EFFECTS AND FATE OF SELECTED INSECTICIDES AFTER APPLICATION TO MICROPLITIS CROCEIPES[1/]

D. L. Bull[2/], E. G. King[3/], and J. E. Powell[4/]

Agricultural Research Service, U.S. Dept. Agriculture

ABSTRACT

Studies of the toxicity of insecticides to adults of the hymenopteran parasitoid Microplitis croceipes (Cresson) have revealed the following general response pattern: (1) organophosphorus insecticides - highly susceptible to phosphorothionate-type chemicals, relatively tolerant of phosphates; (2) organochlorines - highly susceptible to cyclodienes, relatively tolerant of toxaphene, highly tolerant of DDT; (3) carbamates - tolerant of oxime-type compounds; and (4) pyrethroids - highly tolerant. Studies of the fate of ^{14}C- labeled preparations of the cis- and trans-isomers of permethrin, fenvalerate, DDT, aldrin, and malathion have shown that (1) all these insecticides were readily absorbed by M. croceipes adults; (2) the absorbed pyrethroids and DDT were metabolized, but the extent of metabolic detoxification seemed insufficient to account for the substantial tolerance of M. croceipes to these compounds; (3) aldrin was metabolized extensively to its equally toxic microsomal epoxidation product dieldrin, but there was very little detoxification of either compound; and (4) malathion was extensively detoxified, but the array of metabolic products also included small concentrations of the highly toxic oxygen analog malaoxon.

This information is reviewed and discussed in relation to effects and mode of action of different types of insecticides. The implications of this toxicological data in development of pest management strategies involving conservation or augmentation of populations of M. croceipes in cropping systems where insecticides are used are also discussed.

REVIEW AND DISCUSSION

It is well-established that the conservation or augmentation of populations of natural enemies can play an important role in the management of crop pests. In some production systems, however, the use of insecticides can neutralize the effects of biological control because of the devastating impact some compounds have on many beneficial species. In some cropping systems, such as cotton, insecticides often must be used for adequate control of certain major pests. In such systems, a desirable goal in developing pest management strategies would be to identify and use insecticides which would provide satisfactory control of pests while having minimum adverse effect on major beneficial species. To facilitate the attainment of this goal, it is essential that we develop a database on the responses of target pests and important codistributed natural enemies to different types of insecticides. It is also important that we identify and understand the factors which influence such responses. The purpose of this report is to review and

---

1/Hymenoptera: Braconidae
2/College Station, TX 77841
4/Mississippi State, MS 39762
3/Stoneville, MS 38776

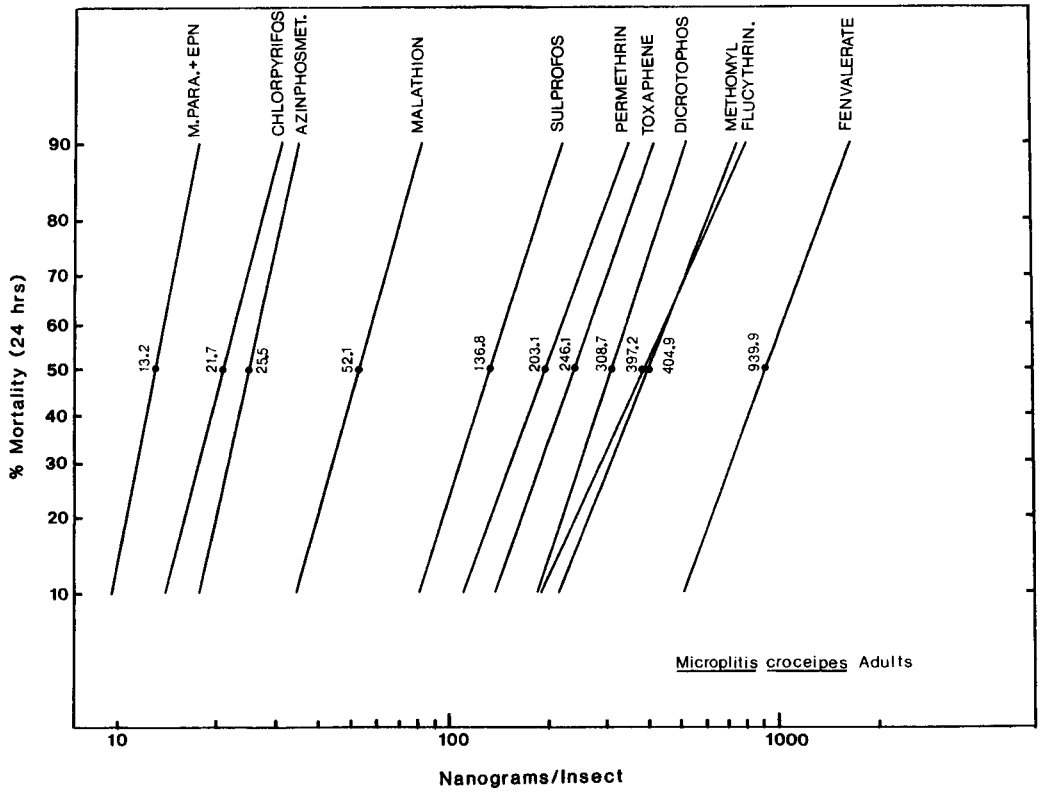

FIG. 1. Dosage-mortality data from tests of topical applications of different insecticides to M. croceipes adults. (Data adapted from Powell et al. 1986).

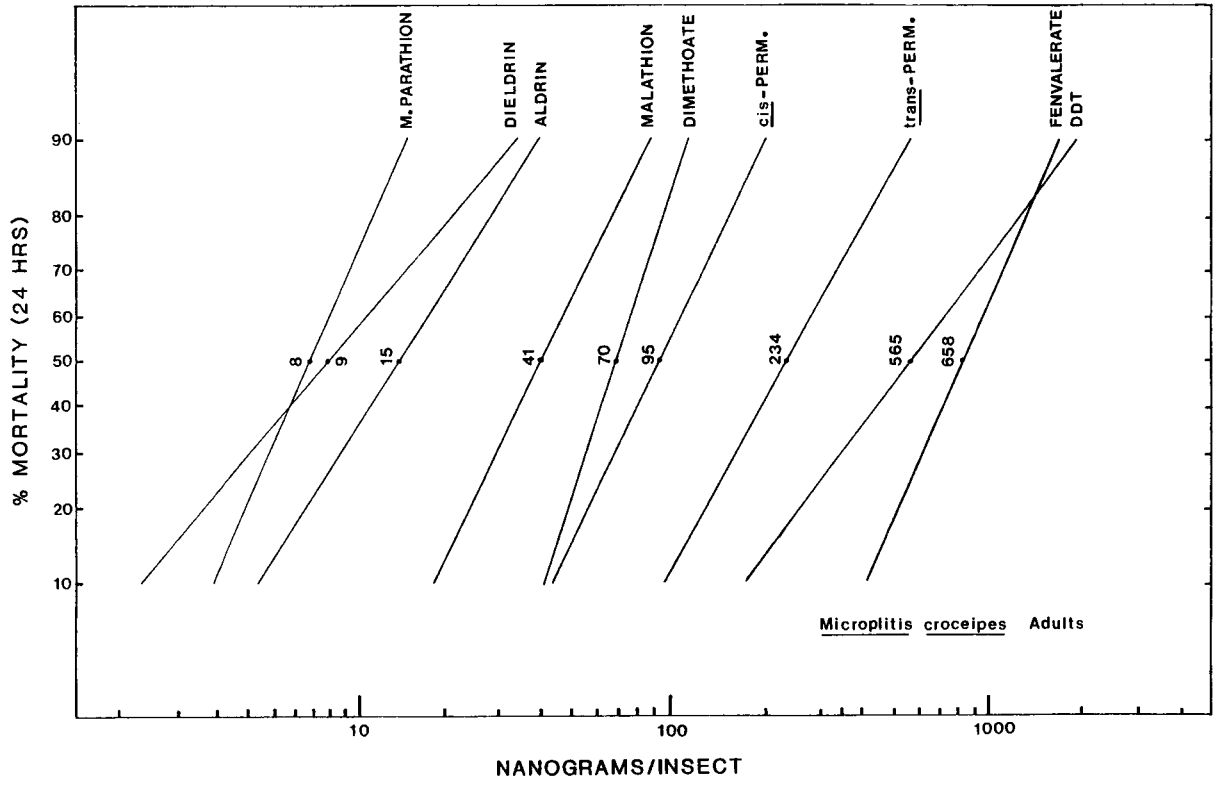

FIG. 2. Dosage-mortality data from tests of topical applications of different insecticides to M. croceipes adults. (Data in this and succeeding figures all adapted from Bull et al. 1987).

discuss some of the work that has been done recently to characterize the response of Microplitis croceipes (Cresson) to insecticides in general, and especially to the pyrethroids.

King et al. (1985) reported that M. croceipes, an important larval parasite of Heliothis pests of cotton in the USA, is commonly observed in fields in and around production areas subjected to insecticide control programs. As a first step in explaining the latter phenomenon, Powell and Scott (1985) conducted replicated field tests in which they caged laboratory-reared M. croceipes adults on terminal growth of cotton that was either untreated or treated with thiodicarb, fenvalerate, or flucythrinate at the recommended field-application rates. Observations of test insects at 24 h posttreatment revealed surprisingly little mortality was caused by any of the insecticides, all of which are highly effective in the field against Heliothis spp. (Table 1). It is

TABLE 1. Survival of Microplitis croceipes Adults in Treated Cotton[a/]

Insecticide (g. AI/Ha)	No. wasps	% mortality
Fenvalerate (112.1)	76	20.8 a
Thiodicarb (672.8)	78	16.2 ab
Flucythrinate (44.9)	64	7.8 bc
Untreated	72	3.7 c

[a/]Data adapted from Powell and Scott (1985); numbers in the % mortality column followed by different letters are significantly different ($P \leq 0.05$).

important to note that M. croceipes adults (1-4 days old) used in these tests, as well as those discussed later, were from a laboratory colony established at Stoneville, Mississippi in 1981 with insects collected at Portland, Arkansas and maintained continuously since then without exposure to insecticides (Powell et al. 1986).

Subsequent to the field tests, Powell et al. (1986) evaluated the topical toxicity to M. croceipes adults of different types of insecticides representative of those that might be encountered in the field. In general (Fig. 1) the phosphorothionate-type organophosphorus (OP) insecticides, especially a methyl parathion-EPN mixture, exhibited the greatest toxicity and the pyrethroids the least. The oxime-carbamate, methomyl, a phosphate-type OP, dicrotophos, and the organochlorine, toxaphene also had relatively low levels of toxicity. Although not shown in Fig. 1, Powell et al. (1986) reported that another oxime-carbamate, thiodicarb, as well as chlordimeform and diflubenzuron were essentially nontoxic to these parasites at a dose of 2,500 ng/insect. Katayama et. al (1987) found similar results in studies with M. conceipes adults that were exposed to residues of insecticides on filter paper.

Bull et al. (1987) also conducted topical toxicity tests with M. croceipes adults, featuring for the most part the insecticides that were also used for studies of rates of absorption and metabolism. The results (Fig. 2) indicated that methyl parathion and the cyclodiene compounds, dieldrin and aldrin, were clearly the most toxic of those tested and, as reported by Powell et al. (1986), fenvalerate was the least toxic. The cis and trans isomers of permethrin were tested separately, and both exhibited low levels of toxicity. The cis isomer was ca. 2.5 times more toxic than trans-permethrin. It is interesting to note that M. croceipes was also highly tolerant of DDT. This result

was not unexpected because such a cross resistance/tolerance pattern has been observed in other species, and most likely is related to similarities in the mode of action of pyrethroids and DDT (Plapp and Vinson 1977, Plapp and Bull 1978, Miller and Adams 1982, Miller et al. 1983, Sparks et al. 1985).

The topical toxicity data for selected insecticides against M. croceipes adults (Powell et al. 1986, Bull et al. 1987) are especially interesting when LD_{50} values are expressed in terms of μg of insecticide/gram of live weight, and compared to similar data that have been reported for insecticide-susceptible 3rd-instar tobacco budworms, Heliothis virescens (F.) (Table 2). In the column showing the ratio of

TABLE 2. Comparative Topical Toxicity of Insecticides to Microplitis croceipes Adults and Third-Instar Tobacco Budworms.

	LC_{50} - μg/gram of live weight		
Insecticide	M. croceipes (MC)	H. virescens (TBW)	Ratio MC/TBW
Chlorpyrifos	3.8	79.5[a/]	0.05
Methyl parathion	1.4	4.7[b/]	0.29
Dicrotophos	55.2	53.3[c/]	1.03
Sulprofos	24.4	13.6[d/]	1.79
Methomyl	72.3	24.8[e/]	2.92
Permethrin	36.3	1.4[f/]	25.93
Fenvalerate	146.4	0.4[f/]	366.00

Source of data: a. Whitten and Bull 1974, b. Whitten and Bull 1970, c. Bull and Lindquist 1964, d. Bull 1980, e. Lentz et al. 1974, f. Sparks et al. 1983

a M. croceipes LD_{50} dose to that of the tobacco budworm, a value of 1 represents equivalent toxicity to both species. It is clear that the selectivity balance for chlorpyrifos and methyl parathion favors the pest, while the reverse is true for permethrin and, especially, for fenvalerate. Dicrotophos, sulprofos, and methomyl have selectivity values slightly favoring the parasite. Comparable results have been reported in studies with adults of the parasite Campoletis sonorensis (Carlson) (Plapp and Vinson 1977), and with larvae of the predator Chrysopa carnea (Stephens) (Plapp and Bull 1978).

Because M. croceipes had widely varying levels of susceptibility to some of the insecticides that are effective against its primary hosts, Bull et al. (1987) initiated tests to determine the reasons for these different responses. Factors which contribute to pesticide tolerance or resistance often are associated with a naturally efficient or an acquired enhanced capacity for metabolic detoxification of the insecticide. Another major factor involves natural or acquired target site characteristics which may diminish interactions of the insecticide with critical components of neutral receptor sites. Other factors that sometimes are important are reduced rates of cuticular penetration or translocation of toxicants and, in rare cases, behavioral adaptations that may allow the insect to avoid contact with the toxicant.

Bull et al. (1987) evaluated six different insecticides to assess the influence of cuticular penetration and metabolic detoxification on their relative toxicity to M. croceipes adults. These insecticides were radiolabeled with ^{14}C, and their fate was determined through

replicated tests using topical applications and conventional radiometric, analytical procedures. Data illustrated in Fig. 3 compare the

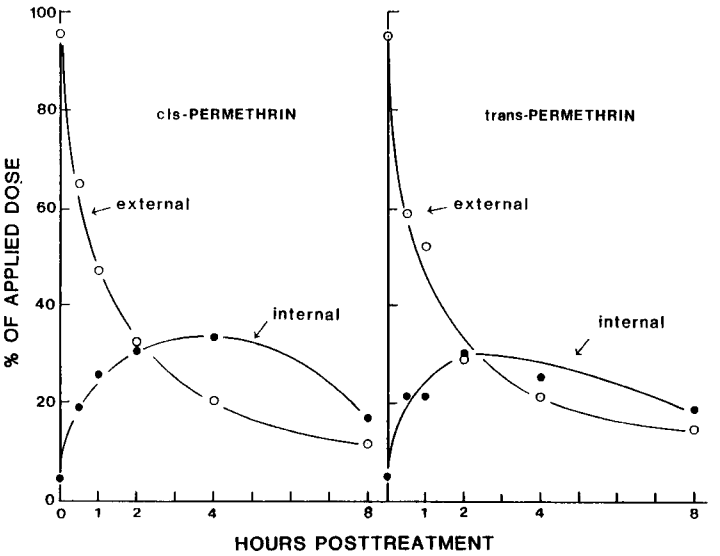

FIG. 3. Absorption and internal accumulation of radioactive materials in M. croceipes adults at different times posttreatment with [^{14}C]cis- and trans-permethrin (0.004 μg/insect).

rates at which external residues of cis- or trans-permethrin declined, and internal residues accumulated, during an 8-h experimental period. Both isomers were readily absorbed through the cuticle, reaching maximum internal concentration at 2-4 h posttreatment and then declining as the rate of excretion exceeded that of penetration. Statistical comparisons indicated there were no significant differences (t-test, $P \leq 0.05$) in the rates of absorption and internal accumulation of the two isomers.

The results shown in Fig. 4 indicate that fenvalerate also was readily absorbed through the insect cuticle and appreciable concentrations of radioactive material accumulated internally. Rates at which these events occurred were only slightly slower than observed with the permethrin isomers.

Results shown in Table 3 compare the relative distribution of each of the three radiolabeled pyrethroids and their combined nontoxic metabolites in internal extracts at different times posttreatment. Micropli-tis croceipes adults definitely were able to metabolize substantial portions of both cis- or trans-permethrin and fenvalerate. Statistical comparisons indicated there were no significant differences (t-test, $P \leq 0.05$) in the metabolic detoxification of the two permethrin isomers, but there apparently was less metabolism of absorbed fenvalerate than of the permethrin isomers. Qualitative and quantitative analyses of radioactive materials excreted at different times posttreatment indicated the presence of the parent pyrethroids as well as their nontoxic metabolic products. However, there was no evidence of any major differences between the permethrin isomers in excretion rates or concentrations of products recovered, or of any unusual pattern in the excretion of fenvalerate and its products.

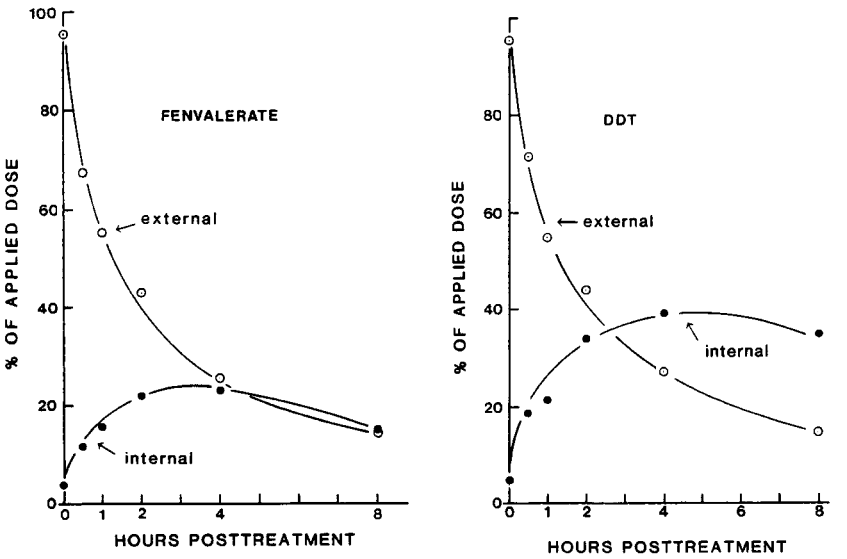

FIG. 4. Absorption and internal accumulation of radioactive materials in M. croceipes adults at different times posttreatment with [^{14}C]fenvalerate or [^{14}C]DDT (0.05 μg/insect).

TABLE 3. Comparative Metabolism of ^{14}C-Labeled cis- and trans-Permethrin and Fenvalerate by M. croceipes Adults[a/]

Hrs Posttrmt.	% of applied dose[b/] as indicated product in internal extracts					
	cis-permethrin		trans-permethrin		fenvalerate	
	parent	metab.	parent	metab.	parent	metab.
0.5	12.4	6.3	16.1	6.3	9.5	2.2
1	18.2	7.6	14.1	7.3	11.8	4.1
2	19.4	11.2	21.2	8.9	16.5	5.4
4	23.5	10.0	18.2	7.2	19.2	3.5
8	12.6	4.5	14.0	5.1	12.3	3.0

[a/]These data and those shown in subsequent tables are adapted from Bull et al. (1987).
[b/]Dose of permethrin isomers was 0.004 μg/insect and of fenvalerate was 0.05 μg/insect.

DDT also was readily absorbed by M. croceipes adults although at a slightly slower rate than observed with the pyrethroids (Fig. 4). Relatively large fractions of the applied dose accumulated internally, reaching a peak after ca. 4 h. Metabolism studies indicated that there

was very little detoxification of DDT (Table 4). At all times posttreatment, the parent compound was by far the predominant radioactive

TABLE 4. Metabolism of [^{14}C]DDT by M. croceipes Adults (0.05 μg/insect).

	% of applied dose as indicated radioactive material -			
	Internal extracts		Container wash	
Hrs. Posttrmt.	DDT	metabolites	DDT	metabolites
0.5	17.2	1.3	7.9	1.7
1	20.3	1.7	20.6	2.2
2	31.4	2.8	20.2	3.0
4	35.6	3.3	19.9	3.0
8	31.0	4.3	32.8	5.4

material found in either the internal extracts or in washes of the holding containers, which would include products derived from excretion and any contact loss.

These results obtained with the pyrethroids and DDT seem to support a tentative conclusion that the differences between the toxicity of the cis- and trans-isomer of permethrin to M. croceipes, and the relatively high tolerance of this insect to permethrin and fenvalerate, as well as to DDT, most likely cannot be attributed to any unusual characteristics associated with absorption, metabolism, or excretion of these materials. If this is true, then the relatively high level of tolerance of M. croceipes to pyrethroids and DDT probably is attributable to factors associated with the interactions of these chemicals with target site receptors. Bull et al. (1987) demonstrated that combining cis-permethrin with chlordimeform in a 1:10 ratio caused a 2-fold reduction in the LD_{50} value, but had no effect on absorption and metabolism of cis-permethrin. Plapp (1979) reported that chlordimeform synergized the activity of permethrin against the tobacco budworm and Campoletis sonorensis (Carlson). In subsequent studies Chang and Plapp (1983) found that coadministration of chlordimeform significantly increased the binding of both cis-permethrin and DDT to neural receptors of the tobacco budworm, and they attributed the synergistic action of chlordimeform to this phenomenon.

Bull et al. (1987) reported that aldrin was absorbed at about the same rate as DDT, but there was a greater internal accumulation of absorbed radioactive material (Fig. 5). In these tests it was necessary to use a fairly toxic dose of [^{14}C]aldrin because of the very low specific activity of the radioactive preparation. Although the treated insects were alive throughout the 6-h test period, most were prostrate after 2 h; it is likely that this condition of intoxication influenced the responses measured. Major portions of the absorbed aldrin were converted to dieldrin by metabolic epoxidation (Table 5). However, in this case, metabolism was counterproductive because dieldrin is as toxic as aldrin. Metabolic detoxification of either aldrin or dieldrin was essentially nonexistent. The major point is that there is substantial microsomal oxidase activity in M. croceipes adults. This enzyme system is very important in the metabolism of insecticides and other xenobiotics.

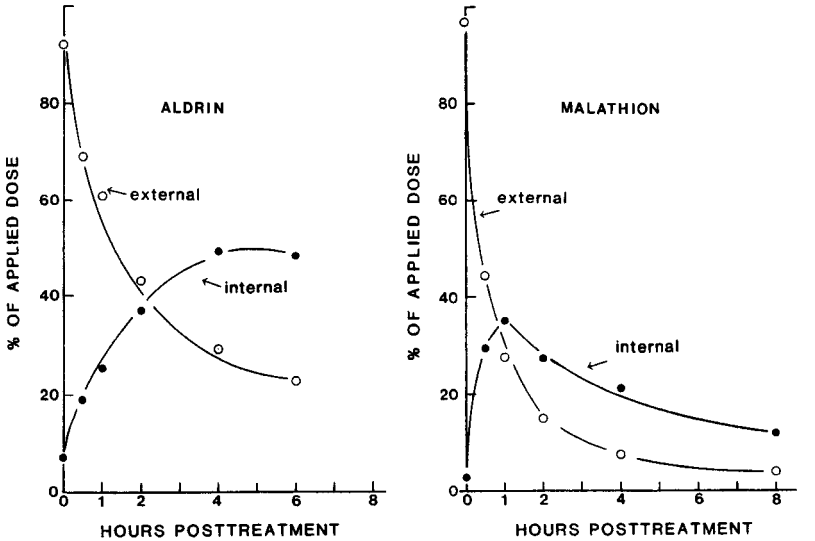

FIG. 5. Absorption and internal accumulation of radioactive materials in M. croceipes adults at different times posttreatment with [^{14}C]aldrin (0.05 μg/insect) or [^{14}C]malathion (0.01 μg/insect.

TABLE 5. Metabolism of [^{14}C]Aldrin by M. croceipes Adults (0.05 μg/insect).

Hrs. Posttrmt.	% of applied dose as indicated radioactive materials - in internal extracts		
	Aldrin	Dieldrin	Polar metabolite(s)
0.5	9.1	6.0	1.3
1	9.6	15.3	0.4
2	11.6	22.0	0.1
4	17.4	30.7	0.5
6	12.6	34.1	1.0

Malathion and some other phosphorothionates were among the most toxic of insecticides tested against M. croceipes. It is well-established that OP insecticides of this type are inactive per se and require activation to their oxygen analogs through biological reactions catalyzed by microsomal oxidase enzyme systems. The same reaction that activates these insecticides also makes them less stable to degradation by hydrolytic enzymes. Bull et al. (1987) found that the rates at which malathion penetrated the cuticle and accumulated internally were the most rapid among the six compounds tested (Fig. 5). Internal radioactive materials reached peak concentration at 1 h posttreatment and then declined rapidly as rates of excretion exceeded absorption. Malathion was extensively metabolized by M. croceipes, primarily to nontoxic metabolites (Table 6). However, small concentrations of the

TABLE 6. Metabolism of [^{14}C]Malathion by M. croceipes Adults (0.01 μg/insect).

Hrs. Posttrmt.	% of applied dose as indicated radioactive material - Internal extract		Container wash	
	Malathion	Metabolites	Malathion	Metabolites
0.5	16.2	13.5	10.9	3.9
1	19.4	15.5	15.1	4.4
2	15.0	12.5	27.4	11.6
4	12.7	9.9	35.2	15.3
8	8.5	3.6	35.4	21.5

highly toxic oxygen analog, malaoxon, were included among the array of transformation products detected. Given the very rapid rate at which malathion was absorbed, it is likely that the rate of metabolic detoxification was insufficient to counteract the rapid accumulation of the inhibitor at the site of action.

In studies of the in vitro activity of certain enzyme systems implicated in the metabolism of insecticides, Bull et al. (1987) reported that the specific activity of soluble esterases was about 10-fold higher in subcellular preparations of midguts of 5th-instar tobacco budworm than in abdomens of adult M. croceipes. Studies of the effects of increasing concentrations of paraoxon on this enzyme system indicated that inhibition leveled off at a concentration of 10^{-5}M, at which point about 20% of the total enzyme activity was uninhibited in M. croceipes compared with 40% in tobacco budworm. It is possible that the paraoxon-insensitive fraction of these enzyme preparations included the so-called A-esterases which have been implicated in the metabolism of certain organophosphorus insecticides (Aldridge 1953). These authors also found that the specific activity of glutathione-transferases was comparable in the two species, while that of microsomal oxidases was somewhat higher in the tobacco budworm. If these in vitro results are indicative of the relative capabilities of these two species for metabolizing insecticidal substrates, then the pest would appear to have a definite advantage over the parasite in potential metabolic detoxification reactions involving esterase and microsomal oxidase enzymes. Such speculation is valid only for the specific life stages and tissue preparations that were compared in the study. However, the metabolism data reported here generally support earlier conclusions by Plapp and Vinson (1977) that a lack of detoxification capabilities in Campoletis sonorensis was the basis for the selectivity of certain insecticides.

In conclusion, the aforementioned studies have shown that M. croceipes adults have a relatively high level of tolerance to certain insecticides which are highly effective against the tobacco budworm. This selectivity might be exploited in a management program that emphasized conservation of natural enemies as a control component. Chemical insecticides used for such a program would be limited to those having selectivity properties advantageous to the parasite. It is apparent that pyrethroids, and certain oxime-carbamates and phosphate-type organophosphorus insecticides have potential for such use. It is possible that the observed tolerance in M. croceipes to certain of these insecticides could be enhanced through a selection program. If a high

level of insecticide tolerance could be induced in a laboratory population and if economical methods for mass production were available, M. croceipes could have excellent potential for use in an augmentation-type biological control program.

LITERATURE CITED

Aldridge, W. N. 1953. Serum esterases. I. Two types of esterase (A and B) hydrolyzing p-nitrophenyl acetate, propionate, and butyrate, and a method for their determination. Biochem. J. 53: 110-117.

Bull, D. L. 1980. Fate and efficacy of sulprofos against certain insects associated with cotton. J. Econ. Entomol. 53: 110-117.

Bull, D. L., and D. A. Lindquist. 1964. Metabolism of 3-hydroxy-N, N-dimethylcrotonamide dimethyl phosphate by cotton plants, insects, and rats. J. Agric. Food Chem. 12: 310-317.

Bull, D. L., N. W. Pryor, and E. G. King, Jr. 1987. Pharmacodynamics of different insecticides in Microplitis croceipes (Hymenoptera: Braconidae), a parasite of lepidopteran larvae. J. Econ. Entomol. 80: 739-749.

Chang, C. P., and F. W. Plapp, Jr. 1983. DDT and synthetic pyrethroids: mode of action, selectivity, and mechanisms of synergism in the tobacco budworm (Lepidoptera: Noctuidae) and a predator, Chrysopa carnea Stephens (Neuroptera: Chrysopidae). J. Econ. Entomol. 76: 1206-1201.

Katayama, R. W., C. H. Cobb, J. G. Burleigh, and W. R. Robinson. 1987. Susceptibility of adult Microplitis croceipes (Hymenoptera: Braconidae) to insecticides used for Heliothis spp. (Lepidoptera: Noctuidae) control. Fla. Entomol. 70: 531-532.

King, E. G., J. E. Powell, and R. J. Coleman. 1985. A high incidence of parasitism of Heliothis spp. (Lepidoptera: Noctidae) larvae in cotton in Southeastern Arkansas. Entomophaga 30: 419-426.

Lentz, G. L., T. F. Watson, and R. V. Carr. 1974. Dosage-mortality studies of laboratory-reared larvae of the tobacco budworm and the bollworm. J. Econ. Entomol. 67: 719-720.

Miller, T. A., and M. E. Adams. 1982. Mode of action of pyrethroids, pp. 3-27. In J. R. Coats (ed.), Insecticide Mode of Action. Academic Press. New York.

Miller, T. A., V. L. Salgado, and S. N. Irving. 1983. The kdr factor in pyrethroid resistance, pp. 353-366. In G. P. Georghiou and T. Saito (eds.). Pest Resistance to Pesticides. Plenum Press, New York.

Plapp, F. W., Jr. 1979. Synergism of pyrethroid insecticides by formamidines against Heliothis. J. Econ. Entomol. 72: 667-670.

Plapp, F. W., Jr., and D. L. Bull. 1978. Toxicity and selectivity of some insecticides to Chrysopa carnea, a predator of the tobacco budworm. Environ. Entomol. 7: 431-434.

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: 381-384.

Powell, J. E., E. G. King, and C. S. Jany. 1986. Toxicity of insecticides to adult Microplitis croceipes (Hymenoptera: Braconidae). J. Econ. Entomol. 79: 1343-1346.

Powell, J. E., and W. P. Scott. 1985. Effects of insecticide residues on survival of Microplitis croceipes adults (Hymenoptera: Braconidae) in cotton. Fla. Entomol. 68: 692-693.

Sparks, T. C., S. S. Quisenberry, J. A. Lockwood, R. L. Byford, and R. T. Roush. 1985. Insecticide resistance in the horn fly, Haematobia irritans. J. Agric. Entomol. 2: 217-233.

Sparks, T. C., A. V. Pavloff, R. L. Rose, and D. F. Clower. 1983. Temperature-toxicity relationships of pyrethroids on Heliothis

virescens (F.) (Lepidoptera: Noctuidae) and Anthonomus grandis grandis Boheman (Coleoptera: Curculionidae). J. Econ. Entomol. 76: 243-246.

Whitten, C. J., and D. L. Bull. 1970. Resistance to organophosphorus insecticides in tobacco budworms. J. Econ. Entomol. 63: 1492-1495.

Whitten, C. J., and D. L. Bull. 1974. Comparative toxicity, absorption, and metabolism of chlorpyrifos and its dimethyl homologue in methyl parathion resistant and susceptible tobacco budworms. Pestic. Biochem. Physiol. 4: 266-274.