

Barrier Efficacy of Pyrethroid and Organophosphate Formulations Against Subterranean Termites (Isoptera: Rhinotermitidae)

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ABSTRACT In a laboratory bioassay, termites were allowed to tunnel into a 5-cm core sample of sand (pH 8.1) treated with termiticides following an application protocol before construction. Termiticides (active ingredient) tested were: Dursban TC (chlorpyrifos), XRM-5160 (chlorpyrifos), Equity (chlorpyrifos), Dagnet FT (permethrin), Prevail FT (cypermethrin), Biflex FT (bifenthrin), Pryfon 6 (isofenphos), Demon TC (cypermethrin), PP321 (lambda-cyhalothrin), and Sumithion 20MC (fenitrothion). Because the vertical integrity of the treated sand was maintained, termites were exposed to termiticides in the same orientation as would occur under field conditions. Results 3 h after the termiticide application indicated that all formulations of termiticides tested provide equal barrier protection against the eastern subterranean termite, *Reticulitermes flavipes* (Kollar). The Formosan subterranean termite, *Coptotermes formosanus* Shiraki, however, generally tunneled deeper into sand treated with organophosphates than sand treated with pyrethroid termiticides. Treated plots were covered by concrete slabs for 1 yr. Results of a second bioassay with the 1-yr-old samples indicated the loss of barrier efficacy of the isofenphos treatment against both termite species. Possible factors that contributed to isofenphos degradation are alkaline sand, high precipitation, and microbes.

KEY WORDS *Coptotermes formosanus*, *Reticulitermes flavipes*, soil termiticide

CHEMICAL STABILITY OF TERMITICIDES in soil is the critical characteristic required for long-term preventative protection against subterranean termites. To evaluate residual toxicity, Hetrick (1950, 1952, 1957), who adapted Hockenyos' (1939) method, placed soil treated with termiticides in glass jars that were stored beneath buildings for extended periods. Candidate termiticides were evaluated by exposing termites to treated soil in the same glass jars. The ability of termites to tunnel into treated soil was not included in the evaluation. Instead, termite mortality was the sole variable for determining efficacy with this early method.

Termiticides currently in use include pyrethroids that repel termites from tunneling into treated soil (Su & Scheffrahn 1990). Because of the importance of assessing the behavioral responses of termites to termiticide treatment, tunneling ability through treated soil has been included as the evaluation variable in more recent laboratory bioassays (Su et al. 1982, Tamashiro et al. 1987, Jones 1988, Smith & Rust 1990, Su & Scheffrahn 1990, Grace 1991).

The U.S. Environmental Protection Agency (EPA) generally requires that termiticides be evaluated with "ground board" or "concrete slab" tests as conducted by the USDA Forest

Service at several nationwide sites (Kard et al. 1989). In these tests, a termiticide concentration is considered failed when >5 of the 10 replicates were penetrated by field populations of subterranean termites (Kard et al. 1989). These field tests simulate field conditions and are designed to provide realistic efficacy data. Because it is difficult to find a field site in which foraging activity by subterranean termites is uniform over the entire soil surface, Kard et al. (1989) replicated each termiticide concentration 10 times in a randomized-block design. Nonetheless, the lack of termite penetration into treated soil cannot always be attributed to effectiveness of the termiticide. This may be true especially for the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, whose feeding pattern is usually more aggregated at a given food source than that of the eastern subterranean termite, *Reticulitermes flavipes* (Kollar) (Delaplane & La Fage 1989). To overcome the unpredictability of field population behavior, Tamashiro et al. (1987) devised a laboratory bioassay to evaluate *C. formosanus* tunneling into treated soil that had been weathered under a concrete slab.

In this study, selected termiticides were applied onto soil following a preconstruction protocol (NPCA 1985) and covered with small con-

crete slabs. A bioassay was used to evaluate the barrier efficacy of the treated soil against *C. formosanus* and *R. flavipes*.

Materials and Methods

Termiticides (active ingredient and solution concentration applied) tested were: Dursban TC (Termiticide Concentrate) (chlorpyrifos, 1%; DowElanco, Indianapolis, IN), XRM-5160 (chlorpyrifos, 0.75%; DowElanco), Equity (chlorpyrifos, 1%; DowElanco), Dagnet FT (For Termites) (permethrin, 0.5%; FMC Corporation, Princeton, NJ), Prevail FT (cypermethrin, 0.3%; FMC), Biflex FT (bifenthrin, 0.031%; FMC), Pryfon 6 (isofenphos, 0.75%; Miles, Kansas City, MO), Demon TC (cypermethrin, 0.25% and 0.5%; ICI Americas, Wilmington, DE), PP321 (lambda-cyhalothrin, 0.125% and 0.25%; ICI Americas), and Sumithion 20 MC (Microcapsule) (fenitrothion, 1.6%; Sumitomo Chemical, Osaka, Japan). Dursban TC, Equity, Dagnet FT, Pryfon 6, Demon TC, and Prevail FT are commercially registered termiticides in the United States. Sumithion 20 MC is registered in Japan. The remainder of the formulations are experimental products that are not currently registered as termiticides. Chlorpyrifos, isofenphos, and fenitrothion are organophosphates. Permethrin, cypermethrin, bifenthrin, and lambda-cyhalothrin are pyrethroids.

Termiticide solutions were prepared following label instructions and applied to a 5-cm thick plot (40 cm by 40 cm at the top and 50 cm by 50 cm at the bottom) of fill-grade sand that consisted mostly of quartz and calcium carbonate (pH 8.1). Termiticides were applied at a rate of 4.07 liter/m² to simulate the commercial application of preconstruction termiticide treatments (NPCA 1985). The sand contains virtually no organic matter (<0.5%; Anonymous 1984) and is commonly used as a construction substrate in south Florida. Three replicates of each termiticide formulation plus a water control were applied to sand plots to yield a total of 39 plots. The field site was located at the Ft. Lauderdale Research and Education Center, University of Florida, Ft. Lauderdale, FL. The mean monthly precipitation in 1991 was 16.9 cm. The mean monthly temperature ranged from 21.4°C in February to 28.6°C in August.

Three hours after application, 5 cm of sand was core-sampled from each plot with a clear polystyrene tube (1.6 cm i.d. by 11.5 cm long). Four core samples (two subsamples each for two termite species) were taken at random from each sand plot. The holes from which sand samples were taken were filled with similar empty polystyrene tubes (5 cm long) capped on both ends to maintain the integrity of the sand. After the samples were taken, the plot was covered with 6-mil thick polyethylene that served as a foundation-

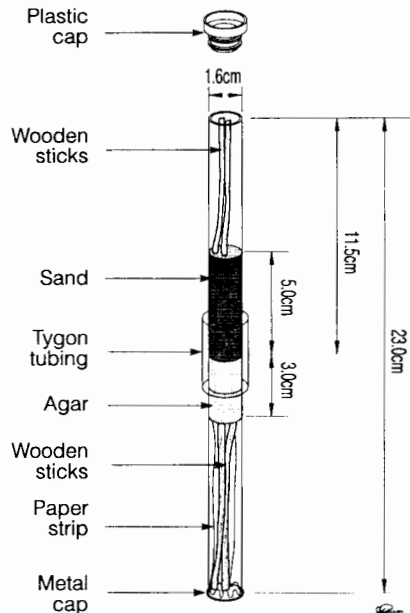


Fig. 1. Bioassay unit composed of sand core tube (upper portion) and termite loaded tube (lower portion) fastened by a Tygon tubing collar.

type vapor barrier. A volume of freshly mixed concrete (50 by 50 cm by 10 cm) was poured over each plot and over two steel bars (1.2 cm diameter by 60 cm long) that penetrated and reinforced the concrete slabs as they hardened. Two layers of fiberglass insulation pads (Manville R-19; 15 cm thick), secured by a plastic net, were placed on each concrete slab to simulate climatic conditions expected for the slabs on which a building is erected. One year after the termiticide application, the concrete slabs were gently lifted by using the steel bars as handles. The polyethylene film was removed to sample sand from each treatment plot. After sand samples were taken, the polyethylene film and the concrete slab were repositioned over the plot.

The tube containing core-sampled sand was connected by a Tygon tubing collar to an identical plastic tube containing 80 workers (plus four and one soldier for *C. formosanus* and *R. flavipes*, respectively). A 3-cm agar segment was placed at the attached end of the tube that contained termites; wooden sticks and a paper strip were provided for termites as food and harborage (Fig. 1). Termites were collected from field colonies in Hallandale and Ft. Lauderdale, FL, for *C. formosanus* and *R. flavipes*, respectively. Two sand subsamples were collected from each plot for each of the two termite species. Samples collected 3 h after treatment and 1 yr later were tested separately. The test was replicated three times by plot for each termiticide by formulation by concentration combination. The test units were held vertically at $28 \pm 1^\circ\text{C}$ for 1 wk. The

Table 1. Vertical distance of sand not penetrated by *C. formosanus* or *R. flavipes* and the associated mortality after a 1-wk laboratory bioassay in which termites were exposed to a 5-cm core sample treated with a termiticide 3 h before bioassay

Treatment ^a	Concn, %	<i>C. formosanus</i>		<i>R. flavipes</i>	
		Distance, cm	Mortality, %	Distance, cm	Mortality, %
CTL	0	0.0 ± 0.0a	9.8 ± 2.3a	0.0 ± 0.0a	9.8 ± 3.4a
PRF ^b	0.75	2.9 ± 0.3b	88.3 ± 6.5b	4.8 ± 0.1b	95.0 ± 2.8d
SUM ^b	1.6	3.6 ± 0.3c	69.8 ± 8.9b	4.9 ± 0.1b	95.0 ± 1.9d
XR6 ^b	0.75	4.0 ± 0.3cd	81.3 ± 12.8b	4.9 ± 0.0b	89.4 ± 10.6d
EQT ^b	1.0	4.5 ± 0.3de	71.0 ± 12.2b	4.9 ± 0.1b	100.0 ± 0.0d
DUS ^b	1.0	4.6 ± 0.2e	79.8 ± 10.1b	5.0 ± 0.0b	91.9 ± 8.1d
BFX ^c	0.031	4.6 ± 0.2e	17.9 ± 6.1a	5.0 ± 0.0b	17.7 ± 3.2ab
PP3 ^c	0.125	4.9 ± 0.0e	12.5 ± 2.2a	5.0 ± 0.0b	32.5 ± 8.3bc
PP3 ^c	0.25	5.0 ± 0.0e	13.1 ± 1.4a	5.0 ± 0.0b	50.0 ± 12.1c
PRV ^c	0.3	4.9 ± 0.0e	7.5 ± 1.4a	5.0 ± 0.0b	15.4 ± 3.9ab
DEM ^c	0.25	5.0 ± 0.0e	8.3 ± 2.4a	5.0 ± 0.0b	14.6 ± 4.0ab
DEM ^c	0.5	5.0 ± 0.0e	13.8 ± 2.7a	5.0 ± 0.0b	23.1 ± 8.8ab
DRG ^c	0.5	5.0 ± 0.0e	11.0 ± 2.0a	5.0 ± 0.0b	11.3 ± 2.9a

Values are means of six samples (two subsamples each of three replicates). Means followed by the same letter within a column are not significantly different ($P = 0.05$; Fisher's least significant difference test [SAS Institute 1987]).

^a CTL, Control; PRF, Prylon 6; SUM, Sumithion 20 MC; XR6, XRM-5160; EQT, Equity; DUS, Dursban TC; BFX, Biflex FT; PP3, PP321; PRV, Prevail FT; DEM, Demon TC; DRG, Dagnet FT.

^b Organophosphates.

^c Pyrethroids.

distance of sand not tunneled through by termites (measured from the top of the sand sample) and the termite mortality at 1 wk were subjected to analysis of variance for a completely randomized design. Significant differences ($P < 0.05$) among means were separated by Fisher's least significant difference test (SAS Institute 1987).

Results and Discussion

Sand Sampled 3 H After Termiticide Treatment. Distance not penetrated in the treated sand by termites and the associated mortality are summarized in Table 1. Except for Dursban and Equity, *C. formosanus* generally tunneled less in sand treated with pyrethroid products (Biflex, PP321, Prevail, Demon, and Dagnet) than with organophosphate termiticides (Prylon, Sumithion, and XRM-5160) ($F = 54.9$; $df = 12, 65$; $P < 0.05$). Pyrethroids caused lower mortality in *C. formosanus* than the organophosphates ($F = 24.7$; $df = 12, 65$; $P < 0.05$) because termites were repelled by the former, resulting in reduced contact. The *R. flavipes* workers did not tunnel significantly into sand treated with any of the tested termiticides ($F = 1078$; $df = 12, 65$; $P < 0.05$). Significantly more *R. flavipes* were killed after exposure to the organophosphates than those exposed to pyrethroids ($F = 34.5$; $df = 12, 65$; $P < 0.05$). The results confirmed our previous conclusion that termites are repelled by pyrethroid barriers, whereas organophosphates prevent termite incursion by lethal contact (Su & Scheffrahn 1990).

Sand Sampled 1 Yr After Termiticide Treatment. One year after the termiticide application, sand treated with Prylon was completely pene-

trated by both termite species (Table 2). The absence of the termiticidal effects of Prylon was further demonstrated by the mortalities similar to the controls. Termites penetrated significantly deeper into sand treated with Biflex and the organophosphate products than with other pyrethroid products ($F = 13.1$ and 22.4 for *C. formosanus* and *R. flavipes*, respectively; $df = 12, 65$; $P < 0.05$). Mortality in the groups treated with organophosphate, as observed above, was higher than that of termites exposed to pyrethroids ($F = 53.1$ and 22.6 for *C. formosanus* and *R. flavipes*, respectively; $df = 12, 65$; $P < 0.05$). Except for Biflex, termites penetrated very little into sand treated with the pyrethroid products. Results of Biflex were more similar to those of organophosphates and likely result from the low application rate (0.031%). Data from 1-yr-old samples were consistent with results from sand sampled 3 h after the termiticide application. Kard et al. (1989) reported that soil treated with isofenphos (0.5 and 1.0% solutions) and covered with concrete slabs was not penetrated by field populations of subterranean termites for >5 yr. Contrary to their results, our data showed the lack of termiticidal activity in sand treated with Prylon (isofenphos) 1 yr after application. The inconsistency indicated the degradation of isofenphos in our sand but not in soil tested by Kard et al. (1989).

Soils tested by Kard et al. (1989) were characterized as approximately neutral to moderately acidic. (Mauldin et al. 1987). Because of the significant calcium carbonate content, sand used in our test was alkaline (pH ≈ 8.1). Abou-Assaf & Coats (1987) reported a partial degradation of isofenphos in both alkaline (pH 8) and acidic (pH

Table 2. Vertical distance of sand not penetrated by *C. formosanus* or *R. flavipes* and the associated mortality after a 1-wk laboratory bioassay in which termites were exposed to a 5-cm core-sample treated with a termiticide 1 yr before bioassay

Treatment ^a	Concn, %	<i>C. formosanus</i>		<i>R. flavipes</i>	
		Distance, cm	Mortality, %	Distance, cm	Mortality, %
CTL	0	0.0 ± 0.0a	4.4 ± 1.9a	0.0 ± 0.0a	11.5 ± 5.1a
PRF ^b	0.75	0.0 ± 0.0a	5.2 ± 1.1a	0.0 ± 0.0a	8.8 ± 4.6a
SUM ^b	1.6	3.6 ± 0.7bc	94.0 ± 3.1b	4.6 ± 0.4cd	98.3 ± 0.9d
XR6 ^b	0.75	2.5 ± 0.6b	87.3 ± 6.9b	3.8 ± 0.5bc	94.0 ± 2.8d
EQT ^b	1.0	2.6 ± 0.9b	90.4 ± 9.3b	3.9 ± 0.6bc	97.3 ± 2.5d
DUS ^b	1.0	2.9 ± 0.8b	82.7 ± 11.3b	2.8 ± 0.7b	96.7 ± 3.3d
BFX ^c	0.031	3.0 ± 0.9b	12.1 ± 3.2a	3.8 ± 0.8bc	22.3 ± 12.6ab
PP3 ^c	0.125	5.0 ± 0.0c	8.5 ± 2.2a	5.0 ± 0.0d	26.3 ± 5.7abc
PP3 ^c	0.25	5.0 ± 0.0c	7.9 ± 0.6a	5.0 ± 0.0d	44.4 ± 13.6c
PRV ^c	0.3	5.0 ± 0.0c	6.3 ± 1.1a	5.0 ± 0.0d	21.3 ± 9.7ab
DEM ^c	0.25	5.0 ± 0.0c	9.2 ± 2.0a	5.0 ± 0.0d	18.3 ± 7.9ab
DEM ^c	0.5	5.0 ± 0.0c	11.3 ± 4.3a	5.0 ± 0.0d	36.5 ± 12.0bc
DRG ^c	0.5	4.8 ± 0.1c	11.5 ± 7.1a	5.0 ± 0.0d	13.1 ± 6.0a

Values are means of six samples (two subsamples each of three replicates). Means followed by the same letter within a column are not significantly different ($P = 0.05$; Fisher's least significant difference test [SAS Institute 1987]).

^a CTL, Control; PRF, Pryfon 6; SUM, Sumithion 20 MC; XR6, XRM-5160; EQT, Equity; DUS, Dursban TC; BFX, Biflex FT; PP3, PP321; PRV, Prevail FT; DEM, Demon TC; DRG, Dragnet FT.

^b Organophosphates.

^c Pyrethroids.

6) soil at high temperature (>25°C). The high pH in our test soil may be responsible for the loss of the isofenphos termiticidal activity. However, data of Abou-Assaf & Coats (1987) do not explain the inconsistency of our data and those of Kard et al. (1989), whose test soil was, in part, acidic.

Isofenphos is more soluble in water (18 ppm) than the other termiticides tested (1.2 ppm for chlorpyrifos, and <1 ppm for pyrethroids). Sumithion is virtually insoluble in water because of its microencapsulated formulation. Because of the subtropical climate in south Florida, the occasional torrential rains may have contributed to the leaching of isofenphos into the surrounding soil. The highest daily precipitation in 1991, for example, was 16.6 cm on 8 October.

Another possible explanation for the loss of the isofenphos biological activity in our soil is microbial degradation. Chapman et al. (1986) reported the rapid degradation of isofenphos in soil previously treated with this organophosphate. Subsequent studies indicated that soil bacteria such as *Pseudomonas* sp. and *Arthrobacter* sp. (Racke & Coats 1987, 1988) adapted to the previous treatment were capable of using isofenphos as a growth substrate (Niemczyk & Chapman 1987). Because the construction sand we used contained extremely little organic matter (<0.5%) (Anonymous 1984), populations of microbial fauna in our sand were probably low at the time of termiticide application. Given the sparse microbial fauna, the application of isofenphos may have provided an adequate growth substrate to produce a selected microbial population >1 yr and greatly reduce the parent insecticide initially applied.

In the bioassay described here, termites were exposed to core-sampled sand in which the integrity of termiticide distribution was maintained. Distance of sand that was not tunneled by termites, therefore, represents the "thickness" of protection provided by soil termiticides. After the tube bioassay, the termite-exposed sand was divided into three equal sections which were subjected to chemical assay for active ingredient concentration. Our preliminary results (Su et al., unpublished data) indicated that termiticides in soil are fairly unevenly distributed depending on the termiticide formulation.

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