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Residual Toxicity of Cyfluthrin Wettable Powder Against *Tribolium confusum* (Coleoptera: Tenebrionidae) Exposed for Short Time Intervals on Concrete*

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Abstract—Adults of *Tribolium confusum* du Val, the confused flour beetle, were exposed to concrete treated with 100, 150, and 200 mg cyfluthrin 20% WP (20, 30, and 40 mg[a.i.]) per m² for 0.5, 1.0, 2.0, and 4.0 h at tri-weekly intervals for 24 weeks after the concrete was treated. Exposure temperature was approximately 22°C and relative humidity was approximately 60%. At the lowest application rate of 100 mg, the percentage of beetles that were still active after 0.5 h of exposure ranged from 78 to 100% during the study. Except for week 1, knockdown at 24 and 48 h post-exposure was at least 82%, and recovery at 168 h post-exposure was 23 to 53%. As exposure interval and application rate increased there was a corresponding decrease in both the percentage of beetles that were upright and running when they were removed from the panel and the percentage that had recovered from knockdown at 168 h post-exposure. All beetles exposed for 1.0, 2.0, and 4.0 h on concrete treated at 200 mg per m² were inactive at 168 h post-exposure. Of the 48 treatment combinations (four exposure times, four post-exposure observations, three application rates), only seven were significant ($P < 0.05$) with respect to weeks post-treatment. © 1998 Published by Elsevier Science Ltd

INTRODUCTION

The confused flour beetle, *Tribolium confusum* du Val, is a major insect pest of flour mills, processing plants, and indoor food warehouses. Infestations are often controlled either by fumigating with methyl bromide or phosphine, using timed aerosol applications of synergized pyrethrins, or by treating flooring surfaces with a residual insecticide. Currently the only insecticide registered in the United States as a broad-scale treatment to flooring surfaces is the pyrethroid cyfluthrin. It is available in emulsifiable concentrate (EC) or wettable powder (WP) formulations. Cyfluthrin can be more toxic than other pyrethroids against *T. confusum*; in one test where bioallethrin, flucythrinate, fenvalerate, cypermethrin, and cyfluthrin were diluted in acetone and applied on filter paper, cyfluthrin had the lowest LD_{50} for beetles exposed for 24 h at 20 and 30°C (Subramanyam and Cutkomp, 1987).

Several researchers have noted the general superiority of WPs compared to ECs on various treated surfaces and the rapid degradation on alkaline concrete (Watters, 1976; White, 1982; Williams *et al.*, 1983; Jain and Yadav, 1989; Barson, 1991). Cyfluthrin WP also gives better residual control of *T. confusum* on concrete surfaces than cyfluthrin EC (Arthur, 1994). Most mills and

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processing plants have concrete floors, and when cyfluthrin is used to control *T. confusum*, the entire floor is not normally treated with the insecticide. Treatments are usually made in those areas where there is a specific problem. It is possible for insects to enter a treated area and escape before they are directly affected by the insecticide residues. The objectives of this study were to determine: (1) The toxicity of cyfluthrin WP on concrete to *T. confusum* exposed for discrete time periods; (2) if short-term exposure would cause eventual mortality when beetles were not knocked down at the completion of the exposure interval; and (3) residual toxicity at a range of application rates as specified by the insecticide label.

MATERIALS AND METHODS

Fifteen square concrete panels (0.094 m^2 by 0.64 cm deep) were constructed by pouring ready-mix concrete into the plywood forms and leveling the surface. Four panels were treated with 20% cyfluthrin WP at the rate of 100 mg per m^2 (20 mg[a.i.]), which is proportional to the lowest label rate of 9.5 g per 94 m^2 (1000 ft^2). Treatments were made by using a spray system equipped with a Teejet nozzle 650033 (Spraying Systems, Wheaton, IL) to spray 3.8 ml of formulated solution onto the panel, which was proportional to the label rate of 40 ml of formulated spray per m^2 (1 gallon per 1000 ft^2). One untreated panel was used as the control for this application rate.

One day after treatment (week 0), four 75 mm diameter by 25 mm tall uncovered glass rings were placed on each panel, and 10 *T. confusum* were placed in each of the four rings. Beetles in the first ring were exposed on the panel for 0.5 h, beetles in the second, third, and fourth rings were exposed

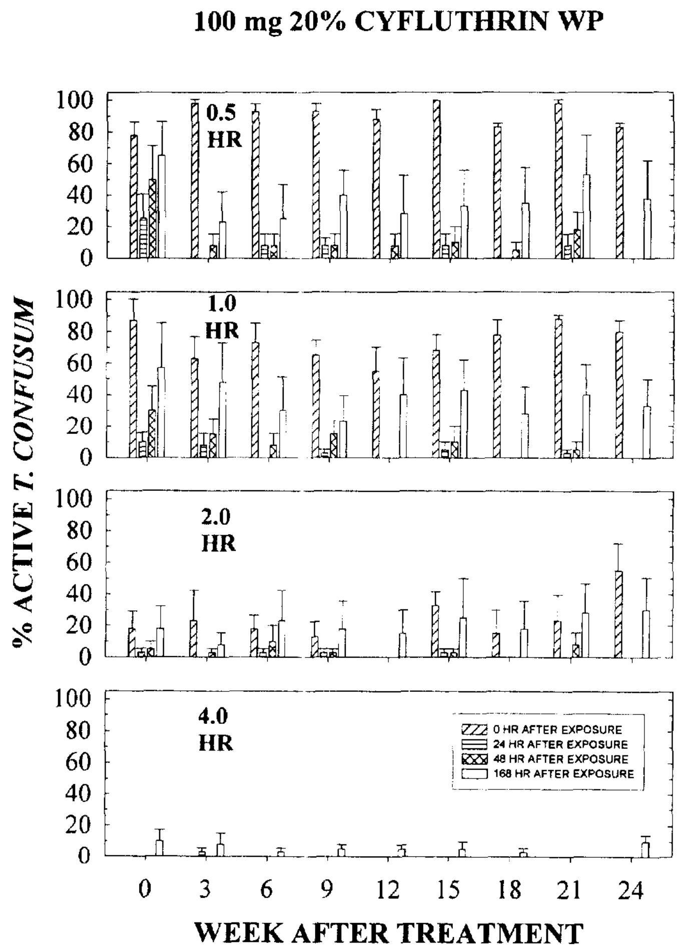

Fig. 1. Percentage (means ± SEM) of *T. confusum* still active 0, 24, 48, and 168 h after exposure for 0.5, 1.0, 2.0, and 4.0 h on concrete treated with 100 mg cyfluthrin 20% WP per m^2. Residual bioassays conducted at 0, 3, 6, 9, 12, 15, 18, 21, and 24 weeks after treatment.

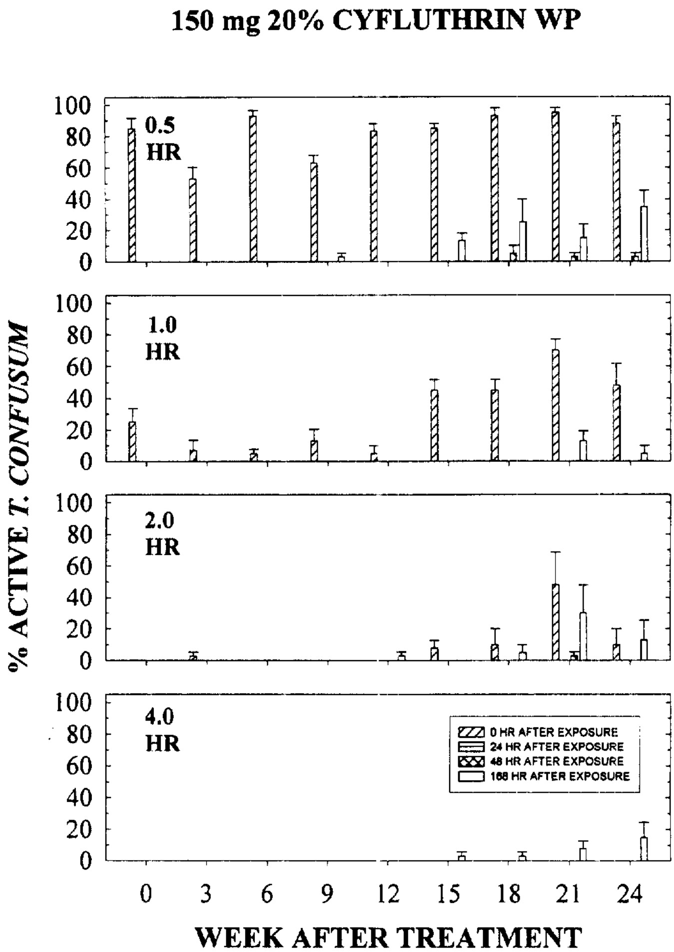

Fig. 2. Percentage (means ± SEM) of *T. confusum* still active 0, 24, 48, and 168 h after exposure for 0.5, 1.0, 2.0, and 4.0 h on concrete treated with 150 mg cyfluthrin 20% WP per m². Residual bioassays conducted at 0, 3, 6, 9, 12, 15, 18, 21, and 24 weeks after treatment.

for 1, 2, and 4 h. After the exposure periods beetles were transferred to standard 100 mm Petri dishes lined with filter paper and classified as active (upright and moving), knocked down (on their backs), or dead + moribund (incapable of moving when prodded). Beetles were not provided with food or water and these assessments were repeated after 24, 48, and 168 h. The beetles were exposed on the concrete and held in the transfer dishes inside the laboratory at approximately 22°C, 60% r.h., 9 h light:15 h dark. After the exposure process was completed, the concrete panels were stored inside a laboratory cabinet until used for the next bioassay in 3 weeks.

The application process was repeated the following week as described above by spraying an intermediate label rate of 150 mg 20% cyfluthrin WP per m^2 (30 mg [a.i.]) on each of four panels. One untreated panel served as the control for this treatment. The exposure procedures and post-exposure observations were as described above. The entire process was repeated the next week by spraying the final concentration of 200 mg 20% cyfluthrin WP (40 mg[a.i.]) per m^2 (the highest label rate) on four of the five remaining concrete panels. The last panel was the untreated control for the 200 mg treatment. Residual bioassays were conducted by repeating the exposure process for all application rates at 3, 6, 9, 12, 15, 18, 21, and 24 weeks after the panels were treated.

The test was analyzed as a split plot model with concentration and exposure time (0.5, 1, 2, 4 h) as main effects and recovery (post-exposure observations at 0, 24, 48, and 168 h) and week (residual bioassays) as repeated measures with the percentage of active beetles as the determining variable. Control mortality was 0 in all except a few cases. When mortality occurred, corrections were made using Abbott's formula (Abbott, 1925). The Means Procedure of the Statistical Analysis System (SAS Institute, 1987) was used to estimate means and standard errors for each observation.

TableCurve software (Jandel Scientific, San Rafael, CA) was used to fit regression equations with week (x) as the independent variable and y (the percentage of active beetles) as the dependent variable, and to conduct lack-of-fit tests (Draper and Smith, 1981) on these equations. When regression models were not significant the data for weeks were averaged.

RESULTS

Cyfluthrin concentrations (100, 150, and 200 mg per m^2) and exposure time (0.5, 1, 2, and 4 h), and the repeated measures residual recovery (0, 24, 48, and 168 h after exposure), and weekly residual activity were highly significant ($P < 0.01$). When the beetles were exposed for 0.5 h on concrete treated at the lowest label rate of 100 mg per m^2, the percentage that were still upright and running immediately after exposure was 78 to 100% during the 24-week testing period (Fig. 1). Except for week 1, the majority of the beetles were knocked down at 24 and 48 h post-exposure, but 23 to 68% of them recovered by 168 h. However, recovery did not follow a consistent pattern with respect to week. As the exposure time increased from 0.5 to 2 h, the percentage of beetles that were still upright and running when they were removed from the concrete gradually decreased. Recovery at 168 h post-exposure also decreased. All beetles were knocked down after 4 h of exposure, although a small percentage eventually recovered and were active at 168 h post-exposure.

At the application rate of 150 mg per m^2, 55 to 95% of beetles were upright and running after 0.5 h of exposure, but recovery at 168 h post-exposure did not exceed 35% (Fig. 2). Most beetles were affected by the insecticide after the 1- and 2-h exposures, except for week 21 in the 1-h exposure. In all but five cases, knockdown was 100% at 24 and 48 h post-exposure. All beetles were knocked down after 4 h of exposure. Results were similar at the highest label application rate of 200 mg per m^2; nearly all beetles still active after being exposed for 0.5 and 1.0 h were knocked down at the three post-exposure intervals (Fig. 3). No beetles were active after the 2.0 h exposures, except for 5 $\pm$ 5.0% at week 1 and 5 $\pm$ 2.9% at week 10, and at 4 h there was no activity at any post-exposure interval.

Only seven of the possible 48 treatment combinations (four exposure times, four post-exposure observations, three application rates), all at the 150-mg application rate, were significant with respect to week ($P < 0.05$, Table 1). Therefore, means and standard errors for the 41 non-significant combinations were estimated by combining data for individual bioassays at the three-week intervals (Table 2). There was no correlation between the percentage of beetles that was still active after 0.5 h exposure and the percentage that was active at 168 h post-exposure, but there was significant

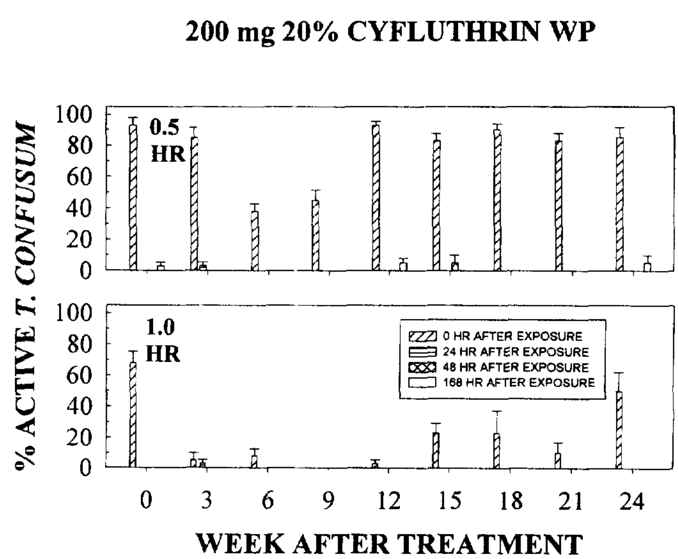

Fig. 3. Percentage (means $\pm$ SEM) of *T. confusum* still active 0, 24, 48, and 168 h after exposure for 0.5 and 1.0 h on concrete treated with 200 mg cyfluthrin 20% WP per m^2. Residual bioassays conducted at 0, 3, 6, 9, 12, 15, 18, 21, and 24 weeks after treatment.

Table 1. Linear regression models ($y = a + bx$) for the percentage of active *T. confusum* exposed on concrete treated with 150 mg of 20% cyfluthrin WP per m^2 at seven hourly exposure and post-exposure recovery combinations

Exposure (h)	Recovery (h)	a	b	r^2	Max. r^2	% of Max.
0.5	0	70.1 ± 4.7	0.9 ± 0.3	0.20	0.72	27.8
	168	−6.2 ± 4.4	1.6 ± 0.3	0.37	0.50	74.0
1.0	0	3.1 ± 6.5	2.2 ± 0.4	0.42	0.74	56.8
	168	−2.0 ± 1.9	0.3 ± 0.1	0.16	0.43	37.2
2.0	0	−4.9 ± 5.9	1.1 ± 0.4	0.18	0.49	36.7
	168	−4.4 ± 4.7	0.8 ± 0.3	0.16	0.35	45.7
4.0	168	−2.9 ± 2.2	0.5 ± 0.2	0.23	0.35	65.7

The percentage of actives is the dependent variable (y) and week (0 to 24) is the independent variable (x). Actual r^2s are listed, along with the maximum available r^2 (max) and the actual r^2 as a percentage of the maximum.

Table 2. The percentage (± SEM) of active *T. confusum* 0, 24, 48, and 168 h after exposure for 0.5, 1, 2, and 4 h on concrete treated with 100, 150, and 200 mg cyfluthrin per m^2

		Application rate (mg m^{-2})		
Exposure (h)	Recovery (h)	100	150	200
0.5	0	90.0 ± 1.8	Reg**[a]	76.9 ± 3.6
	24	6.1 ± 2.4	0	0.3 ± 0.2
	48	12.5 ± 3.8	1.1 ± 0.7	0.6 ± 0.5
	168	37.5 ± 6.8	Reg**	1.4 ± 0.7
1.0	0	72.3 ± 3.7	Reg**	20.8 ± 4.4
	24	2.9 ± 1.2	0	0.3 ± 0.2
	48	8.6 ± 2.7	0	0
	168	37.1 ± 6.3	Reg**	0
2.0	0	21.7 ± 4.5	Reg**	1.1 ± 0.7
	24	1.1 ± 0.5	0	0
	48	3.3 ± 0.5	0	0
	168	20.0 ± 5.3	Reg**	0
4.0	0	0	0	0
	24	0	0	0
	48	0	0	0
	168	0	Reg**	0

The means are listed because regression models were not significant with respect to week ($P > 0.05$).
[a] Regressions significant ($P < 0.05$), equations listed in Table 1.

positive correlation between these two percentages for beetles exposed for 1 and 2 h at the 100 and 150-mg application rates (Table 3).

DISCUSSION

Knockdown and mortality of *T. confusum* increased as the application rate of cyfluthrin WP applied on concrete increased from 100 to 150 to 200 mg per m^2 and as the exposure interval increased from 0.5 to 4 h. *Tribolium confusum* also exhibited a delayed toxic response when it was still active after being removed from the treated concrete. Delayed toxicity could be important when cyfluthrin is applied inside mills and processing plants to control *T. confusum*. Because short

Table 3. Correlation coefficient (r) and probability (P) between the percentage of active *T. confusum* after being exposed for 0.5, 1.0, and 2.0 h and the percentage of active beetles at 168 h post-exposure at each application rate of cyfluthrin

Application rate (mg)	Exposure (h)[a]	r	P
100	0.5	0.19	0.24
	1.0	0.58	0.01
	2.0	0.63	0.01
150	0.5	0.29	0.08
	1.0	0.39	0.02
	2.0	0.92	0.01
200	0.5	0.32	0.06

[a] Survival at the exposure times not listed was always 0, therefore correlation was also 0.

exposure intervals will cause mortality, it may be possible to control infestations of *T. confusum* by treating small areas within an indoor environment.

Barson (1991) also showed a general increase in knockdown and a delayed toxic response of adult *Oryzaephilus surinamensis* (L.) exposed for increasing time periods on filter papers treated with commercial formulations of four organophosphorus insecticides. Exposure time should be considered along with application rate when residual chemicals are evaluated for control of a particular insect species on flooring surfaces, because of the possibility that insects could encounter a treated area yet leave before they are knocked down. Refugia in and around mills and storage facilities can harbor insect populations that may move onto treated surfaces (Pinniger, 1974). At lower application rates, the actual treated area may have to be enlarged to prevent insects from escaping the treated surface. However, if the chemical has delayed toxicity, the insects would absorb enough of the residues to cause knockdown and eventual mortality.

Cyfluthrin WP gave excellent residual control on fresh concrete, in contrast to most organophosphorus insecticides that break down rapidly when applied to new concrete surfaces. Many previous studies have stated that new concrete is alkaline, which helps to hydrolyze the residues and reduce residual efficacy (Burkholder and Dicke, 1966; Lemon, 1967; Okwelogu, 1968; Kilgore and Ming-yu, 1976; White, 1988). As concrete ages, it becomes covered with trash material and may become more neutral in pH, thereby reducing hydrolysis and breakdown. Residual efficacy of organophosphate insecticides on aged concrete surfaces in field sites may also be dependent on climate and internal environmental conditions (Cogburn, 1972).

Mills and processing plants in the United States are usually fumigated with methyl bromide to control insect pests. However, the impending global restrictions on the manufacture and use of methyl bromide will have an impact on pest management programs. The other common grain fumigant, phosphine, cannot be used to fumigate mills because it can destroy electrical wiring. Synergized pyrethrin aerosols are also used in pest control programs, but the piperonyl butoxide synergist used in pyrethrin formulations is currently under review by the U.S. Environmental Protection Agency. These legislative and regulatory actions may affect the use of fumigants and aerosols as insecticidal treatments for indoor structures. Results of this study show that residual applications of cyfluthrin WP could be used to control *T. confusum* and may be an alternative to fumigation or aerosol treatments.

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