EFFECTS OF PESTICIDES ON TRICHOGRAMMA SPP.[1/]

D. L. Bull[2/] and R. J. Coleman[3/]

ABSTRACT

Adult stages of Trichogramma species are generally highly susceptible to most broad-spectrum chemical insecticides. In contrast, immature stages of the parasite developing within host eggs apparently are well protected from even the most toxic compounds. However, with some pesticides there are deleterious effects when pharate adults try to emerge from the host egg. Among the chemical insecticides evaluated, these parasites are generally most susceptible to compounds such as carbaryl, methyl parathion, permethrin, and oxydemeton-methyl. They are relatively tolerant of compounds such as endosulfan and thiodicarb, as well as chlordimeform and methomyl when the latter are used at recommended ovicidal rates. The parasites are not affected by the insect growth regulator diflubenzuron when it is applied in the absence of crop oil. Unfortunately, the oil must be included for diflubenzuron to be fully effective against the boll weevil, Anthonomus grandis Boheman, and crop oils have a highly deleterious effect on the parasites (at least on Trichogramma pretiosum Riley). Microbial pesticides are fully compatible with Trichogramma spp.

It is conceivable that Trichogramma releases could be integrated with applications of certain chemical pesticides, but only under carefully controlled conditions. The most likely use of this biological control procedure is in cropping systems where insecticides are absent or are used only sparingly.

INTRODUCTION

The problems associated with the interactions of entomophagous species with pesticide-contaminated field environments are well documented (Croft 1975). Thus the potential for failure of an augmentative biological control procedure under such conditions was anticipated before we initiated the herein-described pilot test of the use of mass releases of the egg parasite Trichogramma pretiosum Riley in managing Heliothis spp. on cotton. Indeed, a primary factor in selecting locations in Arkansas and North Carolina for the tests was that possible problems with pesticides were predicted to be minimum. As discussed by King et al. (1984), the development of unexpected heavy populations of Heliothis spp. and/or the boll

1/Hymenoptera: Trichogrammatidae. This work was done in cooperation with Texas A&M University, Texas Agricultural Experiment Station, College Station, TX. This paper reports the results of research only. Mention of a pesticide in this paper does not constitute a recommendation under FIFRA as amended. Also, mention of a commercial or proprietary product in this paper does not constitute an endorsement of this product by the U. S. Department of Agriculture.

2/Cotton Insects Research Laboratory, ARS, USDA College Station, TX 77841.

3/Southern Field Crop Insect Management Laboratory, ARS, USDA, Stoneville, MS 38776.

weevil, Anthonomus grandis Boheman, at the test sites prompted cooperating producers to initiate repeated applications of broad-spectrum insecticides during critical phases of the parasite-release program. There is no direct proof that pesticide drift and/or residues on plants adversely affected the Trichogramma that were released during the course of the 3-yr pilot test. However, circumstantial evidence strongly suggests that, during each yr, applications of chemical insecticides on or near fields used for augmentative releases were contributing factors in the erratic or failed performance of the parasites (King et al. 1984). Also, in earlier attempts to evaluate large-scale tests of these parasites in Texas (Stinner et al. 1974a, Ridgway et al. 1977), problems with the boll weevil precipitated insecticide applications which precluded further attempts to mass-release Trichogramma.

Research on the mass-production (Morrison et al. 1975) and aerial application (Bouse et al. 1981) of Trichogramma has resulted in the development of an excellent technology for the field release of large numbers of viable parasites to supplement the actions of natural enemies in controlling lepidopteran pests of plants. Using this technology we have demonstrated that, in the absence of pesticides, releases of sufficient numbers of Trichogramma can result in high rates of parasitism of host eggs and provide effective control of Heliothis spp. on cotton (Ables et al. 1979, Bull et al. 1979). However, the pervasive use of broad-spectrum pesticides in conventional crop production limits implementation of the technique. Parasite releases must be used either in cropping situations where pesticides are not used or, perhaps with careful timing, integrated with other management practices--including insecticide applications. The latter option will require an understanding of parasite-pesticide interactions, and their consequences, as well as the identification or development of selective insecticides that are less detrimental and perhaps compatible with the parasites in an IPM program. In this paper, we review literature relating to the effects of different pesticides on Trichogramma spp., and present the results of recent research on such effects that was conducted in support of the pilot test.

REVIEW OF LITERATURE

Stern (1963) demonstrated that field applications of carbaryl were extremely toxic to Trichogramma semifumatum (Perkins) adults, as well as to immature stages developing in host eggs; trichlorfon, methoxychlor, phosdrin, and demeton were somewhat less toxic at the application rates used. Dutt and Somchoudhury (1980) conducted field tests of the persistent toxicity (PT) of DDT, BHC, endosulfan, endrin, parathion, malathion, diazinon, and carbaryl to adult females of T. perkinsi Girault and T. australicum Girault. Two concentrations (0.05 and 0.1%) of these insecticides in water were sprayed on maize (1000 L/ha) and red gram (1250 L/ha) and then parasites were confined on treated leaves at different times post-treatment through the use of small plastic cages (Somchoudhury and Dutt 1980). In these tests, Dutt and Somchoudhury (1980) found that PT values on both crops were greatest for carbaryl, parathion, endrin, and BHC; diazinon had the lowest PT value and carbaryl the greatest. All the insecticides were more persistent on red gram in spring than in late summer. Trichogramma perkinsi appeared to be slightly more tolerant than T. australicum to most of the insecticides.

Stinner et al. (1974a) conducted a definitive evaluation of the effects of insecticide drift on Trichogramma pretiosum Riley under field conditions in Central Texas. In 1971 these authors placed adults confined in small screen cages at distances 0-14.5 km upwind or downwind of an area where scheduled aerial ULV applications of methyl parathion (1.68 kg/ha) would be made. The parasites were set in place the morning before each application and then returned to laboratory after 12 h for observation of

effects. Virtually all the parasites within 0.4-0.8 km upwind or downwind of the point of insecticide application were killed. Downwind from sprayed fields, ca. 75% were killed at a distance of 1.61 km when there was appreciable wind movement (mean wind speed of 6.4-7.6 km/h) and ca. 30% on a calm day (mean of 1 km/h). Parasite mortality at the 3.2 and 14.5 km distances was low (4-18%). Similar tests were conducted during 1972 in the same area by Ridgway et al. (1973). In these experiments parasites were exposed again to drift from aerial applications of methyl parathion (2.24 kg/ha) but, in this case, the toxicant was applied in 28 L water/ha. Mortalities of adult Trichogramma were high (51-79%) 0.4 km downwind (mean wind speed of 4.8-6.4 km/h) from the treatment area, but no mortality was recorded at 0.8 km downwind or 0.4 and 0.8 km upwind.

In recent tests of the use of mass-releases of T. pretiosum to control Heliothis spp. in two 10 ha fields of cotton isolated from possible insecticide drift, Ables et al. (1979) demonstrated that, in conjunction with natural enemies, releases of the parasites (ca. 120,000/ha/release) at 4-5 day intervals against sustained heavy populations of Heliothis (125,000-462,000 eggs/ha) maintained levels of surviving larvae below 3,000/ha throughout the month of July. Two applications of methyl parathion (0.56 kg/ha) on August 4 and 7 reduced recycling populations of Trichogramma, and natural enemies, to the extent that populations of Heliothis larvae increased precipitously to >40,000/ha within 1 wk posttreatment. However, resumption of parasite releases 2 days following the last insecticide application combined with the recovery of natural enemy populations resulted in rapid (<1wk) reestablishment of high levels of egg parasitism (>80%) and control of surviving Heliothis larvae.

Tipping and Burbutis (1983) evaluated the effects of greenhouse- and field- weathered residues of several pesticides on T. nubilale Ertle and Davis. Pepper plants were sprayed with Bacillus thuringiensis Berliner (Bt), carbaryl, methomyl, methyl parathion, and permethrin at two different rates of application within the range recommended for insect control in vegetables. Residues were weathered for different lengths of time, and then sprayed leaves where brought into the laboratory and exposed to parasite pupae and adults. These tests indicated T. nubilale adults were not affected by Bt, but they were highly sensitive to all four synthetic insecticides--especially methyl parathion (0.22 and 1.12 kg/ha). Permethrin (0.04 and 0.21 kg/ha) residues did not inhibit parasite emergence but did cause a reduction in rates of parasitism. Field-weathered residues of methomyl (0.1 and 0.5 kg/ha) and carbaryl (0.28 and 1.4 kg/ha) generally did not reduce adult parasite emergence. However, greenhouse-weathered residues of carbaryl reduced parasitism almost completely for as long as 21 days posttreatment, and the compound caused significant reductions in the field for as long as 14 days. Based upon their results, these authors concluded that low doses of methomyl (0.22 kg/ha), and Bt, had the best potential for possible integration with augmentative releases of T. nubilale. Hassan and Groener (1977) also reported there were no adverse effects on parasitism of host eggs by T. cacoeciae Marchal when adults were exposed to residues of Bt. Other reports (Franz et al. 1980, Hassan 1983) have also indicated that Bt, the acaricide fenbutatin oxide, and diflubenzuron were harmless to adult T. cacoeciae that were exposed to residues on glass plates.

Jacobs et al. (1984) conducted studies of the effects against T. pretiosum of greenhouse-weathered residues of permethrin (0.12 kg/ha) and endosulfan (0.56 kg/ha) on tomato plants. In these tests, treated leaves were removed at different times posttreatment, infested with eggs of Heliothis zea Boddie (10/leaf, 5 top and 5 bottom), and then exposed to adult parasites (500/leaf). Compared to untreated controls, permethrin significantly reduced rates of parasitism and caused higher adult parasite mortality through 21 days posttreatment. However, endosulfan residues significantly reduced egg parasitism and adult survival for only 1 day

posttreatment. These authors concluded that properly timed T. pretiosum releases might be compatible with the use of endosulfan but probably not with permethrin.

In studies of the effects of spray residues of endrin (0.1%), parathion (0.05%), malathion (0.1%), endosulfan (0.1%), and lindane, (0.1%) on sugar cane leaves against T. australicum and T. japonicum Ashmead, Navarajan et al. (1976) found that endosulfan and lindane were least toxic of the insecticides tested. These authors also found that the emergence of adults of either species was affected little when sprays were applied to parasitized host eggs -- only parathion had an adverse effect.

Although several studies have suggested that endosulfan might be less detrimental to Trichogramma than many insecticides, Navarajan et al. (1979) reported poor parasitism and subsequent adult emergence when T. brasiliensis Ashmead adults were exposed to host eggs sprayed with endosulfan (0.05% solution). However, this result might be misleading because exposures were only done through 24 h posttreatment. These authors also reported that with similar exposure times there was no parasitism of eggs treated with malathion (0.1%) or methyl parathion (0.05%), but that both parasitism and emergence were high when host eggs were sprayed with phosalone (0.07%) or monocrotophos (0.04%).

Bull and House (1983) conducted studies of the effects of different insecticides on parasitism of eggs of the tobacco budworm, Heliothis virescens (F.), by T. pretiosum. In laboratory and greenhouse tests where host eggs were sprayed (using different rates of application equivalent to those recommended for various field uses) before exposure to parasites, methomyl (range of 70-280 g/ha), permethrin (56-224 g/ha), and methyl parathion (560-1661 g/ha) severely inhibited parasitism (ca. 70-100%). The effects of chlordimeform (70-280 g/ha) were moderate (ca. 30% inhibition) and thiodicarb (280-840 g/ha) was essentially inactive. When host eggs were exposed to parasites before spray applications, there was no apparent adverse effect on the development of parasites within the eggs by these five compounds at any of the rates of application that were tested. There was a high rate of emergence (>90%) of adults from treated eggs that were successfully parasitized. Similarly in a study of T. evanescens Westw., Plewka et al. (1975) also found that in general insecticides did not penetrate the chorion of parasitized host eggs (Sitrotroga cerealella Olivier) and that parasites were affected only upon emergence from the host egg. These authors did find that treatment of parasitized eggs with high concentrations (0.25 and 0.5%) of oxydemeton-methyl at an early stage of parasite development increased mortality in the pupal stage. Plewka et al. (1975) also reported that direct effects of oxydemeton-methyl on the fecundity of T. evanescens was less important than indirect effects through shortening the adult life-span.

In greenhouse tests Bull and House (1983) found that residues of methomyl (140 g/ha), chlordimeform (140 g/ha), and thiodicarb (280 g/ha) were inactive at 7 days posttreatment, but at that same time methyl parathion (1121 g/ha) and permethrin (112 g/ha) still caused some inhibition (ca. 30%) of parasitism. Although overall rates of parasitism were lower in tests conducted with cotton in screened field cages, these authors found that the pattern of activity of the insecticides (same rates of application) against the parasites was similar to that observed in the laboratory and greenhouse. The results of these tests suggested that with careful timing Trichogramma releases might be compatible with applications of methomyl (at ovicidal rates), chlordimeform, and thiodicarb. However, it is apparent that the greater persistence of the toxicity of residues of permethrin and methyl parathion (which are heavily used in cotton production) precludes integration of those insecticides with parasite releases.

Bull and House (1983) also demonstrated that residues of the crop oil Savol® severely inhibited parasitism of host eggs by T. pretiosum. Even

after 7 days of weathering in the greenhouse, parasitism of eggs placed on cotton leaves that had been sprayed with Savol (9.31 L/ha) was only 20%, a rate lower than on leaves treated with any of the aforementioned insecticides. The adverse effects of Savol on parasitism of eggs placed on newly treated leaves were not unexpected. In field evaluations designed to test the combined use of spray applications (70 g AI in 4.7 L of Savol/ha) of the diflubenzuron (to manage boll weevils) with releases of T. pretiosum (to manage codistributed populations of Heliothis), House et al. (1980) observed reductions in the rates of parasitism of host eggs that appeared to coincide with applications of the IGR. This result was surprising because previous laboratory tests by Ables et al. (1977) had shown that diflubenzuron alone had no effect on these parasites. Subsequent laboratory studies by House et al. (1980) also clearly demonstrated that diflubenzuron alone had no effect on the parasites; however, they found that applications of diflubenzuron + Savol, and Savol alone, significantly reduced rates of parasitism when compared with untreated controls. House et al. (1980) further demonstrated that vegetable oils (corn oil, cotton seed oil, and soybean oil -- all at rates equivalent to 4.7 L in 89.9 L of water/ha) severely inhibited parasitism of freshly-sprayed host eggs. Thus it is apparent that the persistence and potential adverse effects of crop oils as well as pesticides must be considered if augmentative releases of Trichogramma are likely to be used as part of a pest management system. This is especially important because of the current use of vegetable oils as diluents for the pyrethroid and other insecticides that are applied to cotton.

It is conceivable that the problem of extreme susceptibility of Trichogramma spp. to most broad spectrum insecticides might be minimized through selection of a laboratory strain for increased tolerance and/or resistance to an insecticide(s). Kot et al. (1975) attempted to induce resistance to DDT and demeton-S-methyl in five different populations of T. evenescens. They found that single-line selection through 71 generations failed to establish a genetically stable resistant strain. After 34 generations, the resistance level increased to 22 times greater than the unexposed control strain, but subsequently the resistance levels declined to 7.5 times that of controls after 62 generations. These authors concluded that failure to achieve a stable resistant strain was due either to the recessive character for resistance in the species or to inadequacy of the selection method. Krukierek et al. (1975) examined six species and two ecotypes of Trichogramma from different hosts, biocenoses, and geographical regions and found no significant differences in the susceptibility of adult females following exposure to deposits of oxydemeton-methyl on glass slides.

The literature thus clearly indicates that the adult stages of Trichogramma spp. are generally highly susceptible to most chemical insecticides, especially those used in the management of the larval stages of phytophagous Lepidoptera. These parasites may be affected immediately by direct exposure to spray applications or drift of pesticides, as well as to posttreatment contact with residues of pesticides on foliar surfaces -- some of which retain significant levels of toxicity for prolonged periods. However, it is encouraging that immature stages of Trichogramma developing within host eggs apparently are well protected from even highly toxic materials. Clearly there is a need for more information on parasite-pesticide interactions, particularly those species that have potential for use in management programs which include augmentative mass-releases.

The ensuing experimental section of this paper presents additional information on the susceptibility of immature stages of Trichogramma to pesticides and on the relative toxicity of surface residues of several different pesticides to adults of two different species of the parasite.

METHODS AND MATERIALS

Parasites. Trichogramma pretiosum and T. exiguum Pinto and Platner were reared separately on eggs of either the tobacco budworm or the Angoumois grain moth, Sitotroga cerealella. Adult parasites from each culture were obtained by emergence manipulation procedures similar to those described by Stinner et al. (1974 b): 8-day-old parasitized eggs were isolated in gelatin capsules (size 000), cold-programmed in the dark for 5 days at 17°C and 30-40% RH, and then removed and held in an environmental chamber at 27°C and 50-60% RH for 4 h in light to allow for rapid and uniform emergence of adults.

Pesticides. The test compounds, which were obtained from commercial sources, included azinphosmethyl, Baculovirus heliothis (Elcar®, used alone or in combination with the feeding stimulants Coax® or Gustol®), chlordimeform, dimethoate, methyl parathion, methomyl, permethrin, phosmet, toxaphene, and the herbicide DSMA.

Spray Treatments. Oviposition substrates (paper toweling) bearing eggs (6-24 h old) of the tobacco budworm were obtained from an insecticide-susceptible colony that has been maintained continuously for several years. These egg groups were then divided into subgroups of ca. 100-300 eggs, each of which was placed in a standard glass Petri dish. Adult parasites that had been obtained from a laboratory culture at 2 h postemergence were introduced into the petri dishes (ca. 1000/dish) where they were allowed to parasitize the host eggs over a 15-min period. The parasitized eggs were then removed from the petri dish and held at 27°C for 1, 2, or 5 days before being treated with insecticides.

Each group of parasitized eggs was then divided into two subgroups, one for use in insecticide treatments and one for use as an untreated control. Insecticide treatment was accomplished by placing egg groups beneath a spray tower and spraying them with an aqueous suspension of the insecticide at the selected rate in a final volume equivalent to 93.4 L/ha. The eggs were then allowed to air dry 2 h before transfer to individually compartmented holding containers (0.5 cm diam x 0.25 cm deep). These eggs were then held at 27°C for observations of parasite development during a 10-12 day posttreatment period.

Residual Treatments. Desired ranges of concentrations of pesticides were prepared by serial dilutions of stock solutions using acetone, or distilled water in the tests involving Elcar and DSMA. Five concentrations were used to establish dosage-mortality curves. Five replications, each with at least 20 insects, were tested at each of the 5 different concentrations. Toxicity was assessed by exposing adult parasites to films of pesticide residues coated on the inner surfaces of 18 x 150 mm culture tubes. The technique used was similar to that reported by Stam et al. (1978) in studies of a parasite of a whitefly. A microapplicator syringe was used to deliver 0.15 ml of the pesticide solution to each culture tube; treated tubes were then rotated manually on their sides until the entire surface was coated and the solvent evaporated.

After a 15-min waiting period the adult parasites were introduced into the culture tubes by removing the short section of the gelatin capsule and positioning the remaining section containing the parasites just inside the lip of the culture tube. A 9 cm^2 piece of fine mesh cloth was placed over the opening of the culture tube and a nontapered 18 mm diam. rubber stopper with an 8 mm hole was inserted to hold the capsule containing the parasites. This holding cage was left in an inverted position to allow the parasites to climb out of the capsule and up the inner surface of the culture tube. Approximately 5-min later, the empty gelatin capsule was removed, the stopper was replaced, and the tubes were placed in an upright position in a test tube rack. A droplet of a mixture of honey and water was placed on the outer surface of the fine mesh cloth in the stopper. Thus, the test insects were supplied a food source and ventilation was

provided to minimize any fumigant action. The tubes containing the Trichogramma were then placed in a separate environmental chamber maintained at 27°C and 50-60% RH under continious light. Mortality was observed 4 h after initial exposure, the criterion of death was inability of the parasites to cling to the inner surface of the culture tubes. Percent mortality was corrected for natural mortality of parasites held in tubes treated only with acetone or distilled water.

Field Evaluations. Screen cages (1.8 x 1.8 x 5.5 m long) were placed over actively growing cotton plants in the field. All cotton within these cages was sprayed with natural pyrethrins to remove both pest and beneficial insects before initiation of tests with the parasites. On the following day, plants were sprayed manually (between 7 and 8 a.m.) with aqueous suspensions of the different insecticides at recommended rates in a final volume equivalent 46.7 L/ha. These treatments were timed so that on the day that tests with parasites were initiated, residues aged 5, 2, 1 and 0 days were available. Each insecticide was applied in a separate cage. Ten mated female tobacco budworm moths were released into each cage on the evening of the same day following the application of the insecticide to produce the 1 day residue and allowed to oviposit overnight. The following morning applications were made to produce the 0 day residues and Trichogramma (200,000/ha) were released in all cages that same afternoon (4-5 p.m.). White and tan host eggs were then collected daily for three days beginning the morning following parasite release. Eggs were individually placed in compartmented holding cards and observed for parasitism.

Data Analysis. Results of different tests were subjected to statistical analysis using standard computerized programs. Data from tests of the effects of spray applications of pesticides on the immature stages of Trichogramma were analyzed by analysis of variance (ANOVA) using a SAS general linear model for unbalanced data; differences between means were evaluated with Duncans Multiple Range Test. Data from replicated tests of the effects of residues of pesticides on adult parasites were analyzed by probit analysis and then differences between LC_{50} means were evaluated via ANOVA and t test.

RESULTS

Laboratory Studies. The results of studies to determine the susceptibility of T. pretiosum to insecticides at different stages of the development of immature forms are shown in Tables 1 and 2. The % emergence of adults was in most cases highest from host eggs treated at 1 day postparasitism but, in general, the immature stages tolerated the insecticide applications quite well whether treated at 1, 2, or 5 days. At conventional ovicidal rates (140 g/ha) methomyl and chlordimeform had little effect on adult emergence (Table 1), a result that agrees well with comparable studies by Bull and House (1983). In each age group, there were significant differences in adult emergence between the high and low doses of these two chemicals. In the single-rate tests with methyl parathion, azinphosmethyl, and permethrin (Table 2), permethrin (112 g/ha) was significantly more effective than methyl parathion in reducing adult parasite emergence from host eggs treated at 1 or 2 days postparasitism; there were no differences among any treatments at 5 days postparasitism.

When T. pretiosum adults were exposed to residues of seven different chemical insecticides (Table 3), the order of toxicity was methyl parathion=methomyl>dimethoate>toxaphene>chlordimeform>phosmet>permethrin. The first two chemicals were significantly alike in their effect; however, the activities among the remaining chemicals were significantly different. Baculovirus heliothis and DSMA had no apparent effect on either adult T. pretiosum or T. exiguum.

TABLE 1. Emergence of Adult Trichogramma from Host Eggs Treated with Different Concentrations of Methomyl or Chlordimeform at Different Times Postparasitism.[a/]

Appl. rate (g/ha)	Day post-parasitism that eggs were treated	No. eggs & (reps.)	% adult emergence ($\bar{x}\pm$SD)	Statistical evaluations[b/] Trmt. times vs. indiv. rates each insec.	Each trmt. time vs. 3 rates each insec. 1	2	5
			Methomyl				
140	1	291(4)	87.9±5.4	ab	a		
	2	515(6)	94.5±6.4	a		c	
	5	406(4)	84.7±4.2	b			e
280	1	325(4)	92.8±6.7	c	a		
	2	385(6)	94.4±2.4	c		c	
	5	1102(12)	50.3±22.5	d			ef
560	1	320(5)	68.5±12.2	e	b		
	2	563(6)	72.5±10.3	e		d	
	5	770(8)	70.0±14.9	e			f
			Chlordimeform				
140	1	371(4)	93.4±3.7	ab	a		
	2	604(7)	94.8±5.9	a		c	
	5	1307(14)	84.3±9.7	b			f
280	1	334(4)	91.2±3.6	c	b		
	2	511(6)	82.2±7.3	cd		d	
	5	322(4)	72.8±8.8	d			f
560	1	505(6)	90.0±7.9	e	b		
	2	365(5)	57.9±6.7	f		e	
	5	568(7)	51.6±17.3	f			g

[a/]Comparable numbers of untreated parasitized host eggs were included as controls with each replicate; % emergence of adults from these ranged from 91 to 100%

[b/]Observations in ANOVA data sets between horizontal lines are significantly different ($P = 0.05$) if not followed by the same letter (according to Duncan's Multiple Range Test).

Results of tests of the residual toxicity of four insecticides to T. pretiosum and T. exiguum reared on eggs of the Angoumois grain moth (AGM) or the tobacco budworm (TBW) are shown in Table 4. As in the previous test, the order of toxicity, regardless of parasite species or the host upon which they were reared, was methyl parathion=methomyl>phosmet>permethrin. The first two insecticides were significantly alike but phosmet and permethrin were significantly different. There were no significant differences in susceptibility attributable to rearing host. Generally, the response of the two parasite species to these insecticides was similar except that in the case of phosmet (AGM host) and permethrin (TBW host), T. pretiosum was significantly more tolerant.

TABLE 2. Emergence of Adult Trichogramma from Host Eggs Treated with Methyl Parathion, Azinphosmethyl, or Permethrin at Different Times Postparasitism.[a/]

Appl. rate (g/ha)	Day post-parasitism that eggs were treated	No. eggs & (reps.)	% adult emergence ($\bar{x}$±SD)	Statistical evaluations[b/] Trmt. times vs. appli. rate	Trmt. time vs. type of insectic. 1	2	5
		Methyl Parathion					
1121	1	297(6)	91.5±6.2	a	a		
	2	537(7)	87.6±10.6	ab		c	
	5	665(8)	79.2±7.8	b			e
		Azinphosmethyl					
280	1	896(11)	80.8±13.4	c	ab		
	2	499(6)	62.3±7.0	d		d	
	5	676(9)	66.6±14.7	d			e
		Permethrin					
112	1	835(11)	72.0±21.9	e	b		
	2	1202(19)	62.1±16.8	e		d	
	5	1476(17)	62.1±15.6	e			e

[a/]Comparable numbers of untreated parasitized host eggs were included as controls with each replicate; % emergence of adults from these ranged from 92 to 100%.

[b/]Observations in ANOVA data sets between horizontal lines are significantly different if not followed by the same letter (according to Duncan's Multiple Range Test).

TABLE 3. Residual Toxicity of Selected Pesticides to Trichogramma pretiosum Adults.[a/]

Pesticide	LC 50(±SE)[b/] (μg/tube X10^{-3})	Slope
Permethrin	3.17(±0.23)a	2.80
Phosmet	1.30(±0.08) b	5.18
Chlordimeform	1.01(±0.03) c	4.21
Toxaphene	0.34(±0.06) d	1.49
Dimethoate	0.16(±0.01) e	4.64
Methomyl	0.04(±0.01) f	1.95
Methyl Parathion	0.02(±0.00) f	4.80

[a/]Parasites were reared on eggs of the Angoumois grain moth.

[b/]LC_{50} values followed by the same letter are not significantly different ($P = 0.05$) according to t test.

TABLE 4. Residual Toxicity of Four Pesticides to Two Species of Trichogramma Reared on Different Hosts.[a/]

Pesticide	*Trichogramma pretiosum* LC_{50} (μg/vial $X10^{-3}$)	Slope	*Trichogramma exiguum* LC_{50} (μg/vial $X10^{-3}$)	Slope
		Angoumois grain moth		
Permethrin	3.17a A	2.80	3.61a A	2.82
Phosmet	1.30 b A	5.18	0.74 b B	3.92
Methomyl	0.04 c A	1.95	0.03 c A	2.62
Methyl parathion	0.02 c A	4.80	0.02 c A	4.95
		Tobacco budworm		
Permethrin	4.47a A	2.33	2.21a B	1.73
Phosmet	1.25 b A	4.06	1.04 b A	4.70
Methomyl	0.04 c A	2.74	0.05 c A	2.71
Methyl parathion	0.03 c A	3.70	0.02 c A	7.30

[a/]LC_{50} values in the same column (lower case letters) or same line (upper case letters) are not significantly different ($P = 0.05$) if followed by the same letter. Log transformation was performed on LC_{50} values to stabilize variance between pesticides prior to ANOVA.

Field Studies. Tests to determine the residual activity of aged residues of azinphosmethyl (280 g/ha) and permethrin (112 g/ha) against *T. pretiosum* adults released in field cages of cotton naturally infested with tobacco budworm eggs (Table 5) indicated that the parasites were adversely

TABLE 5. Effect of Residues of Azinphosmethyl and Permethrin on Parasitism of *Heliothis* Eggs by *Trichogramma* in Field Cages.[a/]

Age of residue (days)	% Parasitism of *Heliothis* eggs on indicated day following parasite release		
	1	2	3
		Azinphosmethyl (280 g/ha)	
5	9.6	5.8	1.4
2	5.6	0.0	0.0
1	3.7	0.0	0.0
0	0.0	0.0	0.0
Untreated	79.4	75.0	83.3
		Permethrin (112 g/ha)	
5	0.0	0.0	8.8
2	0.0	0.0	-
1	0.0	-	-
0	0.0	0.0	0.0
Untreated	96.0	73.0	36.4

[a/]All figures represent average of 2 replications.

affected, even with residues aged 5 days. Subsequent attempts to evaluate residues of these insecticides after they had been aged for longer periods were unsuccessful because of frequent periods of inclement weather.

DISCUSSION

As we found in the pilot test described in this series of papers, and as is clearly indicated by the available literature, there is little encouragement for the use of augmentative releases of Trichogramma spp. to manage lepidopteran pests in an agricultural production system where broad spectrum insecticides will be used as a primary control procedure. The extreme susceptibility of adult parasites to most pesticides severely limits their use unless they can be integrated into a management scheme that features sufficient insecticide-free periods which allow parasites to function normally. However, given the problems with long-range drift and extended persistence of certain chemicals such as the synthetic pyrethroids, this type of control strategy would be hard to achieve with a crop such as cotton except in a rigidly controlled management program involving very large production areas. Perhaps the putative successful use of Trichogramma to manage certain field crop pests in China and Russia is attributable to the establishment of such controls of production practices.

There are indications that Trichogramma might be able to tolerate certain pesticides, such as endosulfan and methomyl, at reduced rates, but these products have limited utility in controlling major phytophagous pests of cotton. That immature stages of Trichogramma developing in host eggs apparently are well protected from even the harshest chemical insecticides is a fortuitous and potentially exploitable phenomenon. It is conceivable that carefully timed applications of a very short residual larvicide/adulticide interspersed with releases of Trichogramma might be used effectively in controlling cotton pests. Unfortunately, suitable chemicals of this type are not commercially available. It seems clear that maximum efficacious implementation of this augmentative biological control procedure could best be accomplished if we had highly selective complementary procedures for managing Heliothis larvae (which either survive the egg parasites or which are present at population densities that cause damage but are too low for effective use of parasite releases) or primary pests such as the boll weevil, pink bollworm, Pectinophora gossypiella Saunders, or different species of plant bugs.

Microbial pesticides--especially Baculovirus heliothis--have shown good potential for integration with Trichogramma releases in managing Heliothis on cotton (Bull et al. 1979), but economic considerations and other problems have restricted futher development and utilization of such materials. Certain benzoylphenylurea IGR's are highly selective for the boll weevil and are essentially inactive per se against Trichogramma. However, diflubenzuron is the only such product on the market and it is effective against boll weevils only when combined with crop oils which can have a devastating effect on the parasites. There are a number of related IGR's currently under investigtion that are active against boll weevils in the absence of crop oil; however, their effects on Trichogramma have not been evaluated. This is certainly a promising area of research that warrants investigation. Perhaps the ideal solution in Heliothis control would involve integration of augmentative releases of Trichogramma with releases of an effective larval parasite or predator. There is intensive research directed to this concept but we do not have at this time economical methods for mass producing and releasing such larval entomophages.

There is no question that the technology developed for mass-producing and releasing Trichogramma is economical and has good potential for use in pest control. However, with current crop production practices in this country, the use of this biological control technique must be limited to cropping systems where pesticides are absent or used sparingly.

LITERATURE CITED

Ables, J. R., S. L. Jones, R. K. Morrison, V. S. House, D. L. Bull, L. F. Bouse, and J. B. Carlton. 1979. New developments in the use of Trichogramma to control lepidopteran pests of cotton. Proc. Beltwide Cotton Prod. Res. Conf. pp. 125-127.

Ables, J. R., S. L. Jones, and M. J. Bee. 1977. Effect of diflubenzuron on beneficial insects associated with cotton. Southwest. Entomol. 2:66-72.

Bouse, L. F., J. B. Carlton, and R. K. Morrison. 1981. Aerial application of insect egg parasites. Trans. ASAE. 24:1093-8.

Bull, D. L., and V. S. House. 1983. Effects of different insecticides on parasitism of host eggs by Trichogramma pretiosum Riley. Southwest. Entomol. 8:46-53.

Bull, D. L., V. S. House, J. R. Ables, and R. K. Morrison. 1979. Selective methods for managing insect pests of cotton. J. Econ. Entomol. 72:841-6.

Croft, B. A., and A. W. A. Brown. 1975. Responses of arthropod natural enemies to insecticides. Annu. Rev. Entomol. 20:285-335.

Dutt, N., and A. K. Somchoudhury. 1980. Persistent toxicity of some insecticides to Trichogramma australicum Girault (Hymenoptera: Trichogrammatidae) J. Entomol. Res. 4:203-14.

Franz, J. M., H. Bogenschuetz, S. A. Hassan, P. Huang, E. Naton, H. Suter, and G. Viggiani. 1980. Results of a joint pesticide test program by the working group: pesticides and beneficial arthropods. Entomophaga 25:231-6.

Hassan, S. A. 1983. Results of laboratory testing of a series of pesticides on egg parasites of the genus Trichogramma (Hymenoptera: Trichogrammatidae). Nachrichtenbl. Dtsch. Pflanzenschutzdienstes (Braunschweig) 35:21-5.

Hassan, S. A., and A. Groener. 1977. The effect of polyhedra (Baculovirus spp.) of Mamestra brassicae on Trichogramma cacoeciae (Hymenoptera: Trichogrammatidae) and Chrysopa carnea (Neuroptera: Chrysopidae). Entomophaga 22:281-8.

House, V. S. J. R. Ables, R. K. Morrison, and D. L. Bull. 1980. Effect of diflubenzuron formulations on the egg parasite Trichogramma pretiosum. Southwest. Entomol. 5:133-8.

Jacobs, R. J., C. A. Kouskolekas, and H. R. Gross. 1984. Effects of permethrin and endosulfan residues on Trichogramma pretiosum, an egg parasitoid of Heliothis zea. Environ. Entomol. 13:355-8.

King, E. G., L. F. Bouse, D. L. Bull, W. A. Dickerson, W. J. Lewis, P. Liapis, J. D. Lopez, R. K. Morrison, and J. R. Phillips. 1984. Potential for management of Heliothis spp. in cotton by augmentative releases of Trichogramma pretiosum. Proc. 1984 Beltwide Cotton Prod. Res. Conf. pp. 232-6.

Kot, J., T. Krukierek, and T. Plewka. 1975. Investigation of metasystox and DDT resistance of five populations of Trichogramma evanescens (Hymenoptera: Trichogrammatidae). Pol. Ecol. Stud. 1:173-82.

Krukierek, T., T. Plewka, and J. Kot. 1975. Susceptibility of parasitoids of the genus Trichogramma (Hymenoptera:Trichogrammatidae) to metasystox in relation to their species, host species, and ambient temperature. Pol. Ecol. Stud. 1:183-96.

Morrison, R. K., R. E. Stinner, and R. L. Ridgway. 1975. Mass production of Trichogramma pretiosum on eggs of the Angoumois grain moth. Southwest. Entomol. 1:74-80.

Navarajan, P. A. V., R. Dass, R. Ahmed, and B. Parshad. 1979. Effect of some insecticides on parasitism by the parasitoid Trichogramma brasiliensis (Trichogrammatidae: Hymenoptera). Z. Angew. Entomol. 88:399-403.

Navarajan, P. A. V., M. Mohanasundarum, and T. R. Subramanian. 1976. Effect of insecticides on the survival and emergence of the egg parasite, Trichogramma spp. Madras Agric. J. 63:557-60.

Plapp, F. W., Jr. and S. B. Vinson. 1977. Comparative toxicities of some insecticides to the tobacco budworm and its ichneumonid parasite, Campoletis sonorensis. Environ. Entomol. 6:381-4.

Plewka, T., J. Kot, and T. Krukierek. 1975. Effect of insecticides on the longevity and fecundity of Trichogramma evanescens (Hymenoptera:Trichogrammatidae). Pol. Ecol. Stud. 1:197-210.

Ridgway, R. L., E. G. King, and J. L. Carrillo. 1977. Augmentation of natural enemies for control of plant pests in the western hemisphere, p. 379-428. In R. L. Ridgway and S. B. Vinson [eds.], Biological Control by Augmentation of Natural Enemies. Plenum Press, New York and London. 480 pp.

Ridgway, R. L., R. K. Morrison, R. E. Kinzer, R. E. Stinner, and B. G. Reeves. 1973. Programmed releases of parasites and predators for control of Heliothis spp. on cotton. Proc. Beltwide Cotton Res. Conf. pp. 92-4.

Somchoudhury, A. K., and N. Dutt. 1980. Field bioecology of Trichogramma perkinsi Girault and Trichogramma australicum Girault (Hymenoptera: Trichogrammatidae) and their time of release for the control of Chilo partellus (Swinhoe) and Heliothis armigera Hubn. J. Entomol. Res. 4:73-82.

Stam, P. A., D. F. Clower, J. B. Graves, and P. E. Schilling. 1978. Effects of certain herbicides on some insects and spiders found in Louisiana fields. J. Econ. Entomol. 71:477-80.

Stern, V. M. 1963. The effect of various insecticides on Trichogramma semifumatum and certain predators in Southern California. J. Econ. Entomol. 56:348-50.

Stinner, R. E., R. L. Ridgway, J. R. Coppedge, R. K. Morrison, and W. A. Dickerson, Jr. 1974a. Parasitism of Heliothis eggs after field releases of Trichogramma pretiosum in cotton. Environ. Entomol. 3:497-500.

Stinner, R. E., R. L. Ridgway, and R. E. Kinzer. 1974b. Storage, manipulation of emergence, and estimation of numbers of Trichogramma pretiosum. Environ. Entomol. 3:505-7.

Tipping, P. W., and P. P. Burbutis. 1983. Some effects of pesticide residues on Trichogramma nubilale (Hymenoptera: Trichogrammatidae). J. Econ. Entomol. 76:892-6.