.9	1	0.11	0.059	6	8/27	No
5	14.6	1	0.07	0.029	9	9/17	No
6	6.1	1	0.16	0.067	14	9/03	No
7	7.7	1	0.13	0.052	14	9/03	No
8	10.1	6	0.59	0.400	5	8/20	Yes
9[a]	18.2	7	0.38	0.292	4	8/13	Yes
10[a]	12.1	12	0.99	0.400	12	8/20	No
11[a]	16.2	36	2.22	0.900	15[b]		No

[a] Received two malathion insecticide treatments on 15 and 21 June, beginning at pinhead square stage of plant growth.
[b] These fields did not capture any other weevils through September.
[c] Single captures averaged 0.1 weevil/ha.
[d] Multiple captures averaged 1.1 weevils/ha.

TABLE 6. Summary of Late Season Boll Weevil Trap Capture in 19 Fields Which Had Zero Boll Weevil Capture From 7 April Through 13 August in Fields Located in Marlboro Co., SC. 1984.

	Number of fields that had captured weevils by indicated date and the total number of boll weevils						
	Week of						
	13 Aug	20 Aug	27 Aug	3 Sep	10 Sep	17 Sep	24 Sep
No. fields with positive capture	0	3	3	9	10	12	14
Total boll weevils	0	11	0	22	10	20	14

The test in Orangeburg County was located in the buffer zone of the SBWE Program and was susceptible to reinfestation by migrant weevils from Georgia. Most of the test fields were located in an area around Cameron and Elloree, SC but four were 22 km southwest of Cameron. The seasonal boll weevils per border trap for this test were estimated to be 0.36/ha which was nine times higher than the Marlboro area.

Insecticide was not applied at the pinhead-square stage of plant growth to 22 of the 40 fields in this test because low numbers of weevils were captured (Table 7). Four of these 22 fields had zero capture from June through September. No weevils were captured in five of the 22 fields during early or mid-season so they were not used in calculating the percent suppression. Traps alone were assumed to eliminate reproduction in 13 of the 22 insecticide-free fields due to the time interval in which no boll weevils were captured and the low trap capture (0-8 weevils) during August and September. Control plots could not be used because the area-wide eradication program was in progress. Reproduction occurred in four of the insecticide-free fields (24%) where 2 to 7 weevils were captured during early and mid-season, and 15-79 weevils were captured in August and September. Three of these fields (fields 19, 20, and 22) were located 22 km southwest of Cameron and were closer to the weevil-infested area in Georgia than the other test fields. Only one egg punctured square (0.1%) was found in replicate 21 (1.6 km west of Cameron) where 62 weevils were subsequently captured in traps during August and September, but no damage was found in any of the other 39 fields sampled.

Two to four insecticide treatments were applied to 18 of the fields (Table 8). Due to the number of weeks of zero weevil capture and the low trap capture through September, it is assumed that traps and insecticide eliminated the weevils in 17 (94%) of these fields. Two of the three fields that received four insecticide treatments had zero boll weevil capture in traps during August and September. The fields that received two, three, or four insecticide treatments had a mean trap capture of 3.2, 1.6, and 0.7 boll weevils per field, respectively, in August and September. However, there was only a limited number of fields in each class. Traps and insecticide were highly effective in these fields in suppressing boll weevil populations where 1-20 weevils were captured during early and mid-season.

The data from Marlboro Co., Orangeburg Co., and the Hampton Co. plots support the hypothesis that grandlure baited traps can be 100%

TABLE 7. Boll Weevils Captured With 2.5 Traps/ha in 22 Fields That Were Not Treated with Insecticide During Early- or Mid-Season, Orangeburg County, SC 1984.

	Number/field		Total Boll Weevils Captured				
Field	traps per fld	ha per fld	2 Apr-28 May	Weevils/ha.	4 June-30 July	Weevils/ha.	6 Aug-1 Oct
1	25	10.1	6	0.59	0		0
2	22	8.9	0		0		0
3	26	10.5	0		0		0
4	25	10.1	4	0.34	0		0
5	20	8.1	0		1	0.12	0
6	25	10.1	0		4	0.40	0
7	10	4.0	0		2	0.50	0
8	25	10.1	0		3	0.30	0
9	33	13.4	0		0		1
10	37	15.0	0		0		2
11	29	11.7	1	0.09	1	0.09	2
12	25	10.1	2	0.20	3	0.30	3
13	39	15.8	0		2	0.13	3
14	26	10.5	0		0		4
15	41	16.6	3	0.18	2	0.12	4
16	33	13.4	0		2	0.15	5
17	33	13.4	1	0.07	1	0.07	5
18	80	32.4	4	0.12	2	0.06	8
(Mean boll weevils/ha)				(0.10)		(0.10)	(0.17)
19	40	16.2	0		2	0.12	17
20	22	8.9	0		4	0.45	15
21	37	15.0	4	0.27	3	0.20	62
22	21	8.5	0		2	0.24	79
(Mean boll weevils/ha)				(0.08)		(0.23)	(3.56)

effective in suppressing populations in areas where competition from male weevils is minimized. The data from Hampton County was significant in that one female responded up to 17 days from date of release, and three females were recaptured four times each in the presence of squaring cotton.

TABLE 8. Boll Weevils Captured with 2.5 Traps/ha in 18 Fields that Received Two - Four Insecticide Applications at the Pinhead Square Stage of Plant Growth, Orangeburg County, SC, 1984

Field	Pin square insecticide treatment		Boll weevils captured		
	Time	Number	4 Jun-30 Jul	after pin-square treatment	6 Aug-1 Oct
23	15 & 21 Jun	(2)	2	0	3
24	15 & 21 Jun	(2)	2	0	4
25	20 & 29 Jun	(2)	1	0	4
26	20 & 27 Jun	(2)	4	1	4
27	20 & 27 Jun	(2)	6	2	1
28	22 & 28 Jun	(2)	1	1	17[a/]
29	15 Jun - 2 Jul	(3)	1	0	1
30	15 Jun - 2 Jul	(3)	5	0	1
31	15 Jun - 2 Jul	(3)	1	0	1
32	14 - 29 Jun	(3)	2	1	4
33	14 - 29 Jun	(3)	5	3	3
34	15 Jun - 2 Jul	(3)	0	0	1
35	15 Jun - 2 Jul	(3)	3	0	2
36	15 Jun - 2 Jul	(3)	4	0	2
37	20 Jun - 12 Jul	(3)	3	0	0
38	15 Jun - 2 Jul	(4)	3	1	0
39	20 Jun - 12 Jul	(4)	1	0	0
40	15 Jun - 2 Jul	(4)	4	0	2

[a/] Field 28 was located 22 km southwest of Cameron, SC and was within 0.8 km of fields 19, 20, and 22 (shown on Table 7).

LITERATURE CITED

Dickerson, W. A. 1983. Improvements to the boll weevil trap. Boll Weevil Technology Transfer Workshop, Florence, SC. Nov. 24-25.

Hardee, D. D., O. H. Lindig, and T. B. Davich. 1971. Suppression of populations of boll weevils over a large area in west Texas with pheromone traps in 1969. J. Econ. Entomol. 64: 928-933.

Hollingsworth, J. P., J. A. Witz, and A. W. Hartstack, Jr. 1978. Retention efficiency of the Leggett boll weevil trap. Southwest. Entomol. 3: 198-209.

Johnson, W. L., E. B. Mitchell, P. M. Huddleston, W. H. Cross, and R. F. Heiser. 1982. Boll weevil capture efficiency: Position and density of traps and grandlure dosage. J. Econ. Entomol. 75: 446-448.

Leggett, J. E., W. A. Dickerson, K. P. Burnham, S. H. Roach, A. R. Hopkins, and F. R. Planer. 1988. Boll weevil (Coleoptera: Curculionidae): Emergence Profile of Overwintered Weevils Measured by Grandlure-baited Traps and Predicting Total Emergence. Environ. Entomol. (In Press).

Leggett, J. E. 1984. Detection probability and efficiency of infield and border traps for capturing overwintered boll weevils (Coleoptera: Curculionidae) at low population levels. Environ. Entomol. 13: 324-328.

Leggett, J. E., E. P. Lloyd, and J. A. Witz. 1981. Efficiency of infield traps in detecting or suppressing low population levels of boll weevils. Environ. Entomol. 10: 125-130.

Leggett, J. E., and H. M. Taft. 1979. Boll weevil: Capture in pheromone traps baited with natural male lure and several concentrations of grandlure. Environ. Entomol. 8: 62-64.

Lloyd, E. P., G. H. McKibben, J. A. Witz, A. W. Hartstack, D. F. Lockwood, E. F. Knipling, and J. E. Leggett. 1981. Mass trapping for detection, suppression and integration with other suppression measures against the boll weevil, pp. 191-203. In E. A. Mitchell [ed.], Management of Insect Pests with Semiochemicals--Concepts and Practices. Plenum Press, New York.

McGovern, W. L., G. H. McKibben, W. L. Johnson, M. E. Merkl and W. H. Cross. 1976. Pheromone production by overwintered boll weevils. Environ. Entomol. 5: 101-102.

McKibben, G. H., W. L. Johnson, R. Edwards, E. Kotter, J. F. Kearny, T. B. Davich, E. P. Lloyd, and M. C. Ganyard. 1980. A polyester-wrapped cigarette filter for dispensing grandlure. J. Econ. Entomol. 73: 250-251.

Snodgrass, G. L., W. L. Johnson, and W. H. Cross. 1979. Efficiency of the Leggett trap in capturing responding boll weevils. J. Econ. Entomol. 72: 378-379.

HEART STRUCTURE AND BEAT IN THE LARVAE OF THE STABLE FLY, STOMOXYS CALCITRANS[1/]

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ABSTRACT

The tubular heart of the third instar larva of the stable fly, Stomoxys calcitrans (L.), contains three enlargements with valved openings, or ostia, in segments ten through thirteen. Three pairs of broad alary muscles are associated with these distensions of the heart tube. A series of 10 to 14 pairs of large pericardial cells are also located along this structure. The larval myocardium consists of a single layer of circular muscle composed of a series of cells joined by intercalated discs. The array of myofilaments is typical for visceral muscles with ten to twelve thin filaments surrounding each thick filament. The Z line is composed of a series of discrete electron dense bodies. The thin filaments of the I band seem to be attached to these dense bodies. The heart beat of the intact larva ranged from 21 to 108 pulses/min with a mean value of 70 beats/min. The predominant character of the myographic recordings was irregular both in amplitude and frequency. Surgical experiments provided evidence that 1) contractions of the myocardium are not dependent on the alary muscles, 2) the posterior end of the heart is the only pacemaker, and 3) the aorta is probably not an actively contracting segment.

INTRODUCTION

The heart in its simplest form is found in the larvae of Diptera. It is a cylindrical vessel consisting of a single layer of muscle cells that extends along the dorsal midline. Although a number of reports have appeared in the literature on the histological, ultrastructural, and morphological properties of the heart in the larvae of Diptera very few attempts have been made to describe the functional characteristics of heart action.

In the present study we have described the principal structural features of the larval heart in the stable fly, Stomoxys calcitrans (L.). We recorded heart action in the intact larvae in the semi-isolated state and after various surgical procedures.

MATERIALS AND METHODS

Stable fly larvae (3rd instar) were taken from rearing pans maintained at the Veterinary Toxicology and Entomology Research Laboratory (Bridges and Spates 1983). The composition of the saline used for dissection and perfusion was (in mM): NaCl 156, KCl 2.7, $CaCl_2$ 2, Glucose 20. The pH was adjusted to 6.8.

[1/]Diptera: Muscidae

Preparation of Tissue for Microscopic Examination. Hearts were prepared for scanning and transmission electron microscopy (SEM and TEM) by fixing the tissue for 2 h in a mixture of 3% glutaraldehyde, 2% paraformaldehyde, and 1% picric acid in 0.05 M phosphate buffer at pH 7.4. After five rinses in the phosphate buffer over a period of 1 h, specimens were placed for 2 h in phosphate buffer containing 1% osmium tetroxide, followed by another five to ten rinses in distilled water over a period of 1 h. They were then dehydrated in a series of increasing concentrations of ethanol, followed by three 15-min rinses in 100% acetone. Specimens were then dried with liquid CO_2 in a Denton critical point drier. The dried specimens were mounted with silver conducting paints on SEM stubs, coated with gold-palladium, and observed with a Cambridge Stereoscan S-4 SEM at 10 kV.

After fixation in 1% osmium tetroxide, those specimens designated for TEM were block-stained overnight in 0.5% aqueous uranyl acetate, dehydrated in ethanol, 100% acetone and embedded in epoxy resin. Thin sections were examined with a Philips 300 electron microscope.

Preparation of the Heart for Physiological Recording. The heart beat of the intact larva was recorded by focusing a television camera through a dissecting microscope on the dorsal surface of the larva as it moved about on the wax surface of a petri dish. The video tape recordings were then analyzed to determine heart action.

Semi-isolated preparations of the heart were obtained by fastening the larva dorsal side down with two minuten pins in a wax-filled petri dish. The cuticle along the ventral surface was then cut, and the severed ends were spread against the wax surface with a series of minuten pins. The major visceral organs were removed to expose the dorsal vessel or heart situated between two large tracheal trunks. Next, 20-50 μl of saline solution were perfused over the heart, and the silver wires (36 gauge) leading to an impedance converter were placed on either side of the heart tube. Myocardiograms were obtained from a standard chart recorder.

RESULTS AND DISCUSSION

Structural Properties of the Larval Heart. The dorsal vessel in the 3rd instar larva extends from the fifth to the thirteenth segment (Fig. 1). However, in segments ten through thirteen this vessel has the

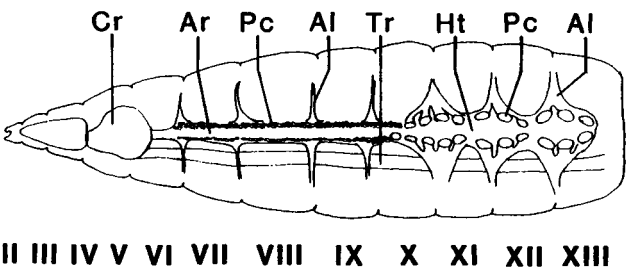

FIG. 1. Basic structural features of the heart (Ht) and aorta (Ar) in the 3rd instar larva-ventral aspect: crop (Cr), alary muscles (Al), pericardial cells (Pc), trachea (Tr).

typical features of the tubular heart with three enlargements that contain valved openings or ostia. Three pairs of alary muscles are associated with these distensions of the heart tube. The muscles originate on the hypodermis between segments and pass beneath the lateral tracheal trunks to insert on the heart by means of a fine network of connective tissue fibrils (Fig. 2A and B). As the alary

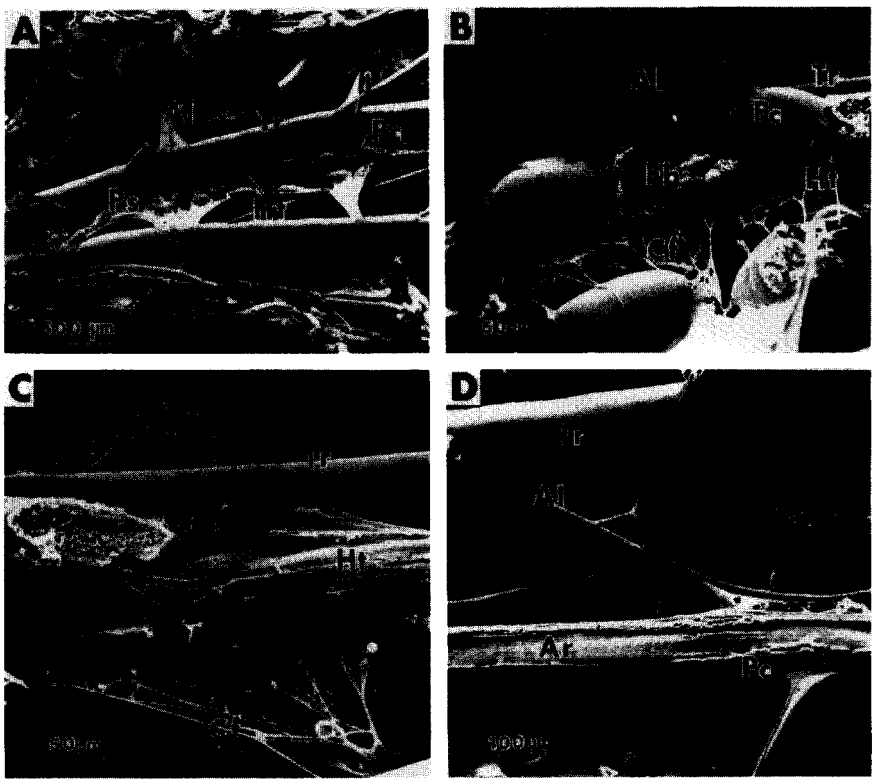

FIG. 2. Structural details of the larval heart and aorta revealed by scanning electron microscopy. A) Electron micrograph of the heart (Ht) and alary muscles (Al) exposed by ventral dissection of larva in segments X through XIII; trachea (Tr) and pericardial septum (PS). B) Junction between the alary muscles (Al) and the heart tube (Ht); pericardial cells (Pc); fat body (Fb); trachea (Tr) and connective tissue attachments (Cf). C) Dorsal connective tissue attachments (Cf) to the heart tube (Ht) between segments X and XI. D) Attachment of narrow alary muscles (Al) to the aorta (Ar) between segments VII and VIII.; trachea (Tr), pericardial cells (Pc).

muscles approach the heart, they fan out along its ventrolateral border and together with a delicate connective tissue membrane form a pericardial septum. A series of 10 to 14 pairs of large pericardial cells are also included in this structure. The heart is suspended from the dorsal hypodermis by a meshwork of thin fibrils that often arise from the intersegmental suture (Fig. 2C). The posterior end of the heart is closed and has fibril attachments to the transverse trachea that connects the two lateral trunks. The aorta by contrast is

supported by alary muscles that have a thin thread-like configuration, and the pericardial cells found along the aorta are much smaller than those near the heart (Fig. 2D).

The array of myofilaments in the muscles of the heart is similar to that reported in other visceral muscles (Smith et al. 1966) with ten to twelve thin filaments surrounding each thick filament. The single layer of muscle cells in the heart wall is covered by an outer and an inner basement membrane (Fig 3A). Both appear to be of equal thickness and to

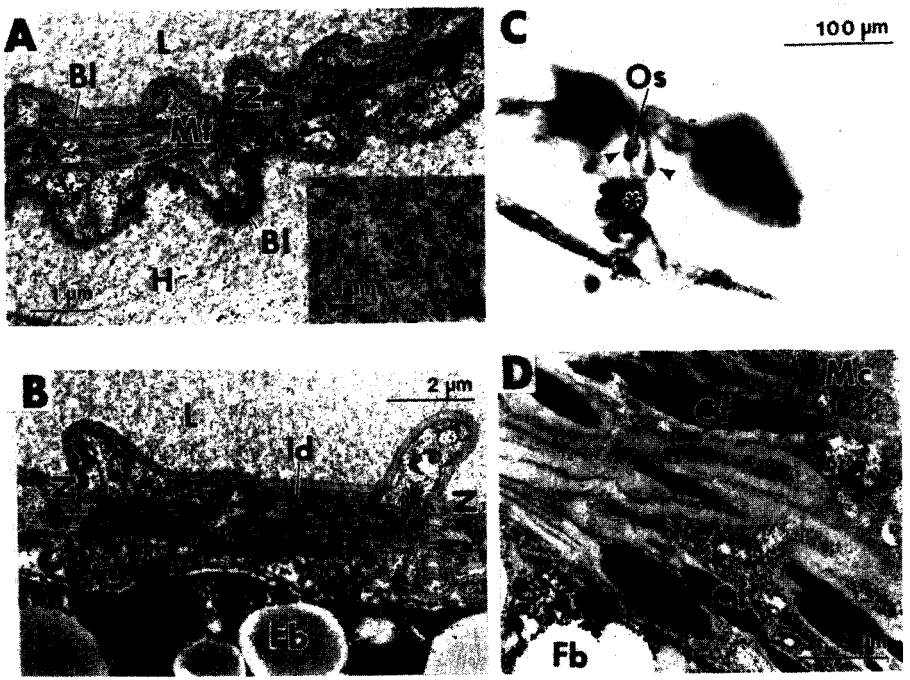

FIG. 3. Various sections through the larval heart. A) Transverse section shows the ultrastructure of the myocardium to consist of a single layer of basal lamina (Bl). H, hemocoel; L, lumen of heart; Mf, myofibrils; Z, Z-discs. Inset, transverse section through myofilaments reveals the 10-12 thin to 1 thick filament ratio typical of insect visceral muscle. B) A transverse section through an intercalated disc (Id) joining two muscle cells at the midline of the heart. Fb, fatbody; L, lumen; Z, Z-disc. C) Longitudinal section through an ostium (Os) showing the paired invaginated folds of the myocardium forming the ostial valve (arrows) and a cluster of cells (asterisk) that forms a luminal septum at the level of the ostia. D) Transverse section through pericardial septum beneath the heart. This region of the septum is composed of connective fibers (Cf) consisting of an electron dense core, covered by an electron lucent sheath of flocculent material resembling a basal lamina. Myocardium (Mc).

consist of a flocculent material. When the myocardium is in the contracted state these membranes assume a pattern of regular folds that corresponds to each sarcomere.

The larval myocardium consists of a single layer of circular muscle composed of a series of cells joined by intercalated discs. The

ultrastructural details of these interfibrillar junctions are shown in Fig. 3B. Two components are evident in the intercalated discs: (1) a central region containing the electron dense material associated with the Z band of the sarcomere, and (2) a zona occludens which extends from the myofibril region to the periphery of the cell. The Z bands by contrast have much smaller deposits of electron dense material that are quite discrete in character. The thin filaments of the I band seem to be attached to the dense bodies of the Z line. Elements of the T system tubules are evident in the sarcoplasm, and they can occasionally be seen forming dyads with the sarcoplasmic reticulum.

The ostia in the heart of the stable fly larva consist of vertical slits in the lateral wall with paired folds that extend into the lumen, forming a valve. Each fold contains a nucleus about the middle of its inward course (Fig. 3C). The ultrastructural features of the connective fibrils that form the larval pericardial septum are shown in Fig. 3D.

Properties of the Heart Beat. The heart beat of the intact 3rd instar larvae ranged from 21 to 108 pulses/min and had a mean value of 70 beats/min in a group of 16 individuals. When very little body movement was evident, the heart rate was generally low; but as movement increased the rate accelerated.

A semi-isolated or in situ preparation was used to study the contractile properties of the heart and aorta in individual segments. The predominant character of activity observed in more than ten preparations was irregular both in amplitude and frequency. The beat frequency was often more regular than the amplitude, and the heart proper generally displayed the highest degree of regularity in the entire preparation. A typical recording sequence of the aorta and heart from various body segments is illustrated in Fig. 4. In this example as

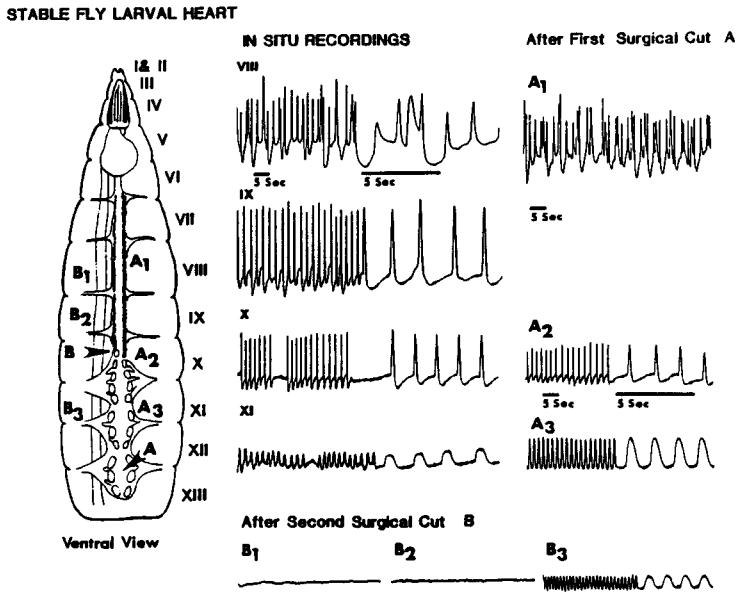

FIG. 4. Profile of cardiac activity from selected segments of a semi-isolated preparation of a larval heart and the effect of surgical transsections in segment 13 (A_{1-3}) and 10 (B_{1-3}). All recordings were made in a serial sequence from the same preparation.

in most experiments, the recordings from the aorta showed the largest contraction amplitudes. However, all myocardial activity seemed to originate in body segments XI and XII as demonstrated by surgical transections at A and B (Fig. 4). After the first surgical cut in segment XIII there was a reduction in the amplitude of contraction in the aorta and an increase for those in the heart. Once a second surgical incision was made just in front of the heart at B, all activity in the aorta stopped; but the heart continued to contract.

Although connections to the heart from the central nervous system had been severed in the in situ preparations just described, there was still the possibility that an intact peripheral nervous system could regulate the heart. This possibility was eliminated by completely removing the heart and aorta from the larvae and then recording the activity. An example of such a preparation is shown in Fig. 5. The

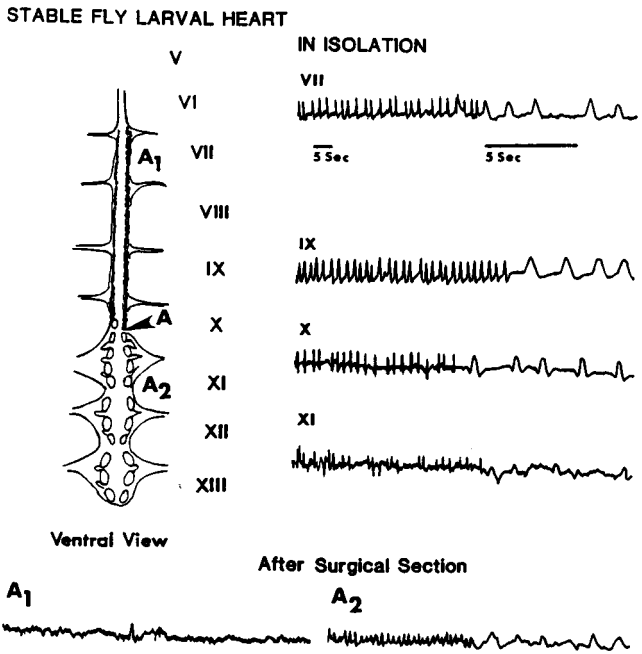

FIG. 5. Cardiac activity of a completely isolated larval heart and the effect of surgical separation of the aorta from the heart. Recordings were made on the same preparation in sequence.

distinction in character between myographs from the aorta and heart are no longer evident. However, surgical section at A again demonstrates that the beat originates in the heart and not the aorta.

As 3rd instar larvae approach pupation there is often noticeable reduction in the amplitude of contractile events, especially in the posterior body segments. Moreover, the measurement of heart activity in vivo becomes less difficult as larvae approach pupation because movement artifacts are at a minimum, and it is possible to get a scan of heart action from an intact larva with the impedance converter.

The dorsal vessel and its associated structural features parallel closely those found in Calliphora erythrocephala (Meigen) by Jensen (1973). The three pairs of alary muscles that support the heart in segments ten through thirteen, for example, follow the basic plan described by Jensen (1973). The muscles originate on the hypodermis between segments and end in a network of connective tissue fibrils that actually attach to the heart wall. Even the distribution of the large and small pericardial cells along the heart is equivalent. Moreover, the ostiae appear as vertical slits with flaps that protrude into the lumen just like those in C. erythrocephala and Musca domestica (L.) (Ranade 1967). The heart in segment eleven contains an interluminal septum or valve which regulates hemolymph flow (Fig. 3C). A similar structure has been reported in C. erythrocephala (Jensen 1973) and Chaoborus crystallinus (De Geer) (Lebrun 1926).

The larval myocardium, like that of the adult stable fly (Cook and Meola 1983), consists of a single layer of circular muscle composed of a series of muscle fibers joined by intercalated discs. However, the large clusters of mitochondria present in the adult heart just beneath the sarcolemma on the luminal surface are not present in the larvae. Moreover, the central band of longitudinal muscle that forms such a distinctive part of the pericardial septum in the adult fly is absent in the larva. By contrast the larval pericardial septum consists simply of a fine network of fibrillose connective tissue without any muscle cells.

Myographic records from semi-isolated preparations of the heart of the 3rd instar larva generally showed both a variable amplitude and frequency. The irregularity in the frequency of the heart beat consisted not only of brief intervals of acceleration or slowing in the rate but also periods of complete interruption of the beat. Such irregularities in the heartbeat are comparable to those reported by Miller (1979) on the heart of housefly larvae. Both surgical experiments with semi-isolated preparations and the complete isolation of functional hearts from the larva provided evidence that: 1) contraction of the myocardium is not dependent on the alary muscles, 2) the posterior end of the heart is the only pacemaker, and 3) the aorta is probably not an actively contracting segment. Similar conclusions have been reached for a number of other insect species (Jones 1977).

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LITERATURE CITED

Bridges A. C., and G. E. Spates. 1983. Larval medium for the stable fly, Stomoxys calcitrans (L.). Southwest. Entomol. 8: 6-10.

Cook B. J., and S. M. Meola 1983 Heart structure and beat in the stable fly, Stomoxys calcitrans. Physiol. Entomol. 8: 139-149.

Jensen P. V. 1973. Structure and metamorphosis of the larval heart of Calliphora erythrocephala. Royal Danish Academy of Sciences and Letters. Biologishe Skrifter 20: 1-19.

Jones J. C. 1977. The circulatory system of insects. Charles Thomas Publisher, Springfield, IL. pp. 41-54.

Lebrun H. 1926. L'appareil circulatoire de Corethra plumicornis. La Cellule 37: 183-200.

Miller T. 1979. Nervous versus neurohormonal control of insect heartbeat. Amer. Zool. 19: 77-86.

Ranade D. R. 1967. The circulatory system of the third instar larvae of Musca domestica. Bull. Ent. Dep. Zool. 8: 13-16.
Smith D. S. 1966. Insect cells, their structure and function. Oliver and Boyd. Edinburgh, UK. pp. 31-59.

ON THE INSECTICIDAL PRINCIPLE AND TIMING OF TREATMENT OF STABLE FLY[1/] LARVAE WITH CALCIUM CYANAMIDE

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ABSTRACT

Tests conducted on calcium cyanamide fertilizer, hydrogen cyanamide, aluminum phosphide and potassium cyanide against stable fly larvae, Stomoxys calcitrans (L.), showed that the most likely toxic material in the calcium cyanamide fertilizer was the cyanamide radical. The quantity of phosphide or cyanide present in the calcium cyanamide fertilizer was insufficient to explain the toxicity. Hydrogen cyanamide was as toxic or more so than the equivalent amount of calcium cyanamide without the presence of any phosphide or cyanide. Applications of calcium cyanamide fertilizer or hydrogen cyanamide were highly effective against stable fly larvae in media after topical treatment for at least 3 days and, in most instances, for 5 days. The reduction in effectiveness after 5 days was 4 to 11% compared with 1-3 day posttreatment.

INTRODUCTION

Calcium cyanamide fertilizer was toxic and affected the growth and development of stable fly larvae, Stomoxys calcitrans (L.), when mixed into a simulated waste (Chamberlain and Matter 1986). However, additional information was needed on how best to apply the calcium cyanamide fertilizer in a practical manner to a simulated waste material. Also, we would like to know more about the insecticidal principle in the calcium cyanamide fertilizer.

In a feedlot the most common areas for development of stable fly larvae are around the edges of the lots, under bunkers, and along the edges of piled-up waste. Larvae do not develop in the open areas where the cattle are constantly treading. Treatment would, therefore, consist of spreading the calcium cyanamide in the common areas. We needed to evaluate how often such treatment would be necessary and if surface application of the calcium cyanamide fertilizer would be sufficient for control of the stable fly larvae. Stable fly larvae also develop in many other situations, such as grass and other materials along seashores and in ensilage.

On the other aspect of our study, the insecticidal principle in calcium cyanamide fertilizer, there is some controversy. Dinelli and Cinelli (1951), working in Italy, concluded that the presence of small quantities of phosphide present in the calcium cyanamide fertilizer was responsible for the toxicity. Phosphides on contact with moisture are converted to phosphine, a gas commonly used to fumigate grain for

[1/] Diptera: Muscidae

control of insect infestations. Dinelli and Cinelli (1951) also concluded that other materials such as ammonia and acetylene were present but in insufficient quantities to be responsible for the toxic effect. They eliminated cyanide as being responsible because the large quantity of calcium oxide present (nearly 31%) would prevent the formation of the acid. In their analysis there were no silanes or arsines present that could have been toxic to insects.

Behling et al. (1940) concluded that the weed control effect of calcium cyanamide was caused by a conversion to cyanamide, as both calcium cyanamide and cyanamide were effective weed control agents at higher concentrations. Servadei and Martelli (1947) concluded that cyanamide, derived from calcium cyanamide, was responsible for the effectiveness of the calcium cyanamide against the sawfly, Hoplocampa brevis Klug. Lee (1954) suggested that the calcium cyanamide was converted to an autonomous toxicant, probably a fumigant, but he did not identify the material.

The most extensive work on the insecticidal principle in calcium cyanamide was that of Kunz (1954). However, his work involved determination of the systemic effect in plants. In experiments where cyanamide or calcium cyanamide was applied to the roots of Vicia faba L., the aphids, Aphis fabae Scopoli, feeding on the leaves of the plant were killed. Frit flies, Oscinella frit (L.), that fed on the leaves of oat plants rooted in a nutrient solution containing 0.005% cyanamide were also killed. However, when either cyanamide or calcium cyanamide was placed on the surface of the soil, there was no effect on any insects feeding on plant leaves. The materials had to be placed in the immediate area of the roots to be effective. The effects of calcium cyanamide were slower to appear than cyanamide, and this led Kunz (1954) to conclude that the calcium cyanamide must first be converted to the cyanamide before it could be absorbed by the plants. Similarly, Arenz and Schröppel (1952) found that Colorado potato beetles, Leptinotarsa decemlineata (Say), that fed on the leaves of plants treated through the roots with a cyanamide solution were killed.

While these earlier studies suggested that cyanamide was responsible for the action of calcium cyanamide, a different situation is encountered when calcium cyanamide is applied to the surface of media containing developing stable fly larvae. Therefore, it became necessary to investigate further whether phosphine or cyanide, known fumigants, were responsible for the action of calcium cyanamide fertilizer. Furthermore, I determined how many days could elapse between infestation and treatment before treatment became less effective and whether cyanamide or calcium hydroxide was effective in controlling stable fly larvae.

MATERIALS AND METHODS

The medium used for growing the stable fly larvae was a mixture by weight of 10% steer manure, 67.5% water and 22.5% of a dry mixture consisting of 72.8% Chemical Specialties Manufacturing Association (CSMA) fly rearing medium, 26.2% coarse ground bagasse and 1% vegetable oil. The medium was made into 4000 g round pats 10 cm thick and 30 cm in diameter. The pats were then deposited in the field on a Krum silty clay loam soil having ca. 38% clay, 2-3% organic matter and a pH of 8.0 in outdoor test plots exposed to the natural temperatures. The soil was thoroughly saturated with water before depositing the pats. Pats were then infested with 4000 stable fly eggs from a laboratory colony, and eggs were placed in the center of the pats about 1 cm below the top surface. The pats were covered with conical galvanized metal funnels (110

cm diameter and 76 cm high) painted white on the outside to reduce heat absorption. The funnel had a 13 cm opening at the top for insertion of a plastic (1.5 liter) container, which in turn had a conical screen so that emerging flies were trapped in the plastic container. The trap was emptied once or twice daily. The funnel also had screened holes, 4-8 cm diameter, near the base to allow for some circulation of air.

The calcium cyanamide fertilizer, cyanamide, aluminum phosphide or calcium hydroxide were applied only to the top surface of the pats either by dusting or sprinkling each material. This procedure was used because the practical application to materials having infestations of stable fly larvae could only be done by superficial dusting or spraying. The calcium cyanamide fertilizer contained 66% calcium cyanamide, 30.6% lime, 3.06% carbon and 0.34% iron oxide. The hydrogen cyanamide was a 50% aqueous solution. The aluminum phosphide was Degesch America, Inc. (Weyers Cave, Virginia) Phostoxin^{R} containing 55% aluminum phosphide and 45% inert ingredients including ammonium carbonate and edible paraffin. The Phostoxin was in the form of a tablet so before use the material was ground into a fine powder. The calcium hydroxide was reagent grade powder. The potassium cyanide used in the laboratory experiment was 99.9% purity.

In determining the amount of each material to be applied, consideration was given to its relationship to the amount of calcium cyanamide fertilizer that was effective for control in previous tests (Chamberlain and Matter 1986). Those tests showed that 0.5% of the active ingredient, calcium cyanamide, was effective. The hydrogen cyanamide was used at an equivalent cyanamide radical concentration, and the calcium hydroxide was used at the same amount as the lime present in the fertilizer. The amount of aluminum phosphide used was determined from the fact that aluminum phosphide is converted to phosphine, the toxic agent, on exposure to moisture. Previous analysis (Dinelli and Cinelli 1951) had shown an average concentration of 4-8 ppm or less of phosphine in samples of calcium cyanamide fertilizer. Concentrations of the Phostoxin used were equivalent of 4 ppm or 40 ppm phosphine in the rearing medium. During the tests, samples of our calcium cyanamide fertilizer and of the hydrogen cyanamide solution were sent to Degesch America for analyses. Their analyses showed 2.3 ppm of phosphine in the calcium cyanamide fertilizer but no detectable amounts in the hydrogen cyanamide solution. To determine how long after infestation a treatment could be applied, the pats were treated either at 1, 2, 3 or 5 days after infestation with the eggs of the stable fly. A second pat was also placed on top of the first pat 1 day after treatment simulating the condition in many cattle-holding facilities where manure accumulates on a daily basis. The second pat was infested with 4000 stable fly eggs at the time of placement. The second pat was treated on the same schedule as the first pat, that is at 1, 2, 3 or 5 days after deposition.

Four replicates of each treatment were conducted. The first was during April-May, the second during June, the third during July-August, and the fourth during September-October 1987. The tests were exposed to the usual variation of temperature during the test periods. The April-May temperatures varied from a 2.2°C low to a 33.9°C high with an average of 19.2°C. The June temperatures varied from a 15.0°C low to a 28.9°C high with an average of 21.9°C. The temperatures varied during the July-August tests from a 17.8°C low to a 35.0°C high with an average of 26.1°C. The September-October temperatures varied from a 3.3°C low to a 33.9°C high with the average of 19.8°C. The time to first emergence of flies varied from 22 days in the spring to 12 days during the summer; fly emergence continued for 13 days during the spring and summer but lasted for 23 days during the fall test.

While Dinelli and Cinelli (1951) dismissed cyanide as a possibility in explaining the toxicity of calcium cyanamide fertilizer, there continues to be confusion about the differences between cyanide (-C≡N) and cyanamide (=N-C≡N). Both materials have the -C≡N radical, but the second nitrogen in cyanamide makes compounds having the cyanamide radical much more stable than compounds having the cyanide radical. In the process of manufacturing calcium cyanamide it is possible for some cyanide to be left in the technical calcium cyanamide, but repeated analyses by the manufacturer indicates the amount to be much < 10 ppm. However, a small laboratory test was conducted to directly compare hydrogen cyanamide and potassium cyanide to determine whether this small quantity might be responsible for the toxicity of the fertilizer to stable fly larvae. Medium consisted of 25% of the same dry medium used in the field tests, without the manure, and 75% water. Concentrations used were 0.03 to 0.12% of hydrogen cyanamide and 0.00075 to 0.006% for the potassium cyanide. Tests were duplicated for each concentration. One hundred newly hatched larvae were added to 200 g of medium immediately after treatment with each concentration. Results of all field tests were analyzed by general linear models (GLM) procedure and Duncan's test for separation of means (SAS Institute 1985). The percent mortality was calculated using Abbott's formula (Abbott 1925).

RESULTS AND DISCUSSION

Calcium cyanamide fertilizer, when applied in the field to the surface of larval medium 1-3 day after egg deposition, reduced stable fly development (> 95%) (Table 1). Five days after treatment, effectiveness was 84%, possibly because some larvae were beginning to pupate at that time. The results from wetting the calcium cyanamide fertilizer were similar to those for the dry fertilizer, and again there was a significant difference between 1-3 day treatment and 5 day treatment. With the hydrogen cyanamide solution, the results were equivalent to those obtained with the calcium cyanamide fertilizer, and at the 5 day treatment there was even less reduction in effectiveness than that seen with the calcium cyanamide fertilizer. The 5 day treatment, however, was significantly different from that of 1-3 days treatment. There was a significant increase in mortality with the 5 day treatment by hydrogen cyanamide compared to calcium cyanamide or calcium cyanamide plus water. Possibly this is related to Kunz's (1954) proposal that calcium cyanamide must first be converted to hydrogen cyanamide to be effective, and the few hours required to build up sufficient concentration allowed a few of the nearly mature larvae to escape the toxic effects.

The aluminum phosphide (as Phostoxin) was applied in an amount that would, upon conversion to phosphine, give a concentration of 4 or 40 ppm in the pat assuming all the material went into the medium. The results indicate that at the 4 ppm application rate, there was no effect on the development of the larvae, and even at the higher rate of 40 ppm there was 27% survival of larvae at 1 day treatment and no effect at the 5 day treatment. The 27 mg or the 270 mg of aluminum phosphide applied were considerably greater amounts than the 0.41 mg of aluminum phosphide that could have been obtained from the 30 g of calcium cyanamide fertilizer, assuming that there were 8 ppm of phosphine equivalents in the fertilizer. The higher amounts of aluminum phosphide were used to obtain a reasonable distribution over the surface of the pat and to insure that, if there was any effect of phosphine on stable fly development, it would have been detected. The 2.3 ppm of phosphine equivalents (3.9 ppm aluminum phosphide) in the calcium cyanamide fertilizer could increase at least 230 fold without any effect on the survival of stable fly larvae.

TABLE 1. Effect of Calcium Cyanamide Fertilizer, Hydrogen Cyanamide, Phosphine, and Calcium Hydroxide on Stable Fly Emergence in Four Separate Field Tests Between April and October 1987.

Material	Concentration of active (%) ingredient	Treatment time, days after infestation	Average[a] no. of flies emerging	% control
$CaCN_2$ fertilizer	0.5	1	12.0 a	98.1
		2	29.0 cde	95.3
		3	27.1 c	96.0
		5	100.8 g	84.0
$CaCN_2$ fertilizer + H_2O[b]	0.5 + 5.2	1	15.5 ab	97.5
		2	39.7 def	93.7
		3	43.6 ef	93.5
		5	95.1 g	85.5
H_2CN_2 solution	0.26	1	20.1 bc	96.7
		2	20.6 c	96.7
		3	32.0 de	95.2
		5	53.7 f	91.8
PH_3	0.0004	1	630.8 i	1.0
		5	671.5 i	0
	0.004	1	171.1 h	73.2
		5	578.6 i	8.4
$Ca(OH)_2$	0.30	1	587.1 i	7.8
		5	600.8 i	4.8
Control	0	1	637.0 i	
		2	618.9 i	
		3	677.8 i	
		5	631.0 i	
H_2O	5.2	1	618.3 i	
		2	632.1 i	
		3	666.5 i	
		5	654.7 i	

[a] Figures followed by the same letter are not significantly different ($P < 0.05$); Duncan's multiple range test, PC SAS (SAS Institute 1985).
[b] Calcium cyanamide treatment followed by water spray.

It would be expected from the method of applying the aluminum phosphide powder (Phostoxin) to the surface of the pat that the phosphine generated would be largely dissipated into the air, but the same expectation would exist for any phosphide in the calcium cyanamide fertilizer applied in the same manner. Thus, phosphine cannot be responsible for the toxic effect of technical calcium cyanamide or hydrogen cyanamide against stable fly larvae.

The calcium hydroxide applied only to the surface of the pats had no effect on the development of the stable fly larvae. Whether intimate mixing of the calcium hydroxide into the medium would have had an effect was not determined. The material was applied in the same manner as the calcium cyanamide fertilizer for comparative reasons. Observations of the pats indicated that the larvae did not disturb the surface of the pats but remained within the pats.

The results of the small-scale laboratory test comparing the toxicity of hydrogen cyanamide and potassium cyanide showed that 0.03%

of hydrogen cyanamide caused 95.5% mortality and that 0.003% potassium cyanide killed 48.9% of the stable fly larvae. For cyanide to be responsible for the toxicity to stable fly larvae under the conditions of the field tests, there would need to be more than a 10% contaminent of cyanide or for a conversion to cyanide of that extent. However, repeated analyses show that no conversion of cyanamide to cyanide occurs (personal communication, S. Kantor, American Cyanamid). It would also be impossible for the cyanide to remain in the hydrogen cyanamide solution to this extent because of its acidity (pH of 4.56).

The concentration of hydrogen cyanamide required for 95% mortality in the field tests was considerably greater than in the laboratory test. This result is not completely unexpected as larvae were used in the laboratory tests and were applied immediately after treatment, while in the field tests eggs were used before treatment. Contact with the larvae was immediate in the laboratory tests while in the field tests either the cyanamide had to penetrate the medium or the larvae had to come to the top 1 or 2 cm before contact was made.

The calcium cyanamide fertilizer or hydrogen cyanamide solution was effective in preventing development of the larvae after application to the surface of a rearing medium that was approximately 10 cm thick. Whether or not the materials would be effective to greater depths was not determined. Until tests with thicker deposits of waste are conducted, it can only be considered that application of calcium cyanamide fertilizer or hydrogen cyanamide must be restricted to situations where 10 cm or less of waste has accumulated.

The calcium cyanamide fertilizer and hydrogen cyanamide solutions were almost completely effective for 3 days at the concentrations tested. They were also 84-92% effective for 5 days after egg deposition. These results indicate that in feedlot or other similar situations where animal waste or waste grain accumulate, treatment on a 5 day or even weekly schedule should provide control of stable flies and possibly other muscoid flies.

It also appears that the toxic action of calcium cyanamide against stable fly larvae is due to the cyanamide and not to some contaminant. Further evidence of the primary function of the cyanamide radical was the fact that the hydrogen cyanamide was at least or more toxic at equivalent concentrations of the calcium cyanamide, yet the method of manufacture of hydrogen cyanamide precludes contamination by phosphide. These results agree with those of Kunz (1954) on the systemic activity of hydrogen cyanamide and calcium cyanamide where he states that "Since the course and picture of deaths were the same in both cases (calcium cyanamide and cyanamide) it is also proved through it that insecticidal activity of calcium cyanamide is due to cyanamide." Grandori (1938) also found that both cyanamide and calcium cyanamide introduced into the midintestine of various insects had the same toxic effect.

ACKNOWLEDGMENT

We thank Sidney Kantor of American Cyanamid for supplying the calcium cyanamide fertilizer and the hydrogen cyanamide. Special thanks go to Donald Shaheen and to L. S. Couch of Degesch-America for supplying the Phostoxin and for conducting the analyses for phosphine. I also thank Jesse J. Matter for technical assistance in conducting the tests.

LITERATURE CITED

Abbot, W. S. 1925. A method for computing the effectiveness of an insecticide. J. Econ. Entomol. 18: 265-267.

Arenz, B., and H. Schröppel. 1952. Über die Auswirkung einer Cyanamidernährung von Kartoffelpflanzen auf den Besatz mit Kartoffelkäferlarven. Z. Pflanzenkrankht. (Pflanzenpath.) u. Pflanzenschutz 59: 9/10: 334-339.

Behling, R. W., W. Utsch, and E. Pfingsten. 1940. Über die Ursachen der Unkrautbekämpfung durch Kalkstickstoff. N.F.-Z. Pflanzenernährg., Düngung u. Bodenkunde 19: 201-218.

Chamberlain, W. F., and J. J. Matter. 1986. Control of stable flies (Diptera: Muscidae) with a unique nitrogen fertilizer, calcium cyanamide. J. Econ. Entomol. 79: 1573-1576.

Dinelli, D., and E. Cinelli. 1951. Sull'azione insetticida della calciocianamide. La Chimica E L'Industria. 33: 125-128.

Grandori, R. 1938. L'azione disinfestante della calciocianamide contro le mosca domestica sperimentalmente dimostrate. Archivio Italiano di Scienze Medichie Colon. e di Parasit Anno XI - Fascicoto N. 11; XVI.

Kunz, H. D. 1954. Über die innertherapeutische insektizide Wirkung des Cyanamids. Z. Pflanzenkr. Pflanzenschutz 61: 481-521.

Lee, Sung-Yang. 1954. Effect of calcium cyanamide on the rice borer. J. Econ. Entomol. 47: 187-197.

Servadei, A., and M. Martelli. 1947. Calciocianamide e DDT nella lotta contro l'Hoplocampa brevis Klug. Redia 32: 183-186.

SAS Institute. 1985. SAS/STAT quide for personal computers, 6th ed. SAS Institute, Cary, N.C.

STRATIFICATION AND SURVIVAL OF DIAPAUSING BURROWING BUGS [1/]

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ABSTRACT

About 50% of an overwintering population of Pangaeus bilineatus (Say) survived the winter each year of a 2 yr study. The insects were stratified within the soil. The majority was located at a depth of 6-8 inches below the surface until the first week in March, at which time they moved toward the surface. This movement coincided with the termination of diapause in the population.

More than 85% of the insects were in diapause through the later part of February. At this time the percentage of diapausing individuals decreased rapidly, and by early April very few were in diapause.

INTRODUCTION

The burrowing bug, Pangaeus bilineatus (Say), is widely distributed throughout the eastern half and southern portion of the United States (Froeschner 1960). The species ranges southward through Mexico and is found in Brazil, Puerto Rico and Hawaii (Hyslop 1934).

Burrowing bugs feed on a wide range of hosts including several cultivated crops. Tissot (1939) reported burrowing bugs feeding on and causing serious damage to pepper seedbeds in Florida. Burrowing bugs were found sucking juice from the cotyledons of spinach seedlings and killing the stand in some fields (Gould 1931). Sailor (1954) reported this species from vegetable crops, and Cassidy (1939) reported the species from cotton. Not only is this pest important in causing direct damage to plants and fruit but also it is the suspected vector of certain virus diseases of plants (Sailor 1954).

The burrowing bug is potentially the most devastating pest of peanuts. Its damage reduces nut quality and can reduce gross income by as much as 20%. Very little is known about the biology and habits of this insect. This study was conducted for the purpose of elucidating certain aspects of the overwintering habits and biology of the pest.

MATERIALS AND METHODS

Burrowing bugs used in this study were collected from peanut fields in Frio County, Texas. Collections were made in early December of 1971 and 1972. The collections were made at this time of year to obtain a high percentage of diapausing individuals. The bugs were taken from harvested peanut fields by sifting the soil and plant residue through a 1/10 inch wire mesh screen.

Collections were held in 8 inch deep wooden cages measuring 6 inches wide x 15 inches long. The cages were filled with 6 inches of soil topped with 2 inches of peanut hulls and plant residue to simulate the natural

[1/] Hemiptera: Cydnidae

overwintering habitat. One hundred burrowing bugs were placed on top of the plant residue in each cage, and the screen top was then secured.

At weekly intervals, from late December through April, one cage was opened and the soil was removed from the cage 1 inch at a time. The soil was sifted through a 1/10 inch wire mesh sieve, and the number of burrowing bugs found at every level was recorded. Surviving insects were taken to the laboratory where they were dissected to determine if they were in diapause.

Diapausing individuals were characterized by gonad atrophy and the presence of a well-formed fat body. Reproductive individuals were distinguished by very little fat body formation and well-developed gonads.

RESULTS AND DISCUSSION

Survival. In each year of this study the highest rate of mortality occurred in the 2 wk period between placing the test population in holding cages and the time when the first dissections were made. During this period the mortality rate was 20% and 35% in the first and second year, respectively. Mortality could have been caused by handling or reproductive bugs dieing because they were incapable of surviving without food. As no great amount of mortality was ever observed in bugs handled in like manner and held for 4-6 wk prior to these tests, it is likely that most of the mortality was due to reproductives in the population. Mitchell and Taft (1966) obtained diapausing boll weevils by starving weevils collected from the field during September and October. They reported 30.6 - 31.4% survival of weevils starved for 2 weeks and only 12.3 - 19.7% survival of weevils starved for 3 weeks.

After the dissections began, the mortality rate was low and relatively constant through the study (Fig. 1). Survival was 62 and 58% in 1971 and 1972 respectively. This is relatively high when compared to a survival rate of 3.8% reported for the boll weevil (Sterling 1971).

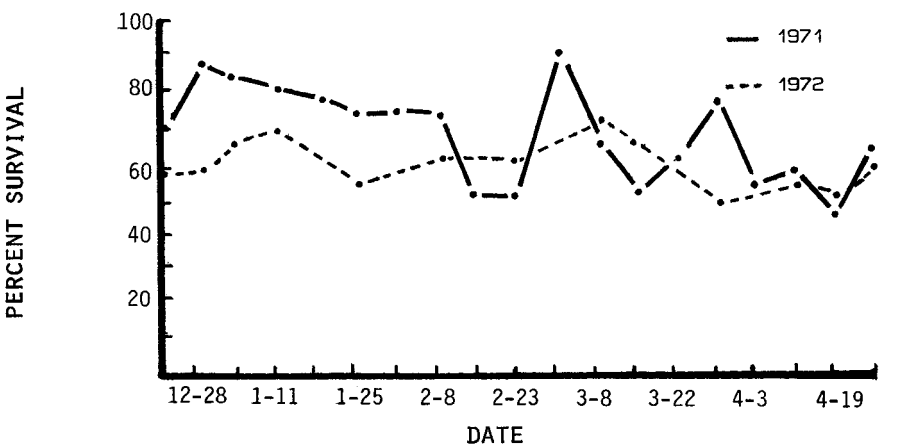

FIG. 1. The percentage survival of burrowing bugs determined at weekly intervals throughout the overwintering period.

Stratification. A distinct pattern was observed in the distribution of the test population in the soil (Fig. 2). From the last week in December until the last week in February the majority of the bugs were found in the bottom 2 inches of the cages (the 6-8 inch depth). As the bugs were limited to a depth of 8 inches by the cage, it was not possible

to determine how deep they would have gone had they not been restricted. Some would have undoubtedly burrowed deeper. However, the restrictions did not appear to have an adverse effect on the survival as evidenced by the low mortality. Also, no excessive clumping was observed on the bottom of the cages.

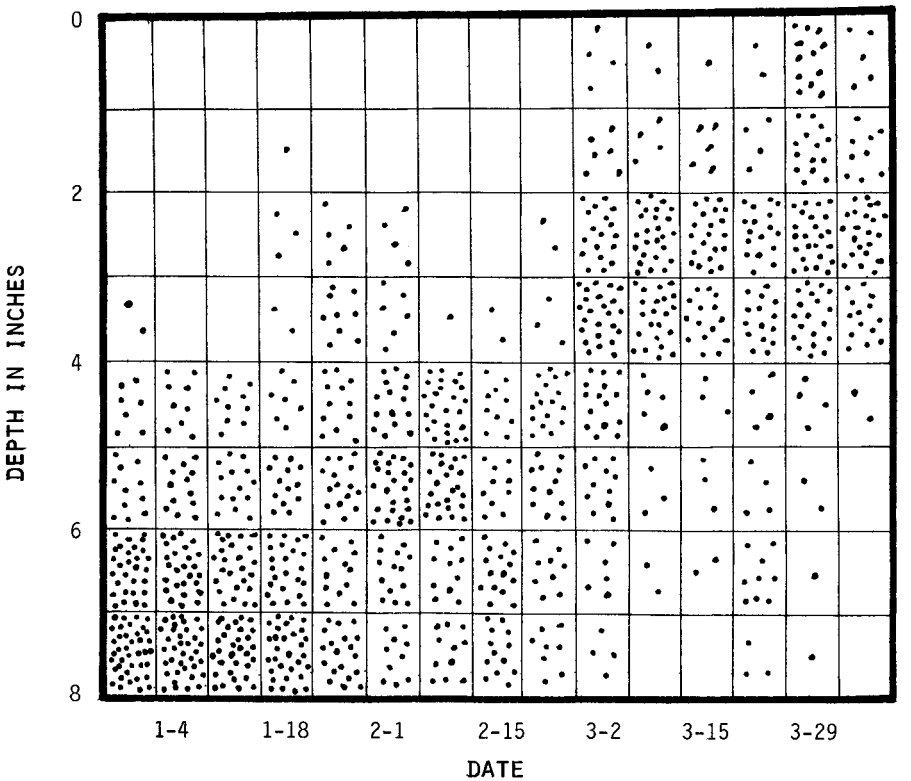

FIG. 2. Distribution of overwintering burrowing bugs in the soil. Each dot represents one bug (average of 2 yr).

During the first week of March the bugs began to migrate upward, and for the duration of the study most of the bugs were found in the top 2 inches of the soil and in the crop residue placed on top of the soil. This upward movement occurred over a 2-3 wk period which coincided with the termination of diapause in the population.

Diapause. From the initiation of this study in late December until the later part of February, the percentage of diapausing burrowing bugs in the population ranged from 88-100% (Fig. 3). There was a rapid decrease in the percentage of diapausing bugs in late February. By the first week in April only a few bugs exhibited the characteristics of diapause.

During the first wk of March, burrowing bus collected from holding cages during subfreezing temperature and taken to the lab for dissection were observed mating. When dissected all exhibited distinct characteristics of diapause. On several occasions at later dates, mating pairs were observed. Dissections showed these bugs also to be in diapause. This phenomenon is not documented in the literture. However,

matings of diapausing mosquitoes have recently been observed by R. W. Meola (personnel communication).

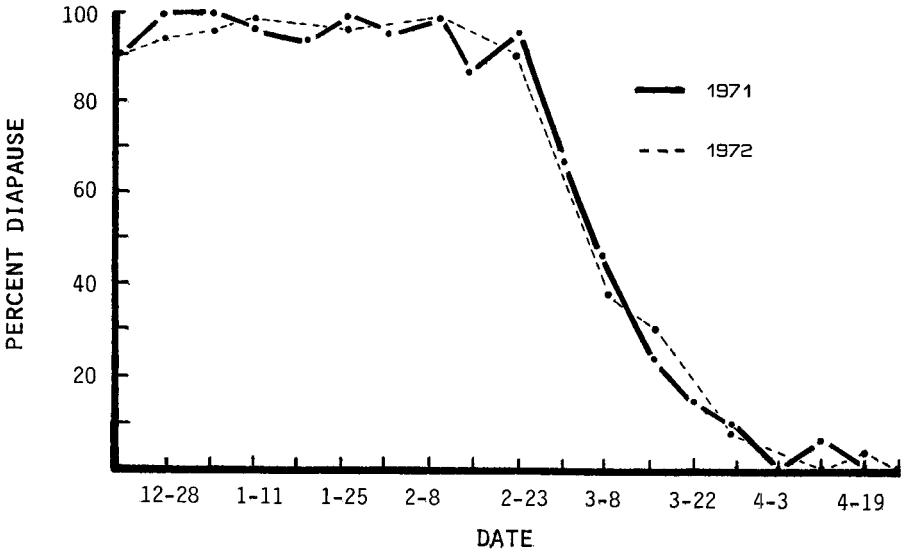

FIG. 3. The percentage of diapausing burrowing bugs occurring in a population at weekly intervals throughout the overwintering period.

LITERATURE CITED

Cassidy, T. P. 1939 U.S.D.A. Bur. Entomol. Plant Quar. Insect Pest Surv. Bull. 19: 322.

Froeschner, R. C. 1960. Cydnidae of the Western hemisphere. Proc. U. S. Nat. Museum. 3: 495-680.

Gould, G. E. 1931. Pangaeus uhleri, a pest of spinach. J. Econ. Entomol. 24: 484-486.

Hyslop, J. A. 1934. Insect findings of recent years which are or may be of interest to nursery inspectors and plant quarantine officers. J. Econ. Entomol. 27: 559-566.

Mitchell, E. R., and H. M. Taft. 1966. Starvation method for obtaining diapausing boll weevils able to survive the winter in hibernation. J. Econ. Entomol. 59: 55-57.

Sailor, R. I. 1954. Concerning Pangaeus bilineatus, (Say). (Hemiptera, Pentatomidae, subfamily Cydninae). J. Kans. Entomol. Soc. 27: 41.

Sterling, W. L. 1971. Winter survival of the boll weevil in the high and rolling plains of Texas. J. Econ. Entomol. 64: 39-41.

Tissot, A. V. 1939. U.S.D.A Bur. Entomol. Plant Quar. Insect Pest Surv. Bull. 19: 455.

AN EVALUATION OF VARIOUS TYPES OF MANURE AND VEGETATIVE MATERIAL AS LARVAL BREEDING MEDIA FOR THE STABLE FLY [1,2]

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ABSTRACT

The feces of four species of domestic animals alone and in combination with two vegetative materials commonly associated with animal production practices were evaluated against a standardized rearing medium for production of the stable fly, *Stomoxys calcitrans* (L.). Pupal production in cattle and horse manure was not significantly different from one another nor from the control media; swine and chicken feces yielded significantly fewer pupae. Of the various animal manures evaluated, pupal weight was greatest from that of horses followed by cattle, swine and chickens, respectively. The addition of Coastal bermudagrass hay or commercial pine wood shavings to the various manure types resulted in increased numbers and weights of pupae with swine and chicken dung. Moistened Coastal bermudagrass hay was as suitable for larval breeding as was cattle or horse manure alone or in combination with such vegetative material; however, larvae were unable to survive in moistened wood shavings alone.

INTRODUCTION

The stable fly, *Stomoxys calcitrans* (L.), has been reported to breed in a wide variety of organic materials from animal manures to mixtures of decaying vegetable matter and animal feces and even moist vegetative matter itself. Sixteen classes of breeding sites have been identified on dairy farms by Meyer and Petersen (1983) including fence lines, drainage ditches and haylage. Stored dung accounted for 31.7% of the pupae recovered. These same authors also reported fence lines, drainage ditches and haylage to account for 26.2, 18.2 and 12.9%, respectively, of stable fly pupae recovered in small feedlots. Spilled feed was reported to be a consistent breeding site in a large feedlot and accounted for 53% of stable fly pupae recovered. Williams et al. (1980) reported that the heaviest infestation of stable fly larvae and pupae during a study over a 41-month period in northwestern Florida was found at a dairy farm in silage; a single sample was estimated to contain 28,920 larvae per cubic foot. With the exception of a study in South Africa by Sutherland (1978), few controlled studies have been conducted to compare the suitability of various types of stable fly larval breeding media associated with the production of livestock and poultry. The present paper, therefore, examines the productivity of manures of several common animal species alone and in combination with certain types of vegetative material commonly associated with animal production as stable fly larval breeding sites.

MATERIALS AND METHODS

Manures were collected during the summer of 1987 at Texas A&M University animal production facilities from cattle, horses, swine and poultry and immediately frozen until tested. Vegetative materials consisted of commercially obtained Coastal bermudagrass hay

[1]Diptera: Muscidae
[2]Technical Article 23957 from the Tex. Agric. Expt. Stn.

and pine wood shavings used for bedding material. The control for all experiments consisted of the standard stable fly rearing media composed of sugar cane bagasse (600 g), meat and bone meal (300 g), whole wheat flour (300 g) and water (3000 ml) routinely used by the USDA Veterinary Toxicology Entomology Research Laboratory, College Station, TX (Bridges and Spates 1983).

Animal manures were evaluated in their natural state. Manure and vegetative mixtures were combined in a 2:1 ratio by weight. Sufficient water was added to the manure and vegetative mixtures as well as the hay and wood chips to produce moisture levels of approximately 80%. All samples were evaluated by adding 50 stable fly eggs (± 6-h old) to 200-g aliquots of each media previously weighed into 500-ml plastic containers; five replicates of each were conducted. Bioassays were subsequently maintained in an incubator at 27° C and 75% RH under a 14:10 (L:D) photoperiod until pupation occurred. Pupae were collected by water floatation, air dried, enumerated and weighed, after which they were returned to the incubator and held for adult eclosion. Data were analyzed by analysis of variance and means were separated with Duncan's New Multiple Range Test at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Results of the experiment are presented in Table 1. Mean stable fly pupal production from cattle (66%) and horse manure (68%) was not statistically different from one another nor from the control medium (68%); however, production from swine (42%) and chicken dung (36%) was significantly less. Mean pupal weight, on the other hand, was significantly greater in horse manure (14.0 mg) followed by that of cattle (12.8 mg), swine (12.6 mg) and chickens (10.9 mg). These results differ substantially from those of Sutherland (1978) in South Africa who reported the lowest larval mortality from feces of swine, horses and cattle, respectively; larvae failed to survive in pure chicken dung. Such differences may reflect geographical and cultural variations in diets of the various animal species which could be manifested in physical and chemical properties of the manures themselves. However, our results do appear to be supported by reports of naturally occurring stable fly breeding sites. Hogsette (1981), for example, demonstrated that the establishment of large equine facilities in central and southern Florida resulted in the creation of habitats suitable for large scale breeding

TABLE 1. Stable Fly Productivity from Various Larval Breeding Media Sources.

Breeding Media	Mean % pupation[a]	Mean pupal wt. (mg)[a]
Control	68a	12.6a
Cattle Feces	66a	12.8a
Cattle Feces/Hay	64a	14.8b
Cattle Feces/Wood Shavings	62a	12.2a
Horse Feces	68a	14.0b
Horse Feces/Hay	70a	14.6b
Horse Feces/Wood Shavings	64a	13.3a
Swine Feces	42c	12.6a
Swine Feces/Hay	54b	13.1a
Swine Feces/Wood Shavings	62a	12.1a
Chicken Feces	36c	10.9c
Chicken Feces/Hay	72a	13.3a
Chicken Feces/Wood Shavings	64a	13.8a
Hay	68a	12.7a
Wood Shavings	0d	0.0d

[a] Mean of five replications; 50 eggs per replication. Means in vertical columns followed by the same letter are not significantly different ($P > 0.05$).

of stable flies as well as house flies. Meyer and Peterson (1983) identified numerous breeding sites associated with cattle manure on dairy farms and feedlots. These same authors, however, reported that swine holding facilities were not major stable fly breeding areas. La Brecque et al. (1972) and Hulley (1983) reported that accumulations of dung below caged chickens in poultry houses served as breeding sites for stable flies as well as other dipterous species.

The addition of Coastal bermudagrass hay to the various manures had no significant effect on pupal production over that from cattle (64%) or horses (70%) alone; however, mean percent pupation increased from 42 to 54% with the addition of hay to swine feces and from 36 to 72% following the addition to chicken dung. Similarly, the addition of wood shavings also resulted in significantly increased mean pupation rates from 42 to 62% for swine dung and from 36 to 64% for chicken feces. Meyer and Petersen (1983) found that swine dung was not a major breeding site of the stable fly, but swine dung and haylage was a consistent house fly breeding site in swine holding facilities. Sutherland (1978) also reported a significant decrease in stable fly larval and pupal mortality with the addition of pine saw dust to chicken feces; he theorized that pure chicken dung was too dense and that larvae subsequently suffered from a lack of oxygen. Stable fly mean pupal weight also increased with the addition of hay to the feces of all four species evaluated; however, differences were significant from the individual manures only with that of cattle (14.8 mg) and chicken (13.3 mg). The addition of wood shavings resulted in significantly increased mean pupal weights over that of the various manures alone only when added to the feces of chickens (13.8 mg).

Coastal bermudagrass hay to which water had been added was as suitable for larval breeding as the control medium resulting in 68% mean pupal production. Stable flies have recently been reported breeding in large round hay bales stored outdoors at 9 of 12 sites surveyed in central Missouri (Hall et al. 1982); bales in advanced stages of decay appeared less attractive than were fermenting bales that were only several months old (Hardin 1982). Larvae were apparently unable to survive in moistened wood shavings since no pupae were recovered.

Adult eclosion rates appreared to be a function of the number of pupae produced from the various media rather than the breeding media itself. Emergence from the puparia averaged above 90% for each of the media evaluated with the exception of wood shavings from which no pupae were recovered.

LITERATURE CITED

Bridges, A. C., and G. E. Spates. 1983. Larval medium for the stable fly, *Stomoxys calcitrans*(L.). Southwest. Entomol. 8: 6-9.

Hall, R. D., G. D. Thomas, and C. E. Morgan. 1982. Stable fly, *Stomoxys calcitrans* (L.) breeding in large round hay bales: initial associations (Diptera:Muscidae). J. Kans. Entomol. Soc. 55: 617-620.

Hardin, B. 1982. The round bale-stable fly connection. U.S.D.A. Agric. Res. 31: 16.

Hogsette, J. A. 1981. Fly control by composting manure at a south Florida equine facility, p. 105-113. *In* R. S. Patterson, P. G. Koehler, P. B. Morgan, and R. L. Harris (ed), Status of biological control of filth flies. A.R., S.E.A., U.S.D.A.

Hulley, P. E. 1983. A survey of the stable flies breeding in poultry manure, and their potential natural enemies. J. Entomol. Soc. South. Afr. 46: 37-47.

La Brecque. G. C., D. W. Meifert, and D. E. Weidhaas. 1972. Dynamics of house fly and stable fly populations. Fla. Entomol. 55: 101-106.

Meyer, J. A., and J. J. Petersen. 1983. Occurrence and parasitism of stable flies and house flies on midwestern feedlots and dairies. Bull. Vector Ecol. 8: 36.

Sutherland, B. 1978. The suitability of various types of dung and vegetable matter as larval breeding media for *Stomoxys calcitrans* L. (Diptera: Muscidae). Onderstepoort J. Vet. Res. 47: 7-11.

Williams, D. F., J. A. Rogers, P. Hester, J. Ruff, and R. Levy. 1980. Preferred breeding media of the stable fly, *S. calcitrans*, in northwestern Florida. Mosq. News. 40: 276-279.

BOLL WEEVIL:[1] GRANDLURE TRAPPING AND EARLY-SEASON INSECTICIDE APPLICATIONS IN RELATION TO COTTON INFESTATIONS IN ARIZONA[2]

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ABSTRACT

Studies were conducted in 1986 and 1987 in Arizona to determine the relationship between numbers of early season boll weevils, Anthonomus grandis Boheman, caught in grandlure-baited traps and cotton square infestations. Grandlure-baited trap catches were significantly correlated to square infestations.

Commercial cotton fields treated in early season at pinhead square stage, when accumulated average trap catches were >5 boll weevils per trap per week for 5 wk prior to the first occurrence of 1/3 grown squares (trap index), had significantly fewer damaged squares during the first fruiting cycle than untreated fields. Both treated and untreated fields had low square infestations (0.3 to 1.1%) during the first fruiting cycle when cumulative trap catches were <5.

These data demonstrate the value of early season trapping and use of a trap index system to detect overwintering boll weevil populations and identify potential problem areas.

INTRODUCTION

The boll weevil, Anthonomus grandis Boheman, has been of increasing concern in Arizona since 1978 following the resumption of perennial cotton growing practices (Bergman et al. 1983). These practices were again banned in 1982, but not before the boll weevil became established in many cotton growing areas of Arizona and southern California. In recent years infestations requiring the need for insecticide applications to prevent economic losses have been prevalent in central Arizona cotton (Moore et al. 1987). Thus, detection and sampling technology is needed to identify potential problem areas.

Early season (pinsquare) insecticide applications to reduce numbers of overwintered boll weevils have been practiced in other areas of the cotton belt to delay development of damaging infestation levels (Taft and Hopkins 1963, Walker et al. 1976). Grandlure, the boll weevil aggregation pheromone (Tumlinson et al. 1969), has been demonstrated to be an excellent tool for monitoring overwintered boll weevil populations (Hopkins et al. 1977, Mitchell 1978). Rummel and Bottrell (1976) observed that the response of overwintered boll weevils to grandlure-baited traps was characterized by peak activity in the spring followed by a period of minimum response during mid-June to mid-August. These results were partially explained when White and Rummel (1978) determined that boll weevil movement into cotton was closely related to the

[1] Coleoptera: Curculionidae
[2] Mention of a proprietary product does not constitute an endorsement by the USDA.

phenology of the cotton plant, and few boll weevils entered cotton fields prior to initiation of cotton fruiting. Peak catches of overwintered boll weevils occurred 4 to 5 wk prior to this time, and boll weevil response to grandlure-baited traps was low at the time boll weevils were entering the cotton field. Based on these observations and those of Mitchell (1978), Rummel et al. (1980) and Benedict et al. (1985) developed grandlure-baited trap indices for determining the need for overwintered boll weevil control in Texas. The results of Johnson and Gilreath (1982) indicated that boll weevil trap indices to determine need for early season control were also applicable under South Carolina conditions.

Grandlure-baited trap catches are highly correlated to emergence patterns from hibernation cages, as well as emergence of feral populations in areas where distinctive emergence from overwintering habitats occur (Carroll and Rummel 1985). This relationship is less obvious in the subtropical areas of Texas and under the mild winter temperature conditions of Arizona where boll weevil activity as measured in grandlure-baited traps occurs throughout the year (Guerra et al. 1982, Guerra and Garcia 1982, Bariola et al. 1984). In Arizona, Bariola et al. (1984) demonstrated that boll weevils emerged from bolls from January through May, and the data of Leggett[3/] (unpublished) indicates that boll weevils emerge from leaf litter and other overwintering sites from April to May.

We conducted grandlure-baited trap and cotton crop phenology studies near Phoenix, AZ in 1986 and 1987 to determine: (1) the relationship of boll weevil trap catches to cotton crop infestations, and (2) the effect of pinsquare insecticide applications on boll weevil infestations. This paper is a report of these studies.

MATERIALS AND METHODS

The Hercon Boll Weevil Scout^{tm} trap (Hercon Division, Health-Chem Corp, New York, NY) was used throughout the studies. Traps were baited with a strip of the Hercon plastic laminated lure containing 12 mg grandlure. Lures were changed every 2 wk, and no toxicant strips were included in the trap.

In both 1986 and 1987, nine commercial cotton fields in Maricopa County were selected as study sites. Fields were ca. 16.2 ha in size and planted between 15 April and 15 May.

One Hercon grandlure-baited trap was placed on each side of each cotton field ca. 3.1 m from the field edges on 5 to 8 May in 1986 and 20 January to 6 February 1987. Traps were examined weekly, and numbers of boll weevils caught were removed from the trap and taken to the laboratory where they were counted.

In 1986, five of nine fields were treated 1-3 times at 5-day intervals with low volume malathion, and four fields were not treated. In 1987, four of nine fields were treated, and five were untreated. Insecticide treatments were initiated 5-7 days after the pinhead square developmental stage of the cotton plant. All fields received 6-10 applications of other insecticides for control of boll weevils and other cotton insects during the remainder of the season with treatments initiated 3-28 July.

Each year cotton fields were inspected weekly from the time of planting until early September. Beginning when 1/3-grown squares were first observed, one 4 m section of row in each quadrant of each field was randomly selected each week and all 1/3-grown squares were counted

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3/ Joseph E. Leggett, USDA-ARS, Western Cotton Research Laboratory, Phoenix, Ariz.

and examined for boll weevil damage. Additionally, 100 squares (1/3-grown, 25 per field quadrant) were collected at random, returned to the laboratory and inspected for boll weevil damage.

Trap data, percentages of boll weevil infested squares and numbers of infested squares per 4 m of row were subjected to regression-correlation analyses to determine the relationships between the numbers of boll weevils captured per trap and levels of square infestations in cotton. The accumulated average numbers of boll weevils captured per trap per field per week for 5 wk prior to the occurrence of 1/3 grown squares was used as the trap index as described by Benedict et al. (1985). Additionally, cotton square infestation data were subjected to analyses of variance using unequal replications, and means were separated using the least significant difference method.

RESULTS AND DISCUSSION

In 1986 and 1987, average numbers of boll weevils caught per wk in grandlure-baited traps in early May were 19 and 18, respectively, declining thereafter to 1 to 2 per trap per wk in mid-May (Fig. 1). In 1987, boll weevil trap catches in March ranged from an average of 15 to 40 per trap per wk. In both years trap catches were less than 1 per trap per wk during June, July and early August. These results for early spring infestation of the boll weevil in Arizona are similar to those reported by Bariola et al. (1984). In Texas minimal response of boll weevils to grandlure-baited traps occurred from mid-June to mid-August, independent of trap placement with respect to nearness to cotton plantings, suggesting that the phenomena was seasonally related (Rummel and Bottrell 1976). The decline in boll weevil catches to < 1 per trap per field per wk in our studies corresponded with the appearance of 1/3-grown squares that first occurred the wk of 25 May in 1986 and the wk of 1 June 1987 (Fig. 1). White and Rummel (1978) reported in Texas that the entry of overwintered boll weevils into cotton appeared to be in response to the fruiting pattern of the plants with the greatest number of boll weevils entering cotton plantings after the occurrence of 1/3-grown squares. In our studies, peak numbers of 1/3-grown squares were found the wk of 20 July 1986 and 13 July 1987 (Fig. 1), and the first boll weevil damaged squares were found an average of 31 days after the occurrence of 1/3-grown squares.

The accumulated average number of boll weevils for 5 wk prior to the occurrence of 1/3-grown squares was significantly correlated to the average percentages of damaged 1/3-grown squares collected at random in cotton fields ($r = 0.90$, $P \leq 0.05$) and to the number of damaged 1/3-grown squares per 4-m of row ($r = 0.86$ $P \leq 0.05$) during the first fruiting cycle (Fig. 2). Predicted percentages of damaged squares and predicted number of damaged squares per 4-m of cotton row were represented by the equations $\hat{y} = 0.2321$ Exp. (0.1505x) and $\hat{y} = 0.1601$ Exp. (0.1309x), respectively. Correlations between numbers of boll weevils captured for four and three wk prior to the occurrence of 1/3-grown squares and percentage of infested squares were $r = 0.80$ (significant ($P \leq 0.05$), and $r = 0.66$ (not significant), respectively. No boll weevils were trapped in four to six fields during the two or one-wk period before the occurrence of 1/3-grown squares, and no correlation existed.

Cotton fields receiving no pinsquare insecticide treatments and with average trap indices > 5 (range 9.3 to 27.7) sustained an average of 6.8% infested 1/3-grown squares during the first cotton fruiting cycle (Table 1). This is compared to 0.3 and 0.8 percent infested squares for cotton fields having trap indices of <5 (range 0.8-4.8) & >5 (range 9.3-94.5), respectively, with pinsquare insecticide applications. In fields receiving no pinsquare treatments, 1.1% infested squares were

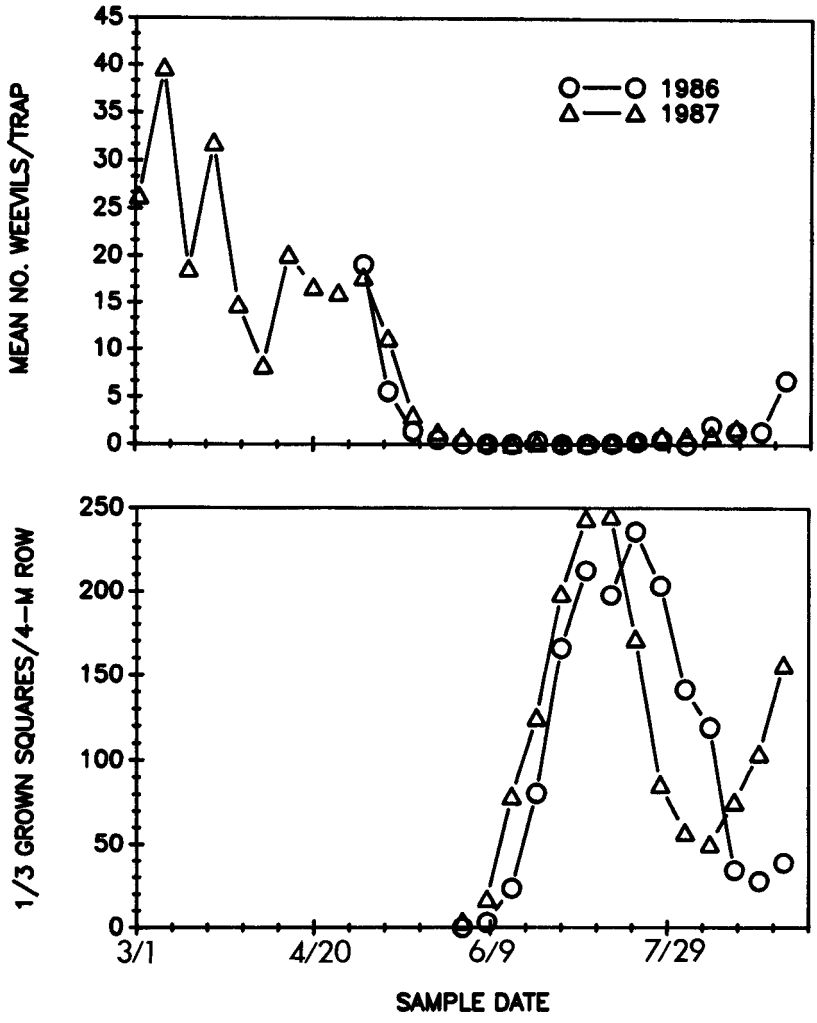

FIG. 1. Seasonal average numbers of boll weevils caught per trap per wk in grandlure-baited traps and seasonal average numbers of 1/3-grown cotton squares in Arizona.

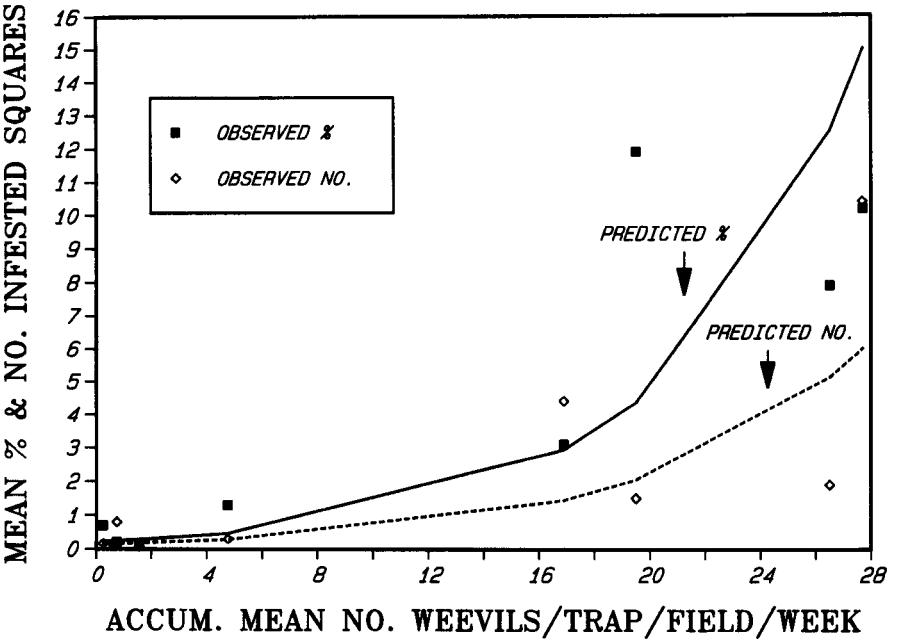

FIG. 2. Relationship between accumulated average numbers of boll weevils caught per trap per 5-wk prior to occurrence of 1/3-grown cotton squares and numbers of boll-weevil damaged squares.

TABLE 1. Effect [a/] of Early-Season Insecticide Applications at Various Trap Index Levels on Percentages of Infested Squares and Number of Damaged Squares per 4 m of Cotton Row. 1986 and 1987.

Treatment	No. of fields	Trap Index	Trap index range	Seasonal avg. square damage	
				%	Damaged squares per 4 m row
No early season	5	> 5	9.3-27.7	6.8 a	3.7 a
insecticide	5	< 5	0.3- 1.6	1.1 b	0.3 b
Early season	4	> 5	9.3-94.5	0.8 b	0.5 b
insecticide	4	< 5	0.8- 4.8	0.3 b	0.3 b

[a/] Means of 3 to 5 replications, 9-10 sampling dates. Means in a column not followed by the same letter are significantly different ($P \leq 0.05$, LSD).

collected when trap indices of < 5 (0.3-1.6) occurred. Numbers of 1/3-grown boll weevil damaged squares per 4 m of row followed similar trends in relation to pinsquare insecticide applications and trap indices.

Cotton fields not receiving pinsquare insecticide applications reached a peak percentage of infested squares in August as did plots receiving pinsquare insecticide, but percentages were 7.2 and 1.9, respectively; and the number of days before damaged squares were detected were 31.2 and 41.3, respectively, following the first occurrence of 1/3-grown squares (Table 2). The differences in infestation levels between fields treated with pinsquare applications and those not treated at pin square may have been influenced by July insecticide applications to all fields.

The relationship between boll weevil infestation and cotton yield reductions in Arizona are not well-established. However, most growers report losses of 1.24 to 2.47 bales per hectare in cotton fields with high-level late-season boll weevil infestations (personal communications). No cotton yield data were obtained in Arizona in the present studies, but it is doubtful that yield increases occurred as a result of the pinsquare applications. Slosser et al. (In press) reported that cotton yield increases in Texas did not occur as a result of early-season boll weevil control in their studies and did occur in only two of twelve other published studies reviewed. In the present experiment, as well as in the studies of Slosser et al. (In press), overwintering boll weevil populations were reduced by pinsquare insecticide applications. The real value of these treatments may be in delaying population development and reducing the number of insecticide applications needed later in the season. For example, Heilman et al. (1976) found that one insecticide application for overwintering boll weevil control at pinhead square and a second application at 1/3-grown square stages of cotton plant development resulted in an average of 59 days before additional insecticide applications were required for boll weevils or tobacco budworms, H. virescens (F.). Beneficial insect populations increased after the second overwintering boll weevil insecticide application and were a significant factor in suppressing tobacco budworm populations.

In 1987, average numbers of boll weevils caught in grandlure baited traps in cotton fields treated with pinsquare insecticides were 0.6, 14.0 and 102.0 in September, October and November, respectively. Numbers of boll weevils caught in September, October and November in cotton fields not receiving early-season insecticide applications were 0.7, 43.0 and 290.0, respectively.

Trap indices for the Rolling Plains and Gulf Coast cotton growing areas of Texas are highly effective tools for determining the need for overwintered boll weevil control action (Rummel et al. 1980, Benedict et al. 1985). Our results suggest that trap indices also may be useful for determining the magnitude of Arizona boll weevil populations and identifying potential problem areas. Additional studies need to be conducted in Arizona to determine the benefits of pinsquare overwintering boll weevil control in relation to cotton yields.

Data from the Texas Rolling Plains show that trap indices > 2.5 during the wk of the occurrence of first 1/3-grown squares indicate the need for overwintering boll weevil control (Rummel et al. 1980). This was based on a plant damage index of 2% oviposition damaged squares when the number of 1/3-grown or larger squares was ≥ 24,710/ha. Similarly, Benedict et al. (1985) suggested that trap indices ≥ 2.5 indicated the need for overwintering boll weevil control in Gulf Coast cotton growing areas of Texas. Our data based on percentage of damaged squares occurring during the first fruiting cycle show an estimated 2% damaged squares when the boll weevil trap index was 10-15. Thus, our data suggest higher trap index-square infestation relationships. This may be

TABLE 2. Effect [a] of Early-Season Insecticide Treatments on Percentages of Infested Squares or Numbers of Infested Squares per 4 m of Cotton Row During June, July and August of the Cotton Growing Season. 1986 and 1987.

Treatment	Damaged [b] first damage	June		July		August	
		Days to Damaged		Damaged		Damaged	
		% Damaged squares/100	squares /4 m row	% Damaged squares/100	squares/ 4 M row	% Damaged squares/100	squares/ 4 M row
No early season insecticide	31.2 a	0.0 a	<0.1 a	3.9 a	2.8 a	7.2 a	3.2 a
Early season insecticide	41.3 b	0.4 a	<0.1 a	1.2 a	0.4 a	1.9 b	0.9 a

[a] Means of 9 plots (4-5 sampling dates each month) for each treatment. Means in a column not followed by the same letter are significantly different ($P \leq 0.05$, LSD).
[b] Days after occurrence of 1/3-grown squares.

the result of higher boll weevil mortality during early season under the hot dry conditions in Arizona (Fye and Bonham 1970), and the Hercon Scout trap that has been reported to capture more boll weevils than the Hardee trap but not the Leggett trap (Leggett 1980). Also, grandlure-baited trap catches are highly correlated to boll weevil emergence in the Texas Rolling Plains and clearly define the temporal relationship of emergence (Carroll and Rummel 1985). Boll weevil captures in grandlure-baited traps in Arizona occur every month of the year (Bariola et al. 1984). Peak catches occur in January and February, declining thereafter to early May and remain low through mid-September and then increase to January. Thus, our trap indices reflect captures of boll weevils active throughout the winter months as well as weevils that have been inactive in diapause sites during winter. The percentages of the boll weevil population that are active in the winter months that survive to become reproductive in cotton, as opposed to those that emerge from being inactive in diapause sites during the winter, must be determined to more accurately determine the relationship of trap catches to cotton infestations.

Boll weevil infestations in Arizona have spread and become established particularly in the central and western areas of the state. The cooperative efforts of the Arizona Cotton Growers Association, Arizona Agricultural and Horticultural Commission and USDA's Animal and Plant Health Inspection Service are being expanded in a Southwestern Boll Weevil Eradication program. The results of the present study indicate the value of early-season boll weevil trap monitoring to detect overwintered boll weevil populations and identify potential problem areas. Early-season trapping as indicated by Rummel et al. (1980) and Benedict et at. (1985) does not negate the need for continued field scouting but does serve as a positive guide to problem areas and is an additional tool that might be used to determine the need for control action. Early-season insecticide applications in Arizona must be based on accurate estimation of boll weevil population levels and crop infestations. The decision to treat should be carefully weighed against the probability of Heliothis spp. and sweetpotato whitefly, Bemisia tabaci (Gennadius) and other secondary pest outbreaks that may occur following treatments with certain chemicals (Moore et al. 1987). The most successful and acceptable application of the pinsquare insecticide strategy for reducing overwintering boll weevil populations may depend on sufficient time lapse between the last pinsquare insecticide treatment and subsequent insecticide applications to allow recovery of beneficial insect populations.

LITERATURE CITED

Bariola, L. A., T. J. Henneberry, and D. Bergman. 1984. Boll weevils (Coleoptera: Curculionidae): Emergence from bolls during the spring, and trapping of adults in Arizona. J. Econ. Entomol. 77: 1166-1170.

Benedict, J. H., T. C. Urban, D. M. George, J. C. Segers, D. J. Anderson, G. M. McWhorter, and G. R. Zummo. 1985. Pheromone trap thresholds for management of overwintered boll weevils (Coleoptera: Curculionidae). J. Econ. Entomol. 78: 169-171.

Bergman, D., T. J. Henneberry, L. A. Bariola, and J. M. Gillespie. 1983. Studies of pest and beneficial insects in Arizona stub and planted cotton. USDA, ARS, Agric. Res. Results ARR-W-32.

Carroll, S. C., and D. R. Rummel. 1985. Relationship between time of boll weevil (Coleoptera: Curculionidae) emergence from winter habitat and response to grandlure-baited pheromone traps. Environ. Entomol. 14: 447-451.

Fye, R. E., and C. D. Bonham. 1970. Summer soil surface temperatures and their effect on boll weevil survival in fallen squares. J. Econ. Entomol. 63: 1599-1602.

Guerra, A. A., and R. D. Garcia. 1982. Seasonal patterns of boll weevil response to grandlure-baited traps in the subtropical Rio Grande Valley of Texas. Southwest. Entomol. 7: 216-220.

Guerra, A. A., R. D. Garcia, and J. A. Tamayo. 1982. Physiological activity of the boll weevil during the fall and winter in subtropical area of the Rio Grande Valley of Texas. J. Econ. Entomol 75: 11-15.

Heilman, M. D., M. J. Lukefahr, L. N. Namken, and J. W. Norman. 1977. Field evaluation of a short season production system in Lower Rio Grande Valley of Texas, pp. 80-82, In Proc. Beltwide Cotton Prod. Res. Conf., Atlanta, GA.

Hopkins, A. R., H. M. Taft, and S. H. Roach. 1977. Boll weevils: Leggett traps as a substitute for woods trash examinations as an indication of potential field populations. J. Econ. Entomol. 70: 445-446.

Johnson, D. R., and M. E. Gilreath. 1982. Boll weevil, Anthonomus grandis grandis Boheman, pheromone trapping as an index of population trends. J. Ga. Entomol. Soc. 17: 429-433.

Leggett, J. E. 1980. Boll weevil: Competition and non-competitive evaluation of factors affecting pheromone trap efficiency. Environ. Entomol. 9: 416-419.

Mitchell, E. B. 1978. Pheromone trapping as an index for initiating control of boll weevils, pp. 115-116. In Proc. Beltwide Cotton Prod. Res. Conf. Dallas, Tx.

Moore, L., T. F. Watson, and M. Lame. 1987. 1987 Insect pest management for cotton. College of Agric., Univ. Arizona, Tucson, AZ,

Rummel, D. R., and D. G. Bottrell. 1976. Seasonally related decline in response of boll weevils to pheromone traps during mid-season. Environ. Entomol. 5: 783-787.

Rummel, D. R., J. R. White, S. C. Carroll, and G. R. Pruitt. 1980. Pheromone trap index system for predicting need for overwintered boll weevil control. J. Econ. Entomol. 73: 806-810.

Slosser, J. E., J. R. Price, and G. J. Puterka. 1988. Evaluation of furrow-diking and early-season insecticide applications on boll weevils (Coleoptera: Curculionidae), bollworms (Lepidoptera: Noctuidae) and cotton yield in the Texas Rolling Plains. J. Econ. Entomol. (In press).

Taft, H. M., and A. R. Hopkins. 1963. A community effort in boll weevil control. USDA, ARS-33-82.

Tumlinson, J. H., D. D. Hardee, R. C. Gueldner, A. C. Thompson, P. A. Hedin, and J. P. Minyard. 1969. Sex pheromones produced by male boll weevils: isolation, identification, and synthesis. Science. 166: 1010-1012.

Walker, J. K., G. A. Niles, J. R. Gannaway, R. D. Bradshaw, and R. E. Glodt. 1976. Narrow row planting of cotton genotypes and boll weevil damage. J. Econ. Entomol. 69: 249-253.

White, J. R., and D. R. Rummel. 1978. Emergence profile of overwintered boll weevils and entry into cotton. Environ. Entomol. 7: 7-14.

SEASONAL BOLL WEEVIL[1/] MOVEMENT BETWEEN NORTHEASTERN MEXICO AND THE RIO GRANDE VALLEY OF TEXAS, USA.

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ABSTRACT

Boll weevils, Anthonomus grandis Boheman, exhibited strong dispersal flights in several directions across the Mexican-American border throughout the noncotton season, regardless of prevailing weather conditions. The greatest distance marked weevils flew in 1 day was 48 km in September and October. The maximum distance marked weevils flew was 272 km (From Jimenez, TAMPS., Mexico, to Brownsville, TX) in 6-7 wk during September and October. Marked weevils released in Santa Teresa, TAMPS., Mexico, in September 1982 were trapped 8 km away, 6-7 months later (March 1983) outside Brownsville, TX. Although native weevils were distributed throughout the Rio Grande Valley of Texas, the greatest numbers were trapped between Brownsville and Mission, TX.

INTRODUCTION

Recent studies by Guerra et al. (1982, 1983) showed that from physiological (feeding, mating, flying, etc.) and biochemical (O_2 consumption) points of view, subtropical boll weevils, Anthonomus grandis Boheman, overwinter in a metabolically active state and remain potentially reproductive during the noncotton season (September-March). Based on the above information and on results of other investigations (Guerra and Garcia 1982, Guerra at al. 1984, Graham et. al. 1978), I suggested that in tropical and subtropical areas weevils probably do not enter a "true" or firm stage of diapause; but they overwinter in the absence of live cotton (in leaf litter or inside dry bolls) in a "resting" or quiescent physiological state. I have recorded weevil catches with grandlure-baited traps during the noncotton season in the state of Tamaulipas, and eastern sections of the state of Nuevo Leon, Mexico, in areas where cotton has not been planted commercially for more than 30 years.

In addition, several workers have reported the existence of numerous boll weevil infested colonies of wild cotton, native Gossypium hirsutum race "punctatum", on the northeastern coastal areas of Mexico (Fig. 1) between the cities of Matamoros and Tampico, TAMPS. (Cross et al. 1975, Anonymous 1939). I found infested colonies of native G. hirsutum in a coastal area called Media Luna (near Santa Teresa, Mexico, ca. 88 km from Brownsville, TX) and in Laguna Morales, near La Pesca, Mexico, (ca. 150 km from Cd. Victoria, Mexico), in coastal sites previously described by W. H. Cross (unpublished data). Lukefahr (1956) reported that boll weevils infested flower buds (as large as cotton squares) of Thespesia populnea (L.) Soland (a tree used for ornament or shade) under natural conditions in South Texas. Lukefahr and Martin (1962) reported Cienfuegosia sulphurea (St.

1/ Coleoptera: Curculionidae

Hil.) Garcke [appears synonymous with C. drummondii (Gray) Lewton] as a native host for boll weevils, and Lukefahr and Martin (1965) later demonstrated reproduction by these weevils on C. drummondii under natural field cage conditions. This noncotton host plant has a wide distribution in North America and has been recorded from coastal areas of the state of Tamaulipas, Mexico, northward to Gonzalez, TX (Fig. 1).

Currently, there is little information available concerning the population dynamics of overwintering weevils in subtropical areas of the US and Mexico. Therefore, I investigated the seasonal weevil movement between the States of Tamaulipas and Nuevo Leon, Mexico, and the Rio Grande Valley of Texas, USA.

MATERIALS AND METHODS

Insect Collections. During this study marked and unmarked native boll weevils were collected in a total of 30 grandlure-baited trap (Leggett and Cross 1971) stations consisting of three traps per station. (Fig. 1). Traps within a station were mounted on wooden stakes ca. 1 m above ground level or on fence posts, and 100 m apart. Each trap was baited with a cigarette filter saturated with 3 mg of grandlure (Bull 1976) and lure dispensers were changed weekly. Except for a test to determine how far a weevil could fly in 1 day, collections at all trap stations were made weekly from August 1982 thru November 1984. The number of trapped weevils was estimated in the Laboratory by volume (Guerra and Garcia 1982).

Long distance flight. To determine the flight capabilities and behavior of subtropical overwintering weevils that migrate during the fall, a mark-release-recapture study was conducted with native weevils collected in the Brownsville, Tx. area. Captured weevils were fed a 5% sucrose solution and kept in a holding room (3X3 m) for 3 days at ca. 29°C, a relative humidity of ca. 55% and a daily 14 h photo phase provided by two 1.2 m daylight flourescent lamps. Twenty four hours before release adult weevils were marked on the elytra with droplets of Aero-Gloss airplane dope (applied with dissecting needles) of different colors. During the 3-yr study period (1982-1984) a total of 10 release stations (indicated as in Fig. 1) were used, but biweekly releases between August and November were made from only five stations per year for 2 yr (1982 - 1983). Weevils released at each station were marked with a dot of paint of the same color during the 4 months releases were made, but the position of the paint dot varied depending on the date of release. Monthly release dates were indicated with a paint dot on the top left (for Aug.), top right (for Sept.), bottom right (for Oct.) and bottom left (for Nov.) of the weevil elytra, respectively. Because marked weevils were released twice a month and traps were inspected for recapture weekly, the time intervals that elapsed between release and recapture were estimated and reported as weekly ranges (Tables 1 and 2) with at least a 1 wk gap. A total of 40,000 weevils were released per station per year (ca. 8000-9000 weevils/station/release). Approximately 75% of the total releases were made during August and September. An additional 25,000 weevils were sprayed with a diluted (acetone) solution of the airplane dope, and 5,000 weevils were released per release station during September 1983. Groups of ca. 5,000 marked weevils were placed inside finely perforated brown paper bags (no. 20) provided with slightly moistened and folded paper towels to ensure a better distribution of the weevils. The paper bags were kept in a holding room automatically kept at ca 21°C until they were transported to the release points. Since previous research (Guerra 1983) indicated weevil activity peaks around noon, weevils were released between 1100 h and 1300 h (CST) close to a tree or shaded bushy area.

To insure that marked weevils were not accidentally transported (on vehicles or clothing) from the release points to the trap sites, the two persons in charge tore the paper containing the weevils and very carefully distributed the moistened paper with the weevils under a tree or close to a bushy area to facilitate a gradual dispersal. Releases were made at least

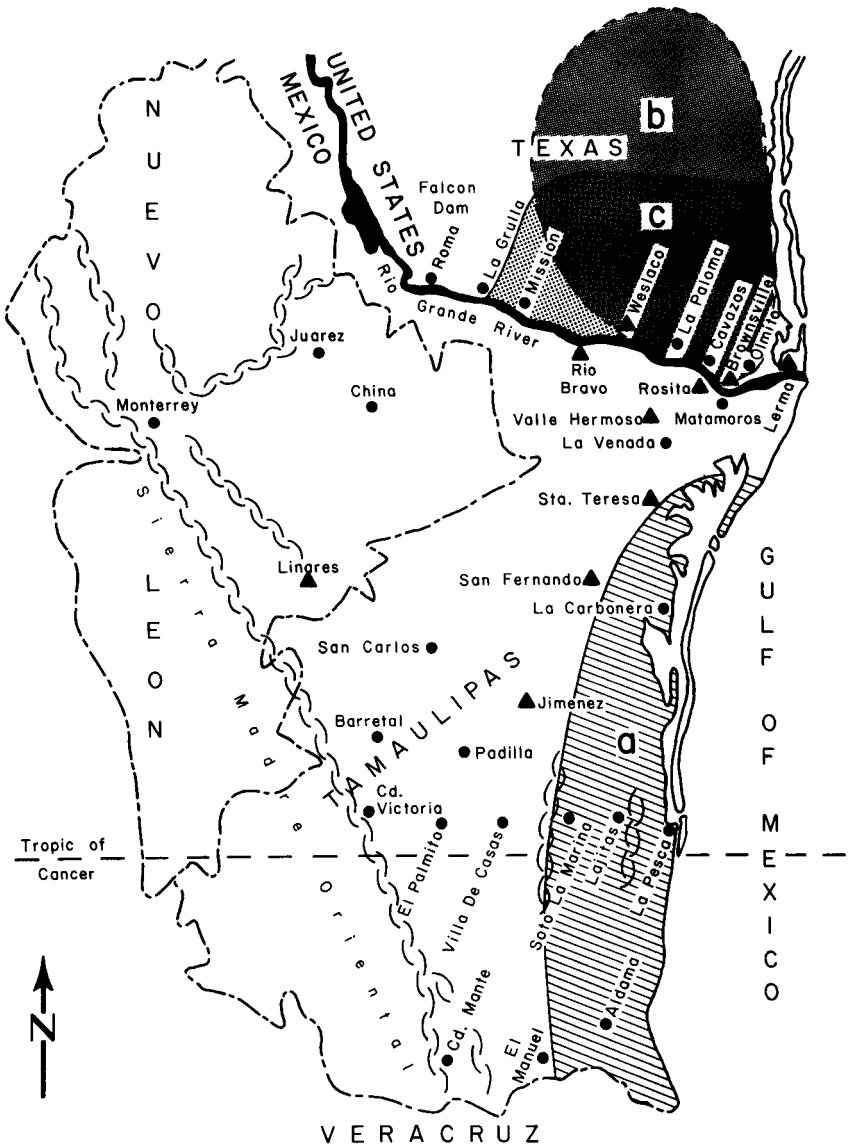

Fig. 1. Distribution of boll weevil trap stations (●, ▲) and release points (▲), native colonies of littoral Gossypium hirsutum race "punctatum" (a), Cienfuegosia drummondii (b), and commercial cotton (c) in southern Mexico and the Rio Grande Valley of Texas.

50 m away from the vehicle (parked with windows rolled-up). Before leaving the release site, people conducting releases checked each other's clothing to make sure no marked weevils were brought back.

Daily flights. To investigate the distance flown by weevils within a 24 h period, daily releases of 3,500 - 4,000 specifically color-marked (as indicated above) weevils were conducted for 4 consecutive days during the 1st weeks of September and October 1982. Releases were conducted on alternate days near Brownsville, TX, and at El Mezquital, Mexico (45 km south of Brownsville, TX). Traps were checked daily after releases. A total of eight trap stations (three traps spaced 100 m apart per station) were distributed around Brownsville, TX (the central trap station), so that two trap stations were located 20 and 40 km away in each of the cardinal directions.

Weevil distribution. To determine the seasonal distribution of native weevils in the Lower Rio Grande Valley of Texas, a total of 9 grandlure-baited trap stations (as those described above) were placed ca. 20 km from each other along the Mexican-American border at or near Lerma, Olmito, Brownsville, Cavazos, La Paloma, Weslaco, Mission, La Grulla, and Roma, Tx. (Fig. 1). To determine the seasonal distribution of native weevils in northeastern Mexico a total of 21 grandlure-baited trap stations (as those described above) were placed at or near Monterrey, Congregacion Juarez, Linares, and China, in the state of Nuevo Leon, Mexico, and at Matamoros, Rosita, Rio Bravo, Valle Hermoso, La Venada, Santa Teresa, San Fernando, La Carbonera, San Carlos, Jimenez, Barretal, Padilla, Cd. Victoria, El Palmito, Villa de Casas, Soto La Marina, and Lajitas, in the state of Tamaulipas, Mexico (Fig. 1).

RESULTS AND DISCUSSION

Results of mark-release-recapture investigations indicated that weevil movement took place in several directions across the Mexican-American border throughout the noncotton season (September-March). However, results of recaptures obtained within a few days after release indicated no apparent relationships between flight distance, flight time, flight orientation and prevailing wind direction (Tables 1 and 2). Most of the marked weevils were trapped between August and November. The maximum flight distances recorded for marked weevils were 224 km (on a NE flight course) for weevils released in August 1983 at San Fernando, TAMPS., Mexico and trapped the same year in November at Brownsville, TX and 272 km flown in a NE course by weevils released in September at Jimenez TAMPS., Mexico, and trapped in October near Brownsville, TX. The longest time periods that elapsed before marked weevils were recaptured were 3 months (three weevils released in August 1982 at Rosita, TAMPS., Mexico were trapped 30 km away in November at Olmito, TX), 4 months (two weevils released in September 1982 at Valle Hermoso, TAMPS., Mexico were trapped 53 km away in December at Rio Bravo TAMPS., Mexico), and 6 months (two weevils from a group released in September 1982 at Santa Teresa, TAMPS., Mexico, were trapped 88 km away in March 1983 at Brownsville, TX).

During releases, it was observed that large groups of weevils started an immediate, moderate-speed flight upwards in a straight or inclined flight pattern (20° to 45°) to an altitude of approximately 13 m before changing to an almost horizontal flight direction. Because weevils are small in size it was very difficult to follow individual or group flight patterns after the initial flight outburst described above. Therefore, it was not determined if marked weevils flew higher than 13 m or continued to follow the nearly horizontal flight pattern observed here.

. During this study none of the weevils marked with diluted acetone sprays of airplane dope were recaptured.

Results of studies on daily flights indicated that the maximum distance marked weevils flew during a 24-h period ranged from 13 km (Brownsville, TX,

TABLE 1. Total Number of Marked Boll Weevils Trapped[a]/ at Various Distances and Directions from Release Point[b]/ during 1982.

Release Station and Date	Trap Station and Date	Number Trapped	Release Recapture Interval (Weeks)	Flight Distance (KM) and Direction
Lerma, TX-SEP	Matamoros, MEX-SEP	17	1-2	11, SW
Lerma, TX-OCT	La Venada, MEX-OCT	33	1-3	21, SW
B'ville, TX-NOV	Olmito, TX-NOV	58	1-2	19, N
B'ville, TX-AUG	La Venada, MEX-SEP	39	1-4	24, S
B'ville, TX-SEP	Lerma, TX-SEP	50	1-3	32, NW
B'ville, TX-OCT	Weslaco, TX-NOV	18	3-4	88, W
B'ville, TX-SEP	Santa Teresa, MEX-OCT	15	2-5	88, SW
Rosita, MEX-NOV	Olmito, TX-DEC	8	1-3	30, SW
Rosita, MEX-NOV	Olmito, TX-NOV	14	3-5	30, SE
Weslaco, TX - SEP	Valle Hermoso, MX-SEP	8	1-3	32, SE
Weslaco, TX-AUG	Rio Bravo, MS-SEP	32	2-4	40, SW
Weslaco, TX-AUG	Olmito, TX-OCT	15	2-5	80, E
Rio Bravo, MS-NOV	Weslaco, TX-DEC	65	2-6	40, NE
Rio Bravo, MEX-OCT	Mission, TX-NOV	6	2-3	48, NW
Rio Bravo, MEX-NOV	Brownsville, TX-DEC	37	2-4	80, E
Rio Bravo, MEX-AUG	La Venada, MEX-OCT	14	3-5	88, SE

a/Each trap station consisted of three grandlure traps baited weekly with 3 mg of grandlure. Weevils were collected weekly.
b/A total of 8000-9000 weevils were released at each release station biweekly between August and November.

TABLE 2. Total Number of Marked Boll Weevils Trapped[a]/ at Various Distances and Directions from Release Points[b]/ during 1983.

Release Station and Date	Trap Station and Date	Number Trapped	Release Recapture Interval (Weeks)	Flight Distance (KM) and Direction
Valle Hermoso, MEX-NOV	Rio Bravo, MEX-NOV	10	2-4	53, NW
Valle Hermoso, MEX-SEP	Rio Bravo, MEX-DEC	2	15-16	53, NW
Valle Hermoso, MEX-SEP	Lerma, TX-NOV	21	2-5	56, E
Valle Hermoso, MEX-AUG	Olmito, TX-SEP	6	1-3	72, NE
Valle Hermoso, MEX-OCT	Rosita, MEX-OCT	25	1-2	40, NE
Santa Teresa, MEX-SEP	Matamoros, MEX-OCT	65	2-5	72, N
Santa Teresa, MEX-OCT	Brownsville, TX-NOV	32	3-4	88, N
Santa Teresa, MEX-SEP*	Brownsville, TX-MAR*	2	23-24	88, N
Santa Teresa, MEX-AUG	Olmito, TX - OCT	28	3-8	109, N
San Fernando, MEX-AUG	Brownsville, TX-NOV	10	6-8	224, N
San Fernando, MEX-AUG	La Carbonera, MEX-OCT	12	1-2	48, SE
San Fernando, MEX-AUG	Santa Teresa, MEX-SEP	9	3-4	64, NE
Jimenez, MEX-OCT	San Carlos, MEX-NOV	14	2-5	48, NW
Jimenez, MEX-SEP	Brownsville, TX-OCT	6	6-7	272, NE
Linares, MEX-SEP	Jimenez, MEX-OCT	4	2-3	120, SE

a/Each trap station consisted of three grandlure traps baited weekly with 3 mg of grandlure. Weevils were collected weekly.
b/A total 8000-9000 weevils were released at each release station biweekly between August and November.
*/Sept. 1982 - Mar. 1983

to Matamoros, TAMPS., Mexico, on a SE flight course) to 48 km (Olmito, TX, to El Mezquital, TAMPS., Mexico, on a SW flight course), respectively. Similar distances were flown following northern as well as southern flight patterns regardless of the prevailing wind direction during September and October 1983. Some marked weevils were trapped 1 to 2 wk after release in traps located only 11 km away. This distance was flown in a SW course by weevils released east of Brownsville, TX in September 1982 and trapped near Matamoros, TAMPS., Mexico.

Results of studies to determine the distribution of weevils in the Lower Rio Grande Valley of Texas indicated that because of a strong fall dispersal behavior weevils abound throughout the entire Valley.

Weevil catches in trapping stations located along the Mexican-American border from the coastal area (Lerma, TX) to an area ca. 125 km from the mountain complex of the Sierra Madre Oriental (Roma, TX) showed that most of the weevils were captured in trap stations located between Brownsville and Mission, TX (Table 3). Moderate to large weevil catches occurred during the noncotton season (September-March), and catches were small to moderate during the cotton season (April-July). Weevil catches in the trap stations which were farthest (La Grulla, Roma and Lerma, TX) from the main agricultural area (Brownsville to Mission, TX) were only obtained from August through November. From December through July weevil catches fluctuated from 0 to a few weevils; in fact only five and one weevils were trapped from December through July at the La Grulla and Roma, TX stations, respectively.

A summary of captures of unmarked (native) weevils (Table 4) indicated that except for weevils captured in China, N.L., Mexico (70 km SW of Hidalgo, TX) no weevils were trapped in the state of Nuevo Leon, east of the Sierra Madre Oriental mountain complex (ca. 150 km from the Rio Grande Valley of Texas). On the other hand, weevils were trapped throughout the state of Tamaulipas, Mexico. Of the total unmarked weevils captured in this state 35, 95, 97, and 98 percent were trapped 25, 50, 100, and 150 km (San Fernando, Mexico), respectively, from the commercial cotton producing areas of the Rio Grande Valley of TX. Of the total weevils trapped in 2 yr (600 weevils) in the central and southern areas of the state of Tamaulipas, below San Fernando, Mexico (ca. 150 km from Brownsville, TX), 73, 25, and 2 percent were trapped within 50, 100, and 150 km of the coast, respectively.

Boll weevil captures in pheromone traps in the Rio Grande Valley of Texas reach maximum peaks at the end of and shortly after the cotton season during August and September. However, large numbers of teneral adults continue to be trapped in the fall and winter after emerging from infested, dried squares and bolls in abandoned cotton fields or infested fruit which was buried during stalk destruction and plowing (K. R. Summy, personal communication). A similar situation occurs in the tropics where weevils remain physiologically active and potentially reproductive for as long as 7 months (Guerra et al. 1984) inside dry bolls during the noncotton season. These weevils cannot escape encapsulation until the rain softens the dry bolls (Guerra et al. 1984). In the subtropical study area, overwintering weevils remain reproductive (if host plants are available) and exhibit continuous adult emergence throughout the noncotton season (September-March), which is coupled with strong dispersal flights in all geographical directions. The flight capabilities of the boll weevil has attracted the attention of many researchers for many years, but the information obtained to date remains incomplete. Hunter and Hinds (1905) reported weevils were capable of flying over bodies of water 16 km in breadth and over land distances of approximately 64 km. In other work, it has been reported weevils are not strong fliers; and it was suggested weevils move from place to place flying a series of short distances, covering distances of up to 64 km in short periods of time (Hunter 1923). Beckman and Morgan (1960) reported weevils from temperate climates were capable of flying over water distances of ca. 55 km. More recently,

TABLE 3. Average Number of Unmarked (Native) Weevils Captured Bimonthly per Trap per Year from August 1982 to July 1984 at Indicated Trap Stations[a/] along the Mexican-American Border in the Rio Grande Valley of Texas.

Trap Station	AUG-SEP	OCT-NOV	DEC-JAN	FEB-MAR	APR-MAY	JUN-JUL
Lerma	1,275	228	17	3	11	8
Brownsville	8,210	2,790	380	237	70	45
Cavazos	4,482	2,162	56	301	48	16
La Paloma	3,807	1,407	74	84	33	20
Weslaco	4,273	792	60	39	65	28
Donna	1,900	578	33	8	59	15
Mission	2,670	1,382	24	12	45	14
La Grulla	660	155	2	0	3	0
Roma	87	12	0	0	1	0

a/Each trap station consisted of three grandlure traps baited weekly with 3 mg of grandlure. Weevils were collected weekly.

TABLE 4. Average Number of Unmarked (Native) Weevils Captured Bimonthly per Trap per Year from August 1982 to July 1984 at Indicated Trap Stations[a/] Throughout the States of Tamaulipas (T) and Nuevo Leon (NL), Mexico.

Trap Station	AUG-SEP	OCT-NOV	DEC-JAN	FEB-MAR	APR-MAY	JUN-JUL	TOTAL
Rosita, T	1,167	702	90	45	10	17	2,031
Valle Hermoso, T	558	380	62	20	3	7	1,030
Rio Bravo, T	1,350	813	58	15	7	15	2,258
China, NL	33	8	10	0	0	0	51
Juarez, NL	0	0	0	0	0	0	0
Monterrey, NL	0	0	0	0	0	0	0
Linares, NL	0	0	0	0	0	0	0
Sn. Carlos, T	0	1	0	1	0	0	2
Matamoros, T	741	585	38	37	17	28	1,446
La Venada, T	940	647	45	13	6	13	1,664
Sta. Teresa, T	149	31	10	2	0	0	192
San Fernando, T	83	45	15	7	0	0	150
La Carbonera, T	13	8	2	8	1	0	32
Jimenez, T	4	9	5	3	0	0	21
Padilla, T	4	3	10	1	0	0	18
Barretal, T	1	1	0	0	0	0	2
Cd. Victoria, T	0	1	0	0	0	0	1
El Palmito, T	1	0	0	0	0	0	1
Villa de Casas, T	117	80	20	15	2	1	235
Soto La Marina, T	13	10	4	10	3	6	46
Lajitas, T	7	20	2	6	3	4	42

a/Each trap station consisted of three grandlure traps baited weekly with 3 mg of grandlure. Weevils were collected weekly.

long-range migration studies reported that marked weevils were captured 72 km (Davich et al. 1970), 53 km (Johnson et al. 1975), 72 km (Johnson et al. 1976), and 98 km (Dickerson, personal communication) away from the release points, respectively. As indicated earlier, soon after releases our marked weevils exhibited a strong upward flight that reached altitudes of over 13 m in a few seconds. Boll weevils have been captured at high altitudes with aircraft-towed nets by Glick (1939). Rummel et al. (1977) found that there is a seasonal variation in the height of weevil flight, with higher flights occurring during late summer and fall. Rummel et al. (1977) captured weevils at altitudes up to 122 m, and they concluded that weevils flying higher than 30 m could be carried away on the wind and accomplish long-range dispersal flights into new breeding and overwintering sites. As shown earlier, overwintering weevils are active flyers and are capable of flying long distances in relatively short time intervals regardless of weather conditions during the noncotton season (September-March). Longevity studies of overwintering weevils conducted at Lubbock, TX (Rummel and Carroll 1985) indicated that 17% of the weevils that emerged when cotton was in the nonfruiting stage survived to infest fruiting cotton. Other workers have reported somewhat similar results with overwintering weevils in South Carolina and indicated that weevils containing more crude lipids lived longer (Fye et al. 1959). Weevils developing in bolls are known to be fatter than weevils developing in cotton squares. In this respect, Guerra and Robacker (1988) have suggested that the massive flight dispersal behavior exhibited by weevils in subtropical areas was possible due to the large amounts of energy provided by the abundant saturated fatty acids stored in the fatty tissues of overwintering boll-fed weevils. This characteristic of subtropical weevils is very important because it offers another alternative for overwintering survival. This situation becomes critical because of the mild winters in the Rio Grande Valley of Texas, where it is common to find numerous abandoned cotton fields producing regrowths with abundant squares and bolls during the noncotton season (K. R. Summy, personal communication). This late supply of cotton fruit becomes vitally important for overwintering weevils, because it provides another means of survival until the next cotton season.

We have mentioned earlier that boll weevils reproduce under natural conditions on native cotton, G. hirsutum race "punctatum", (Anonymous 1939, Cross et al. 1975) and on other noncotton hosts closely related to Gossypium (Hutchinson 1947) like Cienfuegosia sulfurea (St. Hil.) Gracke (Lukefahr and Martin 1962). These species are widely distributed in abundant littoral colonies in coastal areas of the state of Tamaulipas, Mexico and southern Texas (Fig. 1). This perennially viable ecological habitat and the unique physiological characteristics of subtropical weevils (Guerra 1986) could combine to provide another successful alternative for weevil survival during the noncotton season. Since this host plant-insect relationship is prevalent in our area, it is reasonable to speculate on the possible existence of a seasonal migratory cycle. In this system, overwintering weevils disperse from commercial fields after the end of the cotton season in the Rio Grande Valley of Texas and migrate and reproduce on the nearby littoral native cotton or other noncotton hosts in Texas and Mexico, and then they return (both P_1 and F_1 weevils) early the following spring to infest commercial cotton. The possibility that such a migratory cycle exists was partially demonstrated with unmarked weevils trapped in southern Tamaulipas (from San Fernando, Mexico to Cd. Victoria, Mexico) where no commercial cotton was cultivated. This migratory hypothesis is acceptable because it is well-known that insect migration does not necessarily involve return flight by the same individual. The percentage of weevils captured in these areas was always greater (73%) near the coast (where infested native G. hirsutum is abundant) and decreased dramatically (from 25 to 2 percent) in trap stations located 100 and 150 km further inland. In this particular case, a strong seasonal dispersal of native coastal weevils was clearly

indicated. Similar infested colonies of native G. hirsutum have been located by the author and others (W. H. Cross, personal communication) in Mexican coastal areas ca. 88 km from the Brownsville, TX, area, which is certainly within the flight distances reported here.

Although the existence of migratory cycles as suggested here is only hypothetical, the potential implication could be far-reaching and have a tremendous impact on the future of the cotton producing areas in the Rio Grande Valley of Texas. If farmers in northeastern Mexico plant cotton in the near future, as is currently being proposed by the Agricultural Federal Committees of the Mexican Government (SARH-INIA) in an effort to develop an efficient crop diversification program for the state of Tamaulipas (J. Vargas C., SARH-INIA personal communication), their main cotton producing areas will be located directly parallel to those in the Rio Grande Valley of Texas. In the past Mexican farmers have not adhered to a strict and timely destruction of postharvest cotton residues (stalk destruction and plowing). If this situation occurs we can expect to find numerous abandoned or poorly managed, infested cotton fields in northern Mexico. Overwintering weevils migrating to these fields in the fall from the Rio Grande Valley of Texas could survive and possibly reproduce until the next spring, when they (P_1 and F_1 progenies) could fly back to commercial cotton fields in south Texas. A migratory movement of such magnitude could pose a very serious threat to the economy of the cotton industry in the Rio Grande Valley of Texas. Information presented in the present paper on the dispersal behavior of subropical overwintering weevils should be of great value in developing more efficient strategies in future control and eradication programs.

LITERATURE CITED

Anonymous. 1939. Wild cotton survey along the coast in the state of Tamaulipas, Mexico. Mimeo report (copy at Cotton Insects Res. Lab., ARS, USDA, Brownsville, TX).

Beckman, C. M., and L. W. Morgan. 1960. On the flight distance of the boll weevil J. Econ. Entomol. 54: 681-682.

Bull, D. L. 1976. Formulations of grandlure, pp. 5-10. In Detection and Management of the Boll Weevil With Pheromone. Tex. Agric. Exp. Stn. Res. Monogr. No. 8.

Cross, W. H., M. J. Lukefahr, P. A. Fryxell, and H. R. Burke. 1975. Host plants of the boll weevil. Environ. Entomol. 4: 19-26.

Davich, T. B., D. D. Hardee, and Jesus Alcala M. 1970. Long-range dispersal of boll weevils determined with wing traps baited with males. J. Econ. Entomol. 63: 1706-1708.

Fye, R. E., W. W. Mcmillian, A. R. Hopkins, and R. L. Walker. 1959. Longevity of overwintered and first generation boll weevils at Florence, S. C. J. Econ. Entomol. 52: 453-454.

Glick, P. A. 1939. The distribution of insects, spiders, and mites in the air. USDA Tech Bull. 1208.

Guerra A. A., R. D. Garcia, and J. A. Tamayo. 1982. Physiological activity of the boll weevil during the fall and winter in subtropical areas of the Rio Grande Valley of Texas. J. Econ. Entomol. 75: 11-15.

Guerra A. A., and R. D. Garcia. 1982. Seasonal patterns of boll weevil response to grandlure-baited traps in the subtropical Rio Grande Valley of Texas. Southwest. Entomol. 7: 216-220.

Guerra, A. A. 1983. Daily attractive response patterns of boll weevils to grandlure traps in the Lower Rio Grande Valley of Texas. Southwest Entomol. 8: 252-258.

Guerra, A. A., G. Wiygul, and R. D. Garcia. 1983. Oxygen consumption in boll weevil, Anthonomus grandis Boheman (Coleoptera: Curculionidae), from subtropical areas of the Rio Grande Valley of Texas. Comp. Biochem. Physiol. 74: 263-265.

Guerra, A. A., R. F. Garcia, P. R. Bodegas V., and M. E. De Coss F. 1984. The quiescent physiological status of boll weevils (Coleoptera: Curculionidae) during the noncotton season at the tropical zone of Soconusco in Chiapas, Mexico. J. Econ. Entomol. 77: 595-598.

Guerra, A. A. 1986. Boll weevil movement: Dispersal within cotton fields during and after the cotton season in the Lower Rio Grande Valley of Texas. Southwest. Entomol. 11:10-16.

Guerra, A. A., and D. C. Robacker. 1988. Effects of sex, age, and diet on the triacylglyceral fatty acid composition of subtropical boll weevils, Anthonomus grandis Boheman (Coleoptera: Curculionidae). J. Agric. Food Chem. (In Press).

Graham, H. M., N. S. Hernandez, J. R. Llanes, and J. A. Tamayo. 1978. Overwintering habitats of the boll weevil in the Lower Rio Grande Valley, Texas. Environ. Entomol. 7: 345:348.

Hunter, W. D., and W. E. Hinds. 1905. The Mexican cotton boll weevil. USDA Bur. Entomol. Bull. 51.

Hunter, W. D. 1923. The boll weevil problem. USDA Farmer's Bull. 1329.

Hutchinson, J. B. 1947. Notes on the classification and distribution of genera related to Gossypium. New Phytol. 46: 123-141.

Johnson, W. L., W. H. Cross, J. E., Leggett, W. L. McGovern, H. C. Mitchell, and E. B. Mitchell. 1975. Dispersal of marked boll weevils: 1970-1973 studies. Ann. Entomol. Soc. Am. 68: 1018-1022.

Johnson, W. L., W. H. Cross, and W. L. McGovern. 1976. Long-range dispersal of marked boll weevils in Mississippi during 1974. Ann. Entomol. Soc. Am. 69: 421-422.

Lukefahr, M. J. 1956. A new host of the boll weevil. J. Econ. Entomol. 49: 877-878.

Lukefahr, M. J., and D. F. Martin. 1962. A native host plant of the boll weevil and other cotton insects. J. Econ. Entomol. 55: 150-151.

Lukefahr, M. J., and D. F. Martin. 1965. Additional noncotton hosts of the boll weevil and cotton leafworm. J. Econ. Entomol. 58: 784-785.

Leggett, J. E., and W. H. Cross. 1971. A new trap for capturing boll weevils. Coop. Econ. Insect Rep. 21: 773-774.

Rummel, D. R., L. B. Jordan, J. R. White, and L. J. Wade. 1977. Seasonal variation in the height of boll weevil flight. Environ. Entomol. 6: 674-678.

Rummel, D. R., and S. C. Carroll. 1985. Longevity of over-wintered boll weevils (Coleoptera: Curculionidae) following emergence in spring and early summer. Environ. Entomol. 14: 127-130.

APHID FLIGHT ACTIVITY IN RELATION TO SEASONAL ESTABLISHMENT AND GROWTH PERIODS OF TRIFOLIUM SPECIES IN MISSISSIPPI

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ABSTRACT

Sixty-two aphid species representing 37 genera were collected over a 4-yr period in water pan traps located near established plots of several Trifolium species. Yearly frequencies are provided for each species identified. Records from this survey were combined with those from other published studies to form a comprehensive list of the aphids known from Mississippi, now totaling 85 species from 46 genera. The temporal distribution of flight activity of several known vectors of forage legume viruses is discussed in relation to critical periods in the management of clovers for forage production.

INTRODUCTION

Aphids are important pests of leguminous crops grown for forage, seed, and ground cover in the southeastern United States. Aphids reduce longevity and yield of legumes and increase plant stress by removal of fluid and nutrients during feeding. Additionally, aphids contribute to disease development by transmitting plant viruses.

Despite the recognized importance of aphids as pests, few studies document the relative abundance and annual variations in flight activity of aphid species in Mississippi. There are no studies of aphid flight activity in relation to forage legumes in the Southeast. Elliott (1938) and Boudreaux (1951) listed 121 aphid species from 63 genera in Louisiana. Smith and Parron (1978) listed 1,380 species and 277 genera in a taxonomic compilation of aphids of North America, of which only 26 species representing 17 genera were recorded from Mississippi. Shaunak and Pitre (1971) reported 46 species from collections made with yellow pan traps located near corn plantings in Mississippi. Their year-long study related aphid activity to the incidence of maize dwarf mosaic virus disease in corn.

Objectives of the present study were to determine the flight activity of aphids, particularly those species known to vector forage legume viruses, in relation to establishment and growth of clovers, Trifolium spp., and to document temporal fluctuations of aphid flight. Data from previously published studies of aphids in Mississippi (Shaunak and Pitre 1971, Smith and Parron 1978) are compiled and discussed in relation to results from this study.

MATERIALS AND METHODS

Aphid trapping was done in clover from January 1982 through September 1985. Unmodified horizontal tile traps (Irwin 1980) were used

during 1982. Traps used from 1983-85 were modified by addition of an overflow reservoir (Ellsbury and Baer, unpublished data).

The traps were placed near established plots of arrowleaf (Trifolium vesiculosum L.), crimson (T. incarnatum L.), and white (T. repens L.) clovers on the Mississippi Agricultural and Forestry Experiment Station, Leveck Animal Research Center, Mississippi State University, Mississippi State, MS. Traps were placed 3 m apart and 15 cm above ground level in a 1 x 3 (1982 only) or 3 x 3 (1983-85) grid arrangement at the southwest corner of a 2 ha plot area. Nine traps were used each year, except 1982 when three traps were set out.

Trapping fluid consisted of ethylene glycol and water (1:1, v/v). Aphids were collected daily in 1982 from traps without reservoirs and weekly after 1982 from reservoir-equipped traps. Cumulative totals of aphids collected in each year and mean numbers per week for each month were calculated. Specimens were preserved in 70% ethyl alcohol and later mounted on glass slides as necessary for identification. Sweep net samples were collected occasionally from clover plots to determine if aphid species were present that were not otherwise trapped. The nomenclature of Smith and Parron (1978) was used for aphid species names throughout this study.

RESULTS AND DISCUSSION

Aphids from 37 genera were collected during the 4-yr survey period (Table 1). Sixty-two species were identified. Yearly cumulative totals for all aphids collected ranged from 251 to 2559 in 1982 and 1984, respectively. The low number of aphids collected in 1982 was due in part to the use of only three traps. Also, in 1982 overflow reservoirs were not used on the traps, and significant numbers of specimens may have been lost during periods of heavy rainfall. Since the data for 1985 are reported only through September, the number of specimens for that year also is correspondingly lower.

Numbers of each aphid species trapped ranged from one specimen of Sipha flava (Forbes) to 559 of Aphis citricola (van der Goot) during a single year. Not all aphid species were trapped every year, and four species were identified only from sweep net samples. These were Aphis sambuci L., Cinara pinivora (Wilson), Forda marginata Koch and Monelliopsis nigropunctata (Granovsky).

The 10 aphid species trapped in largest numbers during the study were, in decreasing order: Aphis citricola Van der Goot, 873; Acyrthosiphon pisum (Harris), 814; Myzus persicae (Sulzer), 733; Aphis maidiradicis Forbes, 702; Aphis gossypii Glover, 663; Uroleucon ambrosiae (Thomas), 384; Capitophorus elaeagni (del Guercio), 382; Aphis fabae Scopoli, 131; Rhophalosiphum maidis (Fitch), 110; and Lipaphis erysimi (Kaltenbach), 94. Shaunak and Pitre (1971) reported nine of these same species as most numerous in their yellow pan trap collections. Capitophorus elaeagni was not collected by Shaunak and Pitre (1971), but it was the 7th most frequently collected aphid in this study. Of the 10 most frequently collected species, only A. maidiradicis has not been reported previously as a vector of forage legume viruses. Of the 63 species we collected (Table 1), 22 have been identified as known vectors of forage legume viruses (Edwardson and Christie 1986) and 8 of these utilize Trifolium spp. as hosts (Patch 1938, Blackman and Eastop 1984).

Data from this study (Table 1) when combined with those of Shaunak and Pitre (1971) and Smith and Parron (1978) (Table 2) comprise a total of 85 aphid species from 46 genera collected in Mississippi. Of the aphids collected, 23 species were new records for Mississippi (Table 1) in addition to those listed by Smith and Parron (1978).

TABLE 1. Aphids Collected in Mississippi in Association with Clover.

Aphid Species[a]	Previous Records[b]		No. Aphids Collected				
	Sh. & P. '71	Sm. & P. '78	1982[c]	1983	1984	1985	Total
*Acyrthosiphon pisum (Harris)††	X		53	198	108	455	814
Aphis armoraciae Cowen	New Record		1	14	11	25	51
*Aphis citricola van der Goot	X		25	109	570	169	873
Aphis coreopsidis (Thomas)	X		1	17	31	18	67
*Aphis craccivora Koch††	X		4	19	19	26	68
*Aphis fabae Scopoli††	X		6	54	7	64	131
*Aphis gossypii Glover††	X	X	24	202	379	58	663
Aphis hederae Kaltenbach	X		1	11	21	10	43
Aphis helianthi Monell	X		3	16	25	22	66
Aphis maidiradicis Forbes	X	X	6	137	467	92	702
Aphis nerii Boyer de Fonscolombe	X			16	12	6	34
Aphis rubifolii (Thomas)	X			6	13	4	23
*Aphis rumicis L.††	X			5	13	28	46
*Aphis sambuci L.†	X			1			1
*Brevicoryne brassicae (L.)	X			7	11	15	33
*Capitophorus elaeagni (Del Guercio)	X	X	15	140	102	125	382
Capitophorus hippophaes (Walker)	X	X	2	10	7	18	37
Chaitophorus populicola Thomas	X			10	20	18	48
Chaitophorus viminalis Monell	X			5		7	12
Cinara atlantica (Wilson)	X	X		4			4
Cinara pinivora (Wilson)†	New Record				1		1
*Dysaphis radicola (Mordvilko)	X			5		4	9
Forda marginata Koch†				1			1
Glabromyzus rhois (Monell)	X	X		5	1	2	8
Hyalomyzus eriobotryae (Tissot)	X			5	32	17	54
*Hyperomyzus lactucae (L.)	X			7	4	9	20
Lachnochaitophorus obscurus (Tissot)	X			5	7	6	18

TABLE 1. (Cont'd).

Aphid Species[a]	Previous Records[b]		No. Aphids Collected				
	Sh. & P. '71	Sm. & P. '78	1982[c]	1983	1984	1985	Total
*Lipaphis erysimi (Kaltenbach)	X		7	12	39	36	94
Macchiatiella rhamni Fonscolombe	New Record			6	1	2	9
Macrosiphoniella abrotani (Walker)	New Record		2	2	2		6
Macrosiphum avenae (F.)	New Record		3	8	7		18
*Macrosiphum euphorbiae (Thomas)	New Record		1	25	12	6	44
Meliarhizophagus fraxinifolii (Riley)	X		3	3	1		7
Monellia caryella (Fitch)	New Record			15	10	12	37
Monelliopsis nigropunctata (Granovsky)†	X			1			1
Myzocallis discolor (Monell)	X			5	2	1	8
Myzocallis multisetis (Boud. & Tissot)	X		2	1	13	4	20
Myzocallis walshii (Monell)	X		2	1	1	4	8
*Myzus persicae (Sulzer)††	X		21	201	186	325	733
Nasonovia nigra (Hille Ris Lambers)	New Record			7	16	20	43
*Nearctaphis bakeri (Cowen)††	New Record			4	1	4	9
Nearctaphis kachena (Hottes)	X			7	7	3	17
*Pemphigus populicaulis Fitch	New Record			10	5	3	18
Pemphigus populitransversus Riley	X			11	28	5	44
Pleotrichophorus longipes (Gill. & Palm.)	X			6	1	3	10
Rhopalosiphum insertum (Sanderson)	X			5			5
*Rhopalosiphum maidis (Fitch)	X		2	40	50	18	110
Rhopalosiphum rufiabdominalis (Sasaki)	X			7	7	5	19
Sarucallis kahawaluokalani (Kirkaldy)	New Record		1	4	8		13
Schizaphis graminum (Rondani)	X	X	1	7	6	5	19
Sipha flava (Forbes)	New Record			1			1
Stegophylla querci (Fitch)	New Record		1				1
Tetraneura nigrabdominalis (Sasaki)	New Record			1	6	3	10
*Thecabius affinis (Kaltenbach)	New Record				12	2	14

TABLE 1. (Cont'd).

Aphid Species[a]	Previous Records[b] Sh. & P. '71	Previous Records[b] Sm. & P. '78	No. Aphids Collected 1982[c]	1983	1984	1985	Total
*Therioaphis maculata (Buckton)††	New Record		1	5		5	11
*Uroleucon ambrosiae (Thomas)	X		6	115	230	33	384
Uroleucon erigeronensis (Thomas)	X			14	8	3	25
*Uroleucon sonchi (L.)	New Record			7	4	9	20
Uroleucon taraxaci (Kaltenbach)	New Record			8	6	2	16
Uroleucon tissoti (Boudreaux)	New Record			6	7	2	15
Uroleucon tuataiae (Olive)	New Record			6	5	1	12
Uroleucon verbesinae (Boudreaux)	New Record			8	10	4	22
TOTAL			194	1568	2552	1719	6033

[a]Species preceded by * are known vectors of forage legume viruses. Those followed by † were collected only in sweep net samples, and those followed by †† have been reported from Trifolium spp. as host plants.

[b]Sh. & P. '71 (Shaunak and Pitre 1971), Sm. & P. '78 (Smith and Parron 1978).

[c]Traps without overflow reservoir employed in 1982.

TABLE 2. Aphid Species Reported from Mississippi but not Collected in the Present Study.

Shaunak and Pitre, 1971:

Aphis nasurtii Kaltenbach
Aulacorthum solani (Kaltenbach)
Calaphis betulella Walsh
Hysteroneura setariae (Thomas)
Macrosiphum rosae (L.)
Rhodobium porosum (Sanderson)

Smith and Parron, 1978:

Aphis forbesi Weed
Aphis illinoiensis Shimer
Aphis pomi DeGeer
Calaphis betulella Walsh
Chaitophorus essigi Gillette and Palmer
Cinara cronartii Tissot & Pepper
Cinara watsoni Tissot
Eriosoma americana (Riley)
Essigella pini Wilson
Illinoia liriodendri (Monell)
Meguroparsus kislankoi Smith & Heie
Meguroparsus tephrosiae (Smith)
Myzocallis meridionalis Granovsky
Nearctaphis crataegifoliae (Fitch)
Neotoxoptera violae (Pergande)
Periphyllus lyropictus (Kessler)
Periphyllus negundinis (Thomas)
Periphyllus testudinacea (Fernie)
Prociphilus tessellatus (Fitch)
Pterocallis alnifoliae (Fitch)

Temporal distribution of known vectors of forage legume viruses (Fig. 1) coincided with late winter and early spring growth of forage legumes and also with the recommended time of fall seeding and establishment (Van Keuren and Hoveland 1985), approximately from late August to mid-October. Over the 4-yr period, two known vectors, A. pisum and A. fabae, consistently showed seasonal peaks of incidence during the time of maximum growth from late winter to late spring (Fig. 1). It is likely that these species play important roles as vectors of viruses in clovers during these critical periods. The other four frequently collected vector species, M. persicae, A. craccivora, A. gossypii and A. citricola (Fig. 1), usually had bimodal temporal distributions of flight activity that overlapped periods of spring growth and fall establishment for clovers. The temporal distribution of these known vectors suggests that they are important factors in clover virus disease epidemiology.

Year to year variation was observed in flight activity of some vector species (Table 1 and Fig. 1). This was particularly evident for A. fabae and A. gossypii, which had peaks of incidence in traps during the spring of each year of the study, except 1984 when comparatively few aphids of either species were trapped. Similarly, A. citricola was abundant in traps during the fall planting period of each year except

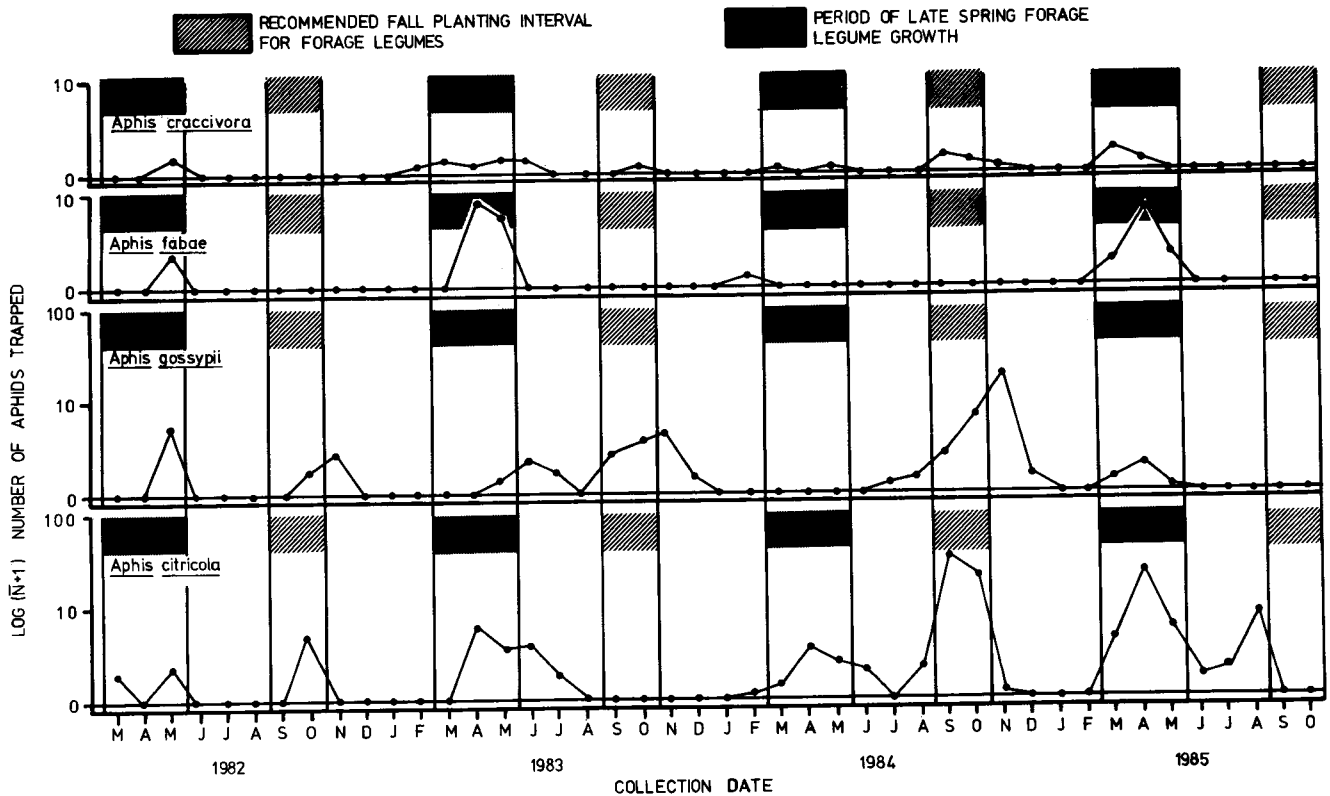

FIG. 1a. Fall planting dates and spring growth period of Trifolium species in the southern United States in relation to mean number of alate specimens of four Aphis species trapped per month at Mississippi State, MS.

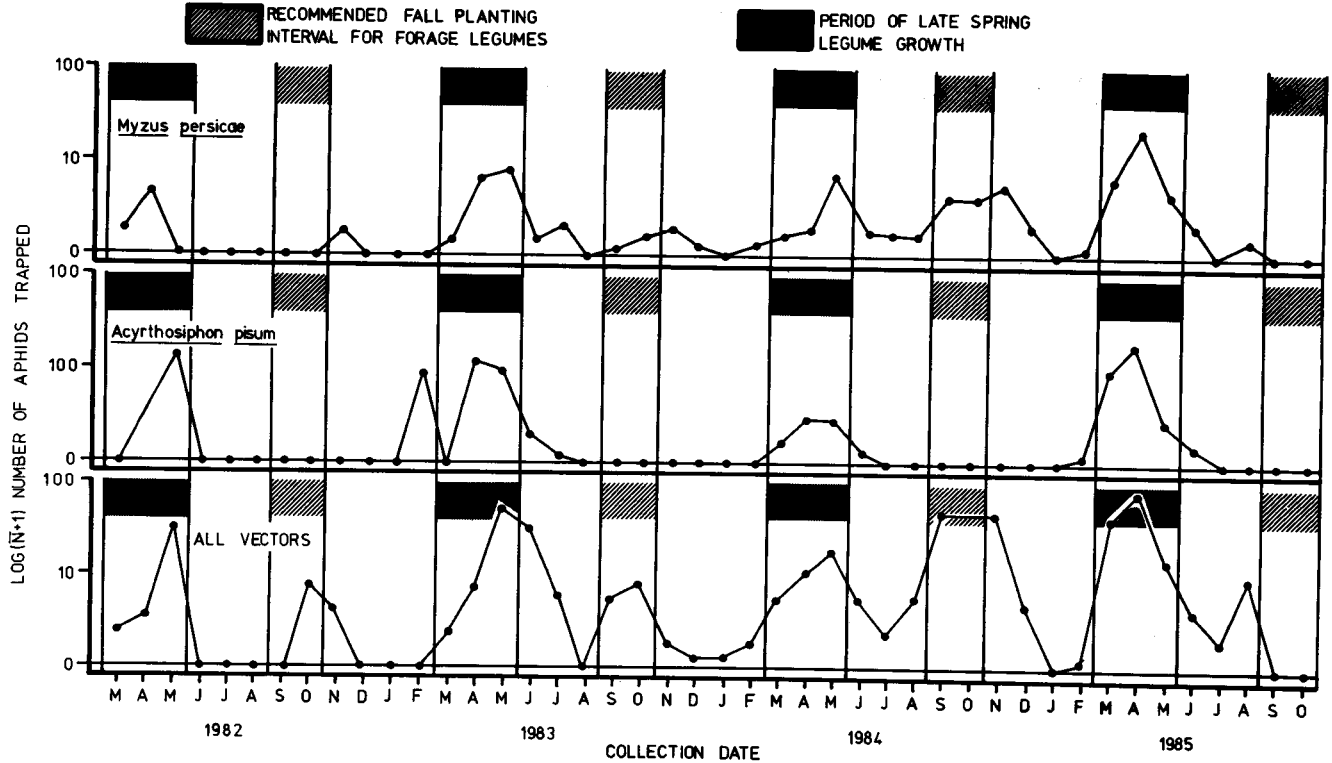

FIG. 1b. Fall planting dates and spring growth period of Trifolium species in the southern United States in relation to mean number of alate specimens trapped per week at Mississippi State, MS for Myzus persicae, Acyrthosiphon pisum and aphid species known to transmit forage legume viruses.

1983. The relative importance of each aphid species as a vector of forage legume viruses thus may vary with fluctuations in their flight activity from year to year.

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LITERATURE CITED

Blackman, R. L., and V. F. Eastop. 1984. Aphids on the world's crops: an identification and information guide. Wiley & Sons. New York.

Boudreaux, H. B. 1951. The insect family Aphididae in Louisiana. Proc. La. Acad. Sci. 14: 14-22.

Edwardson, J. R., and R. G. Christie (eds.) 1986. Viruses Infecting Forage Legumes. Monograph No. 14. 742 pp. Institute of Food and Agricultural Sciences, University of Florida. Gainesville, FL.

Elliott, D. C. 1938. Aphid notes of Louisiana. Proc. La. Acad. Sci. 4: 170-174.

Irwin, M. E. 1980. Sampling aphids in soybean fields. pp. 239-259. In M. Kogan and D. C. Herzog (eds.) Sampling Methods in Soybean Entomology. Springer-Verlag. New York.

Patch, E. M. 1938. Food plant catalogue of the aphids of the world. Bull. Maine Agric. Exp. Sta. 393.

Shaunak, K. K., and H. N. Pitre. 1971. Seasonal alate aphid collections in yellow pan traps in northeastern Mississippi: possible relationship to maize dwarf mosaic disease. J. Econ. Entomol. 64: 1105-1109.

Smith, C. F., and C. S. Parron. 1978. An annotated list of Aphididae (Homoptera) of North America. N. C. Exp. Sta. Tech. Bull. No. 255.

Van Keuren, R. W., and C. S. Hoveland. 1985. Clover management and utilization. pp. 325-354. In N. L. Taylor [ed.]. Clover Science and Technology. Agronomy Monograph No. 25. 616 p. Amer. Soc. Agron. Madison, WI.

NATURAL ENEMIES OF SPIDERS: MUD DAUBER WASPS IN EAST TEXAS[1/]

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ABSTRACT

Spider prey analysis of sphecid wasps was conducted in an east Texas farmland area. Two spider families, Araneidae and Theridiidae, comprised > 90% of the wasps' diet. The most abundant prey of these wasps were the orb-weavers, Gea heptagon (Hentz) (57.1% of total), and Acanthepeira stellata (Walckenaer) (17.7%). The southern black widow, Latrodectus mactans (F.) (5.9%), was also an important component of the diet of these wasps. Remaining families represented < 10%. These sphecid wasps are fairly selective hunters on two-three families of spiders. Individual wasps occasionally may choose predominantly from a single species of spider. Data of other workers are compared to our study.

INTRODUCTION

Female mud dauber wasps provide spiders as food for their immatures. The wasps construct mud nests containing several tubular brood cells. After being stung and paralyzed, the spiders are transported to the nests; and each brood cell is provisioned with some spiders. The wasp then lays an egg on one of these spiders. After hatching, the wasp larva consumes the well-preserved spiders in the brood cell, pupates, and later the adult emerges through a hole chewed in the brood cell.

Two species of sphecid wasps that occur in the United States often exist sympatrically. They are the yellow-legged mud dauber, Sceliphron caementarium (Drury), and the steel-blue mud dauber, Chalybion californicum (Saussure), an obligate hyperparasite. Sceliphron caementarium builds its own nests; C. californicum breaks into the nests of S. caementarium, empties the brood cells, fills them with its own prey, lays an egg and then reseals the nest (Rau 1935b, Muma and Jeffers 1945). The predatory behavior of the two wasp species are described in detail by Eberhard (1970) and Coville (1976, 1987). We analyzed the diet of mud dauber wasps in east Texas to determine their ecological role as predators in a rural area.

MATERIALS AND METHODS

The studies were conducted during the summer of 1985 on

[1/]Hymenoptera: Sphecidae

the L. N. Brown farm, located 5.6 km west of Austonio, near Crockett, Houston Co., east Texas. The farm buildings are surrounded by extensive grassland that serves as a horse pasture and is occasionally mown. The area is dominated by cotton fields and grazing land. Wasp nests were removed from inside and outside of farm buildings in June and July. Dorris (1969) noted that wasps emerged from nests in Arkansas from June to early September, and June and July were the best months for collecting.

A total of 69 nests were collected; 23 nests contained spiders and 20 of these nests contained identifiable spiders. Wasps from the remaining 46 nests had consumed the prey and emerged. The prey were removed from the brood cells and preserved in 70% ethyl alcohol. They were later identified under a microscope to the lowest taxon possible. Voucher specimens were deposited in the collection of the Department of Entomology at Texas A&M University.

Besides the actual prey of the wasps, we also assessed their potential prey (spiders occurring in the wasps' environment) by sampling spiders from the cotton plants and grassland (composed of various grasses and low growing annual Dicotyledonae) near the farm. Twenty-five D-Vac samples (Dietrick 1961) consisting of 1 m of row each were taken weekly in cotton for 13 weeks from June to early September (total spiders = 923). Ten D-Vac samples were taken every three weeks in grassland (330 spiders) on four sampling dates from July to early September, and an undetermined number of samples were taken by sweeping in grassland (1,252 spiders) on nine sampling dates from June to early September. They were returned to the laboratory and later identified and counted under the microscope. Taxonomic literature of spiders is scattered among numerous publications, but Spider Genera of North America by Roth (1985) contains references to revisions of the various groups. Vogel (1970) presents a list of spider species recorded from Texas along with references.

RESULTS AND DISCUSSION

The prey were collected from Sceliphron caementarium or Chalybion californicum nests (Table 1). Since we could not identify the wasp species by its nest and since adult wasps do not remain with the nest, we present the prey of both wasp species grouped together (Table 1).

The wasps' prey consisted exclusively of spiders. Most wasp nests contained one to three species from one or two families. Spiders of the families Araneidae (78.1% of total), Theridiidae (13.0%), Oxyopidae (6.9%), Salticidae (1.6%), Lycosidae (0.2%), and Thomisidae (0.2%) were found in the wasps' nests. The Araneidae and Theridiidae comprised > 90% of the wasps' diet.

Spiders often captured by the wasps included the orb-weavers Gea heptagon (Hentz) (57.1%) and Acanthepeira stellata (Walckenaer) (17.7%) which made up 75% of the wasps' prey. The next most abundant components in the wasps' diet were the comb-footed spiders Tidarren haemorrhoidale (Bertkau) (7.1%) and Latrodectus mactans (F.) (5.9%) and the lynx spider Oxyopes salticus Hentz (6.5%). However, all T. haemorrhoidale were found in one nest, and most O. salticus were found in another nest. Of the spiders collected frequently by wasps, G. heptagon, A. stellata and O. salticus were abundant on the

TABLE 1. Spiders Used as Prey in the Brood Cells of 20 Mud Dauber Wasp Nests Collected on a Farm in east Texas (June/July 1985).

Spider Prey	Sex & Stage of Spider[a/]	Nest No.																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Sum
Theridiidae																						
Latrodectus mactans (F.)	i			4								17	4							2		27
	m			1								1										2
	f												1									1
Tidarren haemorrhoidale (Bertkau)	f															36						36
Araneidae																						
Acanthepeira stellata (Walckenaer)	i			1			1	13	1	4		4	18	23	1	9		1			4	80
	m													1						1		2
	f												1	3	2						2	8
Argiope trifasciata (Forskal)	i					1						1	1									3
Eustala anastera (Walckenaer)	i	1						3					3									7
	f							1				1	2									4
Gea heptagon (Hentz)	i	4		21		3	5		6	3		17		18		2		8	5	1	1	94
	m								1			1		2		1		1	1	1		8
	f	21		17		10	5		53	3		41	10	5	2	5		8	3	1	4	188
Neoscona arabesca (Walckenaer)	i							2														2
	f							1														1
Oxyopidae																						
Oxyopes salticus Hentz	i				5												1					6
	f				25												2					27
Peucetia viridans (Hentz)	i										2											2
Lycosidae																						
Pardosa pauxilla Montgomery	f				1																	1
Thomisidae																						
Xysticus sp.	i													1								1
Salticidae																						
Eris sp.	i							1						1								2
Other	i		2		3						1											6
Total		26	2	44	34	14	11	21	61	10	3	83	40	54	5	53	3	18	9	6	11	508

[a/] i = immature, m = male, f = female.

foliage of mixed grasses, annual Dicotyledonae and cotton plants of that farm area (Table 2). Latrodectus mactans is also common in that area (underrepresented in Table 2 based on our sampling methods). Tidarren haemorrhoidale was probably the most abundant spider in the barn where many wasps built their nests. Thus, the wasps captured primarily spiders that were abundant in that area. However, a comparison of actual prey (Table 1) and potential prey (Table 2) indicates that those wasps are selective predators, since the species diversity of the potential prey is higher than that of the actual prey.

TABLE 2. Percent Species Composition of Spiders (Potential Prey of Sphecid Wasps) from an east Texas Farmland Area in the Vicinity of a Mixed Colony of Sphecid Wasp Nests (summer 1985).

Spider Species	Grassland		Cotton
	Sweep	D-Vac	D-Vac
Uloboridae			
Uloborus glomosus (Walckenaer)		0.9	0.2
Dictynidae			
Dictyna segregata Gertsch & Mulaik	0.1	0.3	3.3
Theridiidae			
Achaearanea globosa (Hentz)		1.2	0.2
Argyrodes fictilium (Hentz)		0.3	
Latrodectus mactans (F.)	0.1		0.9
Theridion australe Banks	0.2	0.3	1.7
Theridion crispulum Simon			0.1
Theridion murarium (Emerton)	0.1		0.3
Thymoites sp.		0.3	
Tidarren sp.			0.1
Mysmenidae			
Mysmena incredula (Gertsch & Davis)		0.3	0.1
Linyphiidae			
Ceraticelus sp.	0.2	0.9	0.1
Eperigone eschatologica Crosby		0.3	0.8
Erigone autumnalis Emerton	0.1		0.2
Grammonota texana (Banks)	0.4	0.9	0.1
Other Linyphiidae		0.3	0.7
Araneidae			
Acanthepeira stellata (Walckenaer)	1.8	0.6	3.5
Argiope trifasciata (Forskal)	0.3	0.6	
Cyclosa turbinata (Walckenaer)	0.2	0.6	0.5
Eustala anastera (Walckenaer)	0.9		0.2
Gea heptagon (Hentz)	0.6	26.4	1.1
Glenognatha foxi (McCook)	0.2	2.4	1.0
Mangora gibberosa (Hentz)	0.9	0.9	0.2
Neoscona arabesca (Walckenaer)	4.1	0.9	0.7
Tetragnatha laboriosa Hentz	0.5	0.6	2.2
Other Araneidae	0.1		
Mimetidae			
Mimetus hesperus Chamberlin	0.1		0.1
Pisauridae			
Dolomedes sp.			0.1
Pisaurina mira (Walckenaer)			0.1

TABLE 2. cont.

Lycosidae			
Lycosa rabida (Walckenaer)	0.2	0.6	0.1
Pardosa sp.	0.2	1.2	1.5
Schizocosa avida (Walckenaer)	0.1	0.6	
Other Lycosidae	0.3		
Oxyopidae			
Oxyopes apollo Brady	0.1	0.3	0.3
Oxyopes salticus Hentz	32.5	32.4	67.2
Peucetia viridans (Hentz)	1.3	0.3	0.3
Clubionidae			
Cheiracanthium inclusum (Hentz)	0.1		1.3
Clubiona catawba Gertsch	0.1		
Anyphaenidae			
Aysha gracilis (Hentz)	0.2		2.0
Wulfila saltabunda (Hentz)		0.6	0.2
Thomisidae			
Misumenoides formosipes (Walckenaer)	0.2		
Misumenops asperatus (Hentz)	0.1		
Misumenops celer (Hentz)	0.9	0.3	
Misumenops dubius (Keyserling)	0.2		
Misumenops sp. (immatures)	30.0	10.3	2.8
Xysticus sp.	0.3		
Philodromidae			
Philodromus sp.	4.2	5.5	1.3
Tibellus duttoni (Hentz)	4.3	2.4	
Salticidae			
Eris sp.	0.1		
Habronattus coecatus (Hentz)	0.1	0.6	
Hentzia palmarum (Hentz)	0.1		0.3
Metaphidippus galathea (Walckenaer)	7.7	2.8	2.1
Phidippus audax (Hentz)	5.1	2.8	1.8
Phidippus pius Scheffer	0.1		
Sarinda hentzi (Banks)	0.1		0.1
Thiodina puerpera (Hentz)	0.2		0.1
Zygoballus rufipes (G. & E. Peckham)	0.3	0.3	0.1

Unfortunately, in this study we were not able to determine which of the spiders listed in Table 1 were killed by *C. californicum* or *S. caementarium*. However, other authors were able to determine these two wasp species' diets separately, as represented in Table 3. The following pattern emerges: *C. californicum* captured predominantly spiders of the families Araneidae and Theridiidae (> 90% of the wasps' diet). In Oklahoma, *Latrodectus mactans* was found to be an "index species" prey of *C. californicum* (Horner and Klein 1979). *Sceliphron caementarium* attacks primarily spiders of the families Araneidae, Thomisidae, and Salticidae. Spiders of the genera *Oxyopes* and *Misumenops* are typical prey of *S. caementarium* (Horner and Klein 1979).

The similarity of the diets of *C. californicum* and *S. caementarium* was calculated by the niche overlap formula of Horn (1966) using prey data from the literature (Muma and Jeffers 1945, Horner and Klein 1979). Overlap values range from zero to 1.0, from entirely different to identical diets, respectively. The calculation was carried out at family level of the identified prey items, but these values may be overest-

imated when compared with calculation at species level. From the data of Muma and Jeffers (1945) we calculated an overlap value of 0.36, and a value of 0.39 from the data of Horner and Klein (1979). These values indicate that the diets of both wasp species in general are distinct, even if some spiders (orb-weavers) are common to the diets of both.

TABLE 3. Proportion of Five Major Food Components in Diets of Sceliphron caementarium and Chalybion californicum.

	Sceliphron caementarium[a/]				Chalybion californicum[a/]			
	MD	MO	MS	OK	MD	MO	OK	FL
	%	%	%	%	%	%	%	%
Theridiidae	0.5	-	8.1	-	67.8	85.9	29.5	25.2
Araneidae	55.7	87.9	36.7	29.5	26.9	13.9	70.0	72.7
Oxyopidae	9.5	2.2	3.0	5.9	1.6	-	-	0.4
Thomisidae	16.1	4.9	19.0	63.1	1.8	0.1	-	1.1
Salticidae	10.1	4.0	20.0	1.0	1.6	0.1	-	0.1
Others	8.1	1.0	13.2	0.5	0.3	-	0.5	0.5

[a/]MD: Maryland - Muma and Jeffers (1945).
MO: Missouri (S.c.) - Rau (1935a), (C.c.) - Landes et al. (1987).
MS: Mississippi - Dorris (1970).
OK: Oklahoma - Horner and Klein (1979).
FL: Florida - Landes et al. (1987).

The species-specific prey preferences may be explained by the different hunting behavior of the two wasp species. Rau (1935b) and Muma and Jeffers (1945) found that S. caementarium hunts among foliage and flowers, while C. californicum searches for spiders near the ground and around and in buildings.

A comparison of our data (Table 1) with those from the literature reveals that the prey of most wasp nests collected in this study fit the foraging pattern of C. californicum (exceptions: nests no. 2, 4, 10, 13, 16). Evidence for this pattern is indicated by the following observations: 1) foliage-hunting spiders (Oxyopidae, Thomisidae, Salticidae), apparently typical prey of S. caementarium, are missing in the prey of most wasp nests; 2) in 80% of the wasp nests, spiders were found that build their webs close to the ground (G. heptagon, immature A. stellata, L. mactans). Latrodectus mactans, described in literature as an "index prey" of C. californicum (Irving and Hinman 1935, Rau 1935a, Horner and Klein 1979), were found in four wasp nests; 3) a large number of the barn-dwelling spider T. haemorrhoidale was found in wasp nest no. 15; and 4) most wasps that hatched from mud dauber nests brought into the laboratory were C. californicum. On the farm C. californicum was more common than S. caementarium.

Sphecid wasps could be useful in their collection of

poisonous spiders of the genus Latrodectus (Irving and Hinman 1935, Rau 1935a). In Maryland and Oklahoma ca. 25% of the diet of C. californicum consisted of Latrodectus (Muma and Jeffers 1945, Horner and Klein 1979). At the same time these wasps are natural enemies of spiders which feed on cotton insects (Nyffeler et al. 1988). These spider-hunting wasps are themselves occasionally killed by web-building spiders (Obin 1982).

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LITERATURE CITED

Coville, R. E. 1976. Predatory behavior of the spider wasp, Chalybion californicum (Hymenoptera: Sphecidae). Pan-Pacific Entomol. 52: 229-233.

Coville, R. E. 1987. Spider-hunting sphecid wasps. Ecophysiology of Spiders. Ed. W. Nentwig. Springer-Verlag, New York, 436 pp.

Dietrick, E. J. 1961. An improved backpack motor fan for suction sampling of insect populations. J. Econ. Entomol. 54: 394-395.

Dorris, P. R. 1969. Spiders collected from mud-dauber nests in Clark County, Arkansas. Ark. Acad. Sci. Proc. 23: 88-90.

Dorris. P. R. 1970. Spiders collected from mud-dauber nests in Mississippi. J. Kans. Entomol. Soc. 43: 10-11.

Eberhard, W. 1970. The predatory behavior of two wasps, Agenoideus humilis (Pompilidae) and Sceliphron caementarium (Sphecidae), on the orb weaving spider Araneus cornutus (Araneidae). Psyche 77: 243-251.

Horn, H. S. 1966. Measurement of overlap in comparative ecological studies. Am. Nat. 100: 419-424.

Horner, N. V., and J. H. Klein, Jr. 1979. Spider prey of two mud dauber wasp species in Comanche County, Oklahoma (Hymenoptera: Sphecidae). Environ. Entomol. 8: 30-31.

Irving, W. G., and E. H. Hinman. 1935. The blue mud-dauber as a predator of the black widow spider. Science 82: 395-396.

Landes, D. A., M. S. Obin, A. B. Cady, and J. H. Hunt. 1987. Seasonal and latitudinal variation in spider prey of the mud dauber Chalybion californicum (Hymenoptera, Sphecidae). J. Arachnol. 15: 249-256.

Muma, M. H., and W. F. Jeffers. 1945. Studies of the spider prey of several mud-dauber wasps. Ann. Entomol. Soc. Am. 38: 245-255.

Nyffeler, M., D. A. Dean, and W. L. Sterling. 1988. Prey selection and predatory importance of orb-weaving spiders (Araneae: Araneidae and Uloboridae) in Texas cotton. Environ. Entomol. (In press).

Obin, M. S. 1982. Spiders living at wasp nesting sites: what

constrains predation by mud-daubers? Psyche 89: 321-335.
Rau, P. 1935a. The wasp, Chalybion cyaneum Fab., preys upon the black widow spider, Latrodectus mactans Fab. (Hymen., Araneae). Entomol. News 46: 259-260.
Rau, P. 1935b. The spider prey of the mud wasp, Sceliphron caementarium (Araneae, Hymen.: Sphecidae). Entomol. News 46: 267-270.
Roth, V. D. 1985. Spider Genera of North America. Privately published by the author. Available from Am. Arachnol. Soc.
Vogel, B. R. 1970. Bibliography of Texas spiders. Armadillo Papers 2: 1-36.

CHARACTERISTICS OF FREE-LIVING LARVAE OF THE LONE STAR TICK IN EASTERN OKLAHOMA: CLUSTER SIZES AND LOCATIONS [1/]

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ABSTRACT

The larval stage of the lone star tick, Amblyomma americanum (L.), was studied under field conditions from July to October from 1981 to 1986 in eastern Oklahoma, USA. Larvae were found in clusters of 25 to 5544 individuals ($\bar{x}$ = 539.3 ± 548.3 SEM) on the tips of vegetation and averaged 20.8 to 26.2 cm above ground. Larvae did not exhibit any obvious preference among 25 plant species for ascension. Differences in the height that larvae clumped depended on the vegetation available since > 90% of the larvae were found at the maximum plant height; larvae were not found on larger trees and shrubs. Transmission of the larvae to the most important host, white-tailed deer, was facilitated by the clumping and location on vegetation used for browse. Other medium to large-sized hosts moving through the vegetation are also readily available for infestation.

INTRODUCTION

Unfed larvae of the lone star tick, Amblyomma americanum (L.), exhibit a combined climbing and aggregating behavior resulting in the occurrence of clusters of larvae on the tips of available vegetation. Under warm and humid conditions the larvae may remain on the vegetation several weeks awaiting a host that may come in contact with them (Lancaster 1958, Hair and Howell 1970). Unfortunately, man is often attacked and bitten by large numbers of this pest during the summer and fall when walking in wooded areas of eastern Oklahoma and the southeastern United States. Due to their small size, the larvae are difficult to locate on the skin and may not be readily detected on the body.

Lone star tick larvae are readily picked up from late June until mid-November in eastern Oklahoma on tick drags (Mount 1981) indicating ascension on vegetation. The location of the questing larvae and the plants ascended have not been studied. Drew and Samuel (1985) reported that Dermacentor albipictus (Packard) larvae aggregated in clumps on vegetation from 4 cm to 4 m above the ground.

The purpose of the present study was to gather information on cluster locations and sizes from populations of

1/ Acari: Ixodidae

larvae in their natural habitat.

MATERIALS AND METHODS

Natural Populations. Observations on natural populations of lone star tick larvae were made during the summer and fall from 1981 through 1986 in woodlots in Sequoyah State Park near Hulbert, Oklahoma. From July through September clusters of larvae were located by searching ground vegetation in an upland oak-hickory habitat or an upland pine habitat. It is assumed that lone star tick larvae climb vegetation to increase the chances of contacting hosts and therefore the locations chosen were termed questing sites. The upland oak-hickory habitat sampled was ca. 1.5-2.0 ha with an overstory predominantly of post-oak, Quercus stellata Wang., and black hickory, Carya texana Buckl., and a wide variety of grasses and woody broadleaf plants that served as questing sites for the larvae. The upland pine habitat sampled was ca. 1.3-1.7 ha and had predominantly short-leaf pine, Pinus echinata Mill, and had a thick mat of dead pine needles that prevented the growth of much ground vegetation. Areas near the edge of the pine habitat had more grasses and broadleaf plants that served as questing sites for the larvae.

In 1981, 125 clusters were located on grasses and non-grasses in upland oak-hickory on three sample dates, and the height of each cluster was recorded. All heights in the studies were measured to the highest part of the clusters. In 1982, 105 clusters were located on grasses and non-grasses in oak-hickory and pine habitat on two sample dates, collected on masking tape, and counted.

In 1983, 472 clusters were located in upland oak-hickory habitat and the plant type, plant height, number of clusters of larvae per plant, and cluster height were recorded. In addition, a square meter sampler was centered and lowered over the plant containing the larvae, and the numbers of grasses and woody broadleaf plants within the square were counted. Both living and dead plants were counted, and branches or twigs present were included in the broadleaf category.

In 1984, 1985, and 1986 the same procedures as used in 1983 were used to routinely sample both the oak-hickory and pine habitats. Larvae in the pine habitats were found on dead pine needles or on assorted plants (grasses and non-grasses in addition to fallen sticks and branches). The temperature and rainfall patterns were obtained from the National Oceanic and Atmospheric Administration (NOAA) weather station located at nearby Wagoner, Oklahoma (ca. 16 km distant) and compared with the 20 year averages (1950-1969) for the area.

Releases of Laboratory Reared Ticks. In August 1982, 50 laboratory reared masses of 4-5 wk-old larvae (ca. 4000-5000 larvae/mass) from individual females were released at the bases of 25 different narrow and broadleaf plant species (two plants/species). The plants chosen ranged in height from 8 cm (short-leaf pine seedling) to 132 cm (pokeberry, Phytolacca americanum L.). At 1 day, 1 wk and 2 wk after release, the numbers of clusters of larvae and the cluster heights were recorded. The types of plants selected were

typical of those found in woodlots of eastern Oklahoma and were located in bottomland oak-hickory habitat on the Kerr Center for Sustainable Agriculture Ranch near Poteau, Oklahoma.

In July and August 1986, 160 releases of laboratory reared 4-5 wk-old larvae (ca. 3000-5000 larvae/mass) were made on the ground near two plant species commonly found in woodlots on the Kerr Ranch. A single mass of larvae was released at the base of each of 80 buckbrush, Symphoricarpos orbiculatus Moench, plants (non-grass) and 80 broadleaf uniola, Uniola latifolia Michx. plants (grass); 50 masses each on 30 July and 30 masses each on 4 August. The height of each plant with larvae, the number of clusters of larvae, and the height of each cluster were recorded weekly. Hourly rainfall records during the studies were checked at the Wister 3NE raingauge (NOAA) that is operated on the ranch. Temperatures and humidities were recorded on a Belfort hygrothermograph located in wooded habitat on the ranch.

RESULTS AND DISCUSSION

Natural Populations. The clusters of larvae located in 1981 were mostly on grasses (88.8%) and ranged from 1.0 to 88.9 cm ($\bar{x}$ = 25.7 $\pm$ 13.5 SEM) above ground. In 1982, larvae were found on more non-grasses (35.0%) than in 1981 and were located from 5.1 to 41.9 cm ($\bar{x}$ = 15.7 $\pm$ 2.7 SEM) above ground. The lower cluster height average in 1982 compared to 1981 was due to the discovery of several clusters on dead pine needles. The number of larvae per cluster ranged from 25 to 5544 ($\bar{x}$ = 539.3 $\pm$ 548.3 SEM). Nearly 50% of the clusters had < 500 larvae, and there were few larger clusters (> 2000 larvae) (Table 1). Some clusters were not spherical

TABLE 1. Range of Sizes of Lone Star Tick Larval Clusters Located on Vegetation in Oak-Hickory Habitat of Cherokee County, Oklahoma in July and August.

Number of larvae in cluster	Number of clusters located	% of total clusters
1 - 499	52	49.5
500 - 999	33	31.4
1000 - 1999	14	13.3
2000 - 2999	4	3.8
3000 - 3999	1	1.0
4000 - 5600	1	1.0

but took the elongated shape of the underside of leaves.

The location of clusters of larvae found on 1080 plants in oak-hickory habitat from 1983-1986 are given in Table 2. Both grasses and non-grasses were chosen as questing sites for the larvae. Overall, 64.6% of the total plants found containing larvae were non-grasses. In 1984, grasses outnumbered non-grasses 19.1 to 7.8 in the square meter samples but non-grasses outnumbered grasses 215 to 89 as questing sites (Table 2).

A more important factor in plant selection by the larvae

TABLE 2. Location of Lone Star Tick Larvae on Ground Vegetation in Upland Oak-Hickory in Sequoyah State Park, Hulbert, Oklahoma.

Plant type	No. plants with larvae	$\bar{x}$ No. plants per m^2	$\bar{x}$ Plant height (cm)	$\bar{x}$ Larval cluster height (cm)	$\bar{x}$ No. clusters per plant	$\bar{x}$ Larval clusters at maximum plant height (%)
				1983		
Grass	208	12.8	20.8	18.7	1.9	97.0
Non-grass	264	11.3	25.2	22.5	2.2	94.2
Combined	472	24.1	23.3	20.8	2.1	95.1
				1984		
Grass	89	19.1	18.1	17.3	1.9	97.1
Non-grass	215	7.8	26.0	24.6	2.2	91.3
Combined	304	26.9	23.7	22.5	2.1	93.2
				1985		
Grass	31	6.2	16.4	15.8	1.2	90.1
Non-grass	169	8.4	30.8	28.1	1.8	91.1
Combined	200	14.6	28.6	26.2	1.7	91.0
				1986		
Grass	54	3.6	20.2	19.6	1.2	100.0
Non-grass	50	7.0	26.9	25.4	1.2	93.2
Combined	104	10.6	23.4	22.4	1.2	95.0
Overall $\bar{x}$			24.8	23.0		

a/ Sticks and small branches were included in the non-grass plant group.

was apparently the height of the plant. Because larvae are probably not able to determine plant height directly, other factors such as plant stem diameter and texture may be important. However, Koch (unpublished data) was unable to show any preference by larval A. americanum for wooden dowels of 0.31, 0.50, 0.66, 0.76, and 0.95 cm diam in the laboratory. Non-grasses were generally taller than grasses and in 1985; for example, non-grasses outnumbered grasses as plants with questing larvae (169 to 31), but with a mean plant height of 30.8 cm compared to 16.4 cm (Table 2).

Larvae were generally found at the top of the plants. On plants that averaged from 18.1-30.8 cm, > 90% of the clusters of larvae were found at the maximum plant heights (Table 2).

The maximum heights of the pine needles used as questing sites were low, 9.2-11.0 cm above ground, with an average ground cover of 5 cm deep (Table 3). All clusters of larvae found on pine needles were located on the tips of the needles (at the maximum height they could climb).

If grasses or non-grasses were in the area that the larvae were found, these would generally be used for questing. For example, 9.2 assorted plants were found per meter in 1984 and assorted plants outnumbered needles 177 to 98 as larval questing sites (Table 3). In 1985 and 1986, however, assorted plant density was only 3.1 and 3.5 per meter,

TABLE 3. Location of Lone Star Tick Larvae on Ground Vegetation in Upland Pine Habitat in Sequoyah State Park, Hulbert, Oklahoma.

Plant type[a/]	No. plants with larvae	$\bar{x}$ No. plants per m^2 [b/]	$\bar{x}$ Plant or needle height (cm)	$\bar{x}$ Larval cluster height (cm)	$\bar{x}$ No. clusters per plant	$\bar{x}$ Larval clusters at maximum plant height (%)
			1984			
Assorted	177	9.2	20.7	19.7	1.7	89
Needles	98	-	9.2	9.2	1.0	100
Combined	275	-	16.6	22.5	1.5	93
			1985			
Assorted	46	3.1	18.7	17.3	1.6	96
Needles	154	-	10.3	10.3	1.0	100
Combined	200	-	12.2	11.9	1.1	99
			1986			
Assorted	46	3.5	27.1	26.5	1.1	93
Needles	91	-	11.0	11.0	1.0	100
Combined	137	-	15.5	15.3	1.0	95

a/ Assorted plants include both grasses and non-grasses in addition to any fallen sticks or branches. Ratios of grasses: non-grasses with larvae were as follows: 1984 (106:71), 1985 (18:28), 1986 (12:34).

b/ The number of pine needles per m^2 were not counted due to their abundance. Dead pine needles covered the ground to an average depth of about 5 cm.

respectively, and needles with larvae on them were ca. 2-3 times more common than on the plants (Table 3).

The number of clusters of larvae per plant ranged up to 10, but most plants had only one or two (Table 2); pine needles never had more than one (Table 3).

Released Ticks. Lone star tick larvae showed little discrimination against any of the 25 plant species in 1982; questing larvae were observed on all 50 plants after 1 day (Table 4). Although some of the plants had pubescence, none appeared to have any of the anti-tick properties that were found in molasses grass, Melinis minutiflora, or Stylosanthes sp. (Sutherst et al. 1982). Plants with leaves and the leaves of grasses seemed to provide protection for the clusters of larvae against the sun, wind, and rain; larvae on bare stems were least protected.

The average height of the plants was 40.1 (± 29.4 SEM) cm, and the average height of larval clusters ranged from 9.6 cm on short (8-20 cm) plants to 35.8 cm on tall (50-132 cm) plants (Table 4). There was a significant (0.05 level) positive correlation (R = 0.76) between plant height and larval cluster height.

The average number of larval clusters per plant was very high after 1 day (3.3 to 6.2) and 7 days (3.2 to 4.3), but after 14 days the average number was reduced to the lower values (1.3 to 2.5) generally found in the park (Table 3). A

TABLE 4. Number and Location of Clusters of Lone Star Tick Larvae Formed from Masses of Ticks Released on 2 August 1982 on 25 Different Plant Species[a/] in Bottomland Oak-Hickory Woodlots on the Kerr Ranch, Poteau, Oklahoma.

Plant sizes (cm)	No. plants	$\bar{x}$ plant height (cm)	No. clusters per plant	Cluster height (cm)
		$\bar{x}$ After 1 Day	[b/]	
Tall (50-132)	17	72.9a (23.4)	4.7a (2.0)	32.3a (12.0)
Medium (21-49)	16	31.9b (8.5)	3.3ab (2.2)	17.7b (7.8)
Short (8-20)	17	11.5c (4.9)	6.2c (5.6)	9.6c (3.4)
		$\bar{x}$ After 7 Days	[c/]	
Tall (50-132)	17	72.9a (23.4)	3.2ab (1.4)	35.8a (14.6)
Medium (21-49)	16	31.9b (8.5)	4.0b (1.7)	21.9b (7.4)
Short (8-20)	17	11.5c (4.9)	4.3b (2.4)	10.8c (3.0)
		$\bar{x}$ After 14 Days	[d/]	
Tall (50-132)	17	72.9a (23.4)	1.3a (0.5)	35.0a (15.7)
Medium (21-49)	16	31.9b (8.5)	2.0a (1.4)	24.2b (11.8)
Short (8-20)	17	11.5c (4.9)	2.5ab (1.5)	13.0c (2.3)

a/ Common species found in Oklahoma woodlots; two plants per species used.
b/ Column means followed by the same letter are not significantly different ($P < 0.05$; least significant difference test of SAS Institute, Inc. 1985). Numbers in parentheses are the standard errors of the mean.
c/ Moderate rainfall of 0.96 cm occurred over a 4-h period and 0.36 cm occurred over a 3-h period ca. 5 and 6 days, respectively, after the larvae were released.
d/ Heavy rainfall of 2.31 cm occurred over a 4-h period ca. 10 days after the larvae were released.

heavy rainfall of 2.31 cm over a 4-h period ca. 10 days after the larvae were released physically decreased the numbers of clusters of larvae. The average temperature and total rainfall for August 1982 in Poteau, Oklahoma were 27.8°C and 67.6 mm compared to a 20-yr average (1950-1969) of 27.5°C and 86.4 mm for August for the same city.

The changes observed over 11 weeks for 160 larval masses released in 1986 are shown in Table 5. Some larvae failed to climb the target plants and were not relocated while others climbed adjacent vegetation of another plant species. Some rainfall occurred each week between observations, except for two weeks, and the temperatures were generally below normal for Poteau, Oklahoma based on the 20-yr average (1950-1969).

Both the grass, broadleaf uniola, and the non-grass, buckbrush, provided suitable sites for questing lone star tick larvae. More than half of the plants had larvae questing at the same locations for 7-8 wk (Table 5). For example, the tallest Uniola plant (105 cm) in the study had a

TABLE 5. Number and Location of Clusters of Lone Star Tick Larvae Formed from Masses of Ticks Released on Two Different Plant Species on 30 July and 4 August 1986 on the Kerr Ranch, Poteau, Oklahoma.

Weeks after release	No. plants with larvae	$\bar{x}$ Plant height (cm)	$\bar{x}$ Cluster height (cm)	$\bar{x}$ No. clusters per plant
		Broad-leaf Uniola		
1	78	48.9 (25.9)	32.0 (14.7)	2.5 (1.8)
2	66	47.6 (25.3)	31.7 (15.5)	2.4 (2.1)
3	55	42.6 (25.4)	31.9 (17.8)	1.9 (1.3)
4	44	45.1 (25.0)	30.7 (20.1)	1.9 (1.5)
5	49	44.9 (26.3)	32.3 (23.8)	1.8 (1.2)
6	47	46.6 (27.6)	26.8 (18.0)	1.9 (1.3)
7	46	42.5 (27.3)	28.3 (19.9)	1.8 (1.4)
8	39	39.3 (23.3)	22.2 (10.8)	1.7 (1.0)
9	21	42.8 (25.6)	24.6 (10.9)	2.1 (1.2)
10	15	41.4 (31.5)	20.0 (10.6)	1.5 (0.6)
11	7	52.4 (24.8)	24.4 (4.1)	1.4 (0.8)
Overall $\bar{x}$		44.9	27.7	1.9
		Buckbrush		
1	69	38.5 (22.0)	32.8 (15.7)	2.4 (2.3)
2	69	36.9 (21.6)	28.8 (13.8)	2.0 (1.4)
3	65	32.6 (21.0)	25.7 (13.2)	1.7 (1.1)
4	57	31.7 (22.5)	25.9 (13.7)	1.7 (0.9)
5	56	32.0 (21.9)	27.3 (15.3)	1.8 (1.0)
6	56	28.7 (20.1)	24.1 (14.2)	1.6 (0.8)
7	48	30.2 (23.2)	23.9 (15.2)	1.6 (0.8)
8	40	26.1 (16.1)	20.3 (10.8)	1.8 (1.1)
9	24	20.2 (11.9)	18.8 (9.5)	1.8 (1.1)
10	13	20.4 (15.4)	19.0 (9.5)	1.7 (1.4)
11	11	24.6 (15.6)	20.4 (8.9)	1.5 (0.7)
Overall $\bar{x}$		29.3	24.3	1.8

a/ Numbers in parentheses are standard error of the means.

large cluster of larvae located at the very top for seven continuous weeks of observation. Natural longevity of lone star tick larvae is usually > 90% for 10-12 wk in bottomland woodlots on the Kerr Ranch (Koch 1984).

Although there was a positive correlation (R = 0.69) between plant height and questing height, the overall mean height of the questing larvae ($\bar{x}$ = 27.7 cm) on the taller Uniola ($\bar{x}$ = 44.9 cm) was very close to the value ($\bar{x}$ = 24.3 cm) observed on the shorter buckbrush ($\bar{x}$ = 29.3 cm) (Table 5). The progressive decrease in the number of the taller buckbrush plants as larval questing sites each week may have been due to the greater exposure of the larvae during wind and rain.

The results of this study demonstrate that nearly any small-diameter plant or plant part available may be ascended by the larvae. Although large clusters of larvae (> 1000 seed ticks) can be found on the underside of leaves of grass

and other low-growing plants in woodlots, smaller clusters (< 500 seed ticks) are most often encountered on the tips of short vegetation. Larvae are usually located at maximum plant height, except on relatively tall plants (50-132 cm) where average cluster heights are 32.3-35.0 cm.

Larvae will quite often climb relatively short plants or plant parts, such as fallen pine needles, when other plants are not available; but the location of larvae at the lower heights probably diminishes their ability to locate suitable hosts which are usually medium and large-sized mammals (Koch 1981, Zimmerman et al. 1987). The location of the larvae on herbage makes the ticks particularly available to the head of grazing white-tailed deer, the most important host of this tick species (Bloemer et al. 1988, Koch 1988).

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LITERATURE CITED

Bloemer, S. R., R. H. Zimmerman, and K. Fairbanks. 1988. Abundance, attachment sites, and density estimators of lone star ticks (Acari: Ixodidae) infesting white-tailed deer. J. Med. Entomol. 25: 295-300.

Drew, M. L., and W. M. Samuel. 1985. Factors affecting transmission of larval winter ticks, Dermacentor albipictus (Packard), to moose, Alces alces L., in Alberta, Canada. J. Wild. Dis. 21: 274-282.

Hair, J. A., and D. E. Howell. 1970. Lone star ticks - their biology and control in Ozark recreation areas. Okla. State Univ. Agric. Exp. Sta. Bull. 679.

Koch, H. G. 1981. Suitability of birds and mammals as hosts for immature stages of the lone star tick, Amblyomma americanum (Acari: Ixodidae). J. Med. Entomol. 18: 253-254.

Koch, H. G. 1984. Survival of the lone star tick, Amblyomma americanum (Acari: Ixodidae), in contrasting habitats and different years in southeastern Oklahoma. J. Med. Entomol. 21: 69-79.

Koch, H. G. 1988. Suitability of white-tailed deer, cattle, and goats as hosts for the lone star tick, Amblyomma americanum (Acari: Ixodidae). J. Kans. Entomol. Soc. 61: 251-257.

Lancaster, J. L., Jr. 1958. Control of the lone star tick. Ark. Agric. Exp. Sta. Rpt. Ser. 67.

Mount, G. A. 1981. Control of the lone star tick in Oklahoma parks through vegetative management. J. Econ. Entomol. 74: 173-175.

SAS Institute. 1985. SAS/STAT guide for personal computers, Version 6 Edition. Cary, NC:SAS Institute, Inc.

Sutherst, R. W., R. J. Jones, and H. J. Schnitzerling. 1982. Tropical legumes kill ticks. Nature 295: 316.

Zimmerman, R. H., G. R. McWherter, and S. R. Bloemer. 1987. Role of small mammals in population dynamics and dissemination of Amblyomma americanum and Dermacentor variabilis (Acari: Ixodidae) at Land Between The Lakes, Tennessee. J. Med. Entomol. 24: 370-375.

A TECHNIQUE FOR HANDLING FIELD-COLLECTED HORN FLIES[1,2]

J. S. Simco[3]

ABSTRACT

A technique has been developed for handling horn flies, Haematobia irritans (L.), that permits transfer of the flies to insecticide resistance test chambers without mouth or mechanical aspiration or use of CO_2 or chill table for immobilization. The method utilizes light attraction for moving the flies, in the number desired, from the collection site to the test chamber. The method ensures that only active flies are introduced for resistance testing or release onto caged animals.

INTRODUCTION

A method for field detection of horn fly, Haematobia irritans (L.), resistance to insecticidal deposits was introduced by Simco (1962). Since the recent development of pyrethroid resistance, other workers (Sheppard and Hinkle 1986, 1987) have developed techniques for determination of horn fly resistance. All these methods, however, require the use of mouth or mechanical aspiration. Aspiration by mouth may result in actual ingestion of a fly and subsequent allergic reaction in some people. Mechanical aspiration may result in injury to flies and could conceivably affect results of tests. Immobilization by CO_2 and chilling, if repeated or continued too long, may result in mortality or weakened flies. The objective of this report is to describe an alternative fly transfer method that reduces hazard to the fly and handler.

MATERIALS AND METHODS

The materials required for utilizing the technique consist of the following:

1) 0.94633 liter Fonda® paper cans 8.5 cm diameter x 17.0 cm long,
2) 7.5 cm expandable stockinette about 25.0 cm long,
3) Common plastic screen ca. 6 mesh/cm,
4) A circular piece of corrugated cardboard 7.75 cm diameter,
5) Clear plastic specimen jar 5.0 cm diameter x 7.0 cm in height with a screw top,
6) A piece of rigid clear plastic tubing 3.5 cm long x 1.0 cm diameter,
7) A rubber faucet washer,
8) A piece of PVC pipe 5.2 cm diameter x 7.0 cm, and

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1 Diptera: Muscidae

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9) Disposable plastic petri dishes and bottom with 1.0 cm hold drilled in center.

The expandable stockinette is hot glued to the lid end of the Fonda can. The center of the lid is pushed out; the lid is put on and glued in place. The bottom end of the can is cut out, leaving about 1.0 cm around the outside. The plastic screen is cut to fit inside the lip of the screened bottom. A 1.0 cm hole is cut with a cork borer or scalpel just off center of the cardboard. The specimen jar serves as a collection-counting chamber. The top is screwed on firmly but can be removed for cleaning. A 1.0 cm hole is drilled in the top, just off center, to correspond with the 1.0 cm hole in the corrugated cardboard used in the bottom of the Fonda can. On the bottom end of the specimen jar, a 1.0 cm hole is drilled in the center and the piece of rigid plastic tubing is hot glued in place. The rubber faucet washer is placed over the tubing and pushed down ca. 0.75 cm to act as a stop. The PVC pipe is used to provide a dark chamber when placed over the specimen jar and may be painted black inside. The bottom half of the plastic petri dish with the 1.0 cm hole is placed on the end of the rigid plastic tube for collection of flies.

The apparatus consists of three major component parts with subparts as shown in Fig. 1. Flies were swept by net from the backs of closely confined animals and transferred to the Fonda can (A) through the expandable stockinette while holding the screened end of the can toward the sunlight. The heavier the infestation on the donor animal the fewer the sweeps, reducing potential injury to the flies. At this point, the container can be transferred to the laboratory or work place in a chilled styrofoam chest (Miller et al. 1977; or if the test location is nearby, the container can be transported without chilling.

When ready to count and transfer flies to the test chamber or to a caged animal, the Fonda can should be inverted on a smooth surface so that the screened end is upward. Cut a 2-3 cm hole in the plastic screen and quickly place the cardboard circle (B) over the opening so that the flies can emerge. Cover the hole with masking tape to prevent emergence of the flies. If the flies were not chilled, the operation must be performed quickly to prevent undue loss of flies. If the flies were chilled, 2-3 min may be available to perform the operation.

Unit 2 consists of the clear plastic specimen jar (A), the lid (B) with the 1.0 cm hole drilled in it, and (C) the PVC pipe cut to act as a sleeve over the specimen jar. When ready to transfer the flies to the specimen jar, the lid (B) must be screwed on and a small piece of masking tape placed over the tube opening on the opposite end of the jar. Place the unit over the opening in the cardboard (Fig. 2). The holes should be aligned so that the flies can travel up to the specimen jar. Several of these units can be operated simultaneously. Allow one or two hundred flies per specimen jar.

Unit 3 consists of the clear, plastic specimen jar covered with the PVC sleeve and the petri dish (Fig. 3). The petri dish may contain a treated filter paper for resistance determination or act as a chamber for transfer of known numbers of flies for other purposes. The flies can be counted accurately as they move through the clear plastic tube.

The system is useful in actual operations. It is quick, easily used, accurate, and provides uninjured, active flies for testing.

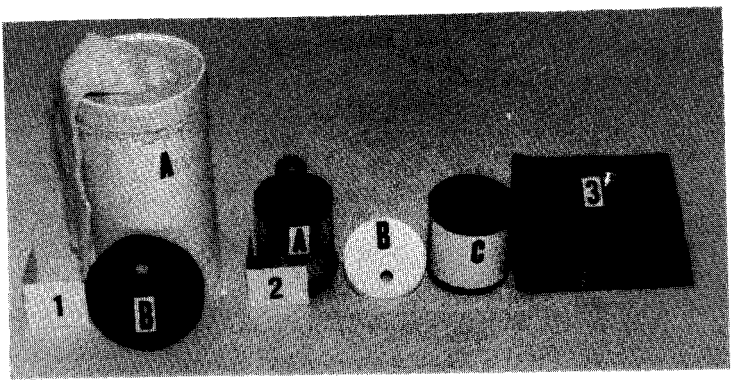

FIG. 1. Collection and isolation apparatus for Haematobia irritans.

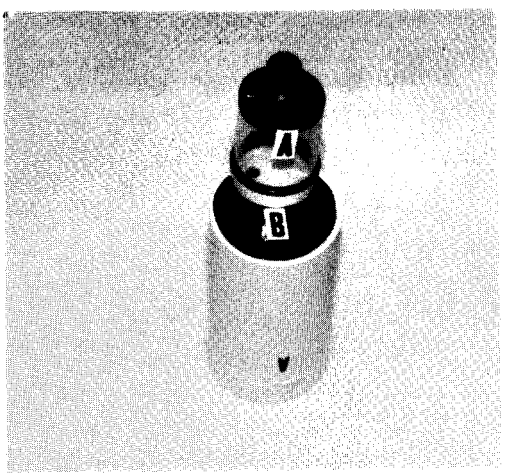

FIG. 2. Collection and isolation apparatus (Units 1 and 2).

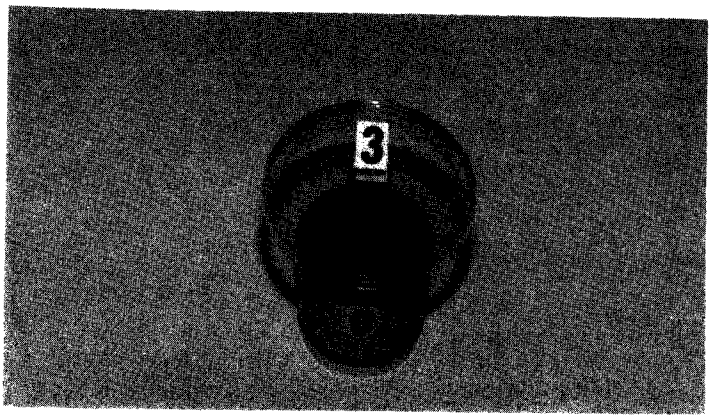

FIG. 3. Counting and testing chamber (Units 2 and 3).

LITERATURE CITED

Miller, J. A., J. L. Eschle, B. F. Hogan, F. C. Wright, and C. I. Edwards. 1977. Techniques for shipping large numbers of adult horn flies. J. Econ. Entomol. 70: 170-182.

Sheppard, D. C., and N. C. Hinkle. 1986. A procedure for evaluation of horn fly, Haematobia irritans (L.) pyrethroid resistance by exposure to pyrethroid residue on glass. J. Agric. Entomol. 3: 100-102.

Sheppard, D. C., and N. C. Hinkle. 1987. A field procedure using disposable materials to evaluate horn fly insecticide resistance. J. Agric. Entomol. 4: 87-89.

Simco, J. S. 1962. A method for field detection of horn fly susceptibility to DDT residues. J. Kans. Entomol. Soc. 35: 167-170.

VOL. 13 NO. 4 THE SOUTHWESTERN ENTOMOLOGIST DEC. 1988
SCIENTIFIC NOTE

SEEDLING DEATH OF *SALICORNIA* ATTRIBUTED TO *METACHROMA*[1] LARVAE

M. E. Stanghellini[2], F. G. Werner[3], B. C. Turner[4], and M. C. Watson[4 5]

A native halophytic *Salicornia* species is currently being evaluated on the seacoast of the state of Sonora, Mexico for its potential as forage for grazing animals and as an oilseed crop. It is planted in March, irrigated daily with undiluted sea water, and harvested in September.

On 1 April 1987 numerous dead and wilted seedlings were observed in plots located in Puerto Peñasco, Sonora. Tap roots of these seedlings had been severed 3-5 cm below the soil surface. Stand loss, both within and between plots, varied from 0 to 35%. Despite numerous isolation attempts on agar medium, no fungi or bacteria were consistently isolated from injury sites on the tap roots. However, careful examination of the soil around wilted seedlings on 12 April 1987 revealed the consistent presence of small beetle larvae in the vicinity of the damaged roots. Some adult beetles were also recovered from the soil.

Treatment of the soil in infested plots with diazinon stopped the spread of the damage and resulted in large numbers of adult beetles coming to the surface by 21 April. These proved to belong to a species of *Metachroma*, perhaps *M. regulare* Jacoby as described and figured by Blake (1970). Since larvae of Eumolpinae in general are reputed to be root-feeders, *Metachroma* larvae were the probable cause of the damage. Voucher adult specimens are deposited in the Department of Entomology, University of Arizona, Tucson, research collection.

LITERATURE CITED

Blake, D. H., 1970. A review of the beetles of the genus *Metachroma* Chevrolat (Coleoptera: Chrysomelidae). Smithsonian Contributions to Zoology, No. 57.

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[1]Coleoptera: Chrysomelidae: Eumolpinae.

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SCIENTIFIC NOTE

REPORT OF LIMITED ESTABLISHMENT OF RED IMPORTED FIRE ANT, SOLENOPSIS INVICTA BUREN[1/] IN ARIZONA

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There has been considerable speculation about how much of the U.S. will ultimately be colonized by the red imported fire ant (RIFA), Solenopsis invicta Buren (Pimm and Bartel 1980, Francke and Cokendolpher 1986). The northern boundary of this insect's range has changed little over the last twenty years, which suggests that cold is the most significant factor limiting its spread. During the same period, its spread westward has proceeded at a fairly rapid pace (Pimm and Bartel 1980). Francke and Cokendolpher (1986) have suggested that this spread will slow considerably as the ants encounter hotter, drier climates. They further suggest that, with man's help, this pest could potentially become established in the arid west in artificially moist habitats. Herein, I report just such an occurrence.

Red imported fire ants routinely hitchhike to new locations on nursery stock shipped from infested areas. On 15 August 1986, RIFA workers were found foraging in a greenhouse in Mesa, AZ, a state with no previously reported infestations. The greenhouse had been abandoned for 3-4 wk, and it seemed unlikely that the RIFA could have been carry-overs from an infested shipment. A detailed survey of the area was conducted by personnel of Arizona Commission of Agriculture and Horticulture (ACAH), and a large mound (about one foot high) was discovered behind the greenhouse. The mound was excavated, and over 250 winged females were collected. Three winged males and tremendous numbers of workers were also found. Their identification was confirmed by Dr. James Trager of the University of Florida, Gainesville. Voucher specimens were placed in the ACAH insect collection in Phoenix. The mound and environs were treated with Dursban 2E® according to label specifications, and the colony was eliminated. A survey of all areas within one mile of the mound was conducted, and no additional RIFA were found.

Judging from the presence of winged reproductives, as well as mound size and sheer numbers of ants found, it seems apparent that this colony had become well-established. Little question should remain that RIFA can establish itself in the arid western U.S. under the appropriate conditions.

1/ Hymenoptera: Formicidae

2/ Current address: Texas Agricultural Experiment Station, P.O. Box 1658, Vernon, TX 76384.

LITERATURE CITED

Francke, O. F., and J. C. Cokendolpher. 1986. Temperature tolerances of the red imported fire ant. pp. 104-113 In C. S. Lofgren and R. K. Vander Meer (Eds.). Fire Ants and Leaf-Cutting Ants: Biology and Management. Westview Press, Boulder, CO.

Pimm, S. L. and D. P. Bartel. 1980. Statistical model for predicting range expansion of the red imported fire ant, Solenopsis invicta, in Texas. Environ. Entomol. 9: 653-658.

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