

Comparison of Eleven Soil Termiticides Against the Formosan Subterranean Termite and Eastern Subterranean Termite (Isoptera: Rhinotermitidae)

NAN-YAO SU AND RUDOLF H. SCHEFFRAHN

Fort Lauderdale Research and Education Center, University of Florida,
Institute of Food and Agricultural Sciences, Fort Lauderdale, Florida 33314

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ABSTRACT Toxicities of 11 topically applied termiticides to the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, and the eastern subterranean termite, *Reticulitermes flavipes* (Kollar) were determined. At LD_{50} , deltamethrin was most toxic (0.12 and 0.01 $\mu\text{g/g}$ for *C. formosanus* and *R. flavipes*, respectively), while chlordane was least toxic (LD_{50} : 45.34 and 20.10 $\mu\text{g/g}$, respectively). *R. flavipes* was more susceptible to all termiticides than *C. formosanus*. The relative susceptibility of the two termite species (*C. formosanus* $LD_{50} \div R. flavipes$ LD_{50}) ranged from 2.0 (chlorpyrifos) to 12.9 (bifenthrin). In a tunneling test in which termites were given a choice of penetrating or avoiding treated soil, all nine pyrethroids tested were repellent at sublethal doses. At appropriate concentrations, termites did not penetrate soil treated with pyrethroids and did not contact the toxicant. Significant mortality was mostly observed as termites tunneled through deposits of chlordane and chlorpyrifos and were killed by constant exposure. Soil treated with chlordane was most vulnerable to termite tunneling activity. Both termite species penetrated the 5 cm soil treated with 10 ppm permethrin, while deltamethrin and cyhalothrin totally stopped tunneling by *R. flavipes* at the concentrations as low as 0.4-0.8 ppm.

KEY WORDS Insecta, *Coptotermes formosanus*, *Reticulitermes flavipes*, tunneling response

FOR NEARLY FOUR DECADES, treatment of soil with termiticides has been the conventional technique for control of subterranean termites. Two cyclodienes, chlordane and heptachlor, have been used for this purpose since 1952. The organophosphate chlorpyrifos became available in 1980, but the cyclodienes continued to be used heavily until their withdrawal in 1987. Two organophosphates and three pyrethroids are currently marketed as termiticides under six brand names for the pest control industry. These termiticides are typically applied to soil beneath or surrounding building foundations to protect structures from subterranean termites.

Organophosphates such as chlorpyrifos kill termites quickly upon contact, resulting in a large number of corpses in a localized area. A previous study with the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, indicated that factor(s) from decomposing termite corpses repelled additional nestmates from the treatment zone (Su et al. 1982). In comparison, pyrethroids are repellents that deter termites from penetrating treated substrates. Although the mechanism by which organophosphates and pyrethroids affect termites may differ, both provide effective protection of structures from subterranean termites when properly applied in the soil.

The longevity of termiticides in soil, an important factor for the evaluation of soil termiticides,

has been monitored extensively under various environmental conditions (Mauldin et al. 1987, Tamashiro et al. 1987). Few data, however, are available for the concentration-dependent toxicity and repellency of termiticides. In a choice test, Jones (1988) demonstrated that permethrin was a repellent. Smith & Rust (1990) provided data on the tunneling activity of the western subterranean termite, *Reticulitermes hesperus* Banks, in soil treated with termiticides. Our study was done to compare the topical toxicity of 11 compounds against *C. formosanus* and the eastern subterranean termite *Reticulitermes flavipes* (Kollar), and to determine the threshold concentrations that impede termite penetration in soil.

Materials and Methods

Beside chlordane (99.9%), the past standard termiticide for subterranean termite control, 10 chemicals were tested. These included four commercially registered termiticides (chlorpyrifos [99.0%], permethrin [94.6%], cypermethrin [92.8%], and fenvalerate [95.0%]), and six experimental pyrethroids (bifenthrin [94.4%], cyhalothrin [89.1%], esfenvalerate [84.0%], silaneophane [90.0%], tralomethrin [27.8%], and deltamethrin [99.2%]). Salveo solvent (27.8%) of tralomethrin was tested in this study, and technical grade materials of other 10 chemicals were used.

Topical Toxicity. Twenty workers (undifferentiated larvae in at least the third instar) per treatment were anesthetized with CO₂ for 30 s before treatment with a 0.5 µl droplet of termiticide solution in acetone at 0–1,000 ppm (wt [AI]/vol). A microapplicator was used to administer the droplet onto the insects' abdomens. A preliminary study with 0, 0.01, 0.1, 1, 10, 100, and 1,000 ppm solutions identified concentration ranges resulting in partial (>0 or <100%) mortalities. Within that range, at least 10 concentrations were then tested for each termiticide applied to termites collected from three colonies of each species. Mean body weight of workers was determined for each colony and species by weighing 5 groups of 10 termites each to the nearest 0.1 mg. Treated termites were transferred to a Petri dish (5.0 cm diameter by 1.5 cm high) containing two cellulose disks moistened with deionized water. The experimental units were held in a constant darkness at 28 ± 1°C. Numbers of dead or moribund workers were recorded and removed from each unit daily for 3 d. Data were subjected to probit analysis (SAS Institute 1985). Volumes (0.5 µl/termite) were converted to doses in µg/g body weight.

Penetration of Treated Soil by Termites. Responses of termites to treated soil were measured in glass tubes (1.4 cm diameter by 15 cm high) containing 5-cm segments of moistened soil sandwiched between two sectors of 7% agar (one measuring 1 cm, the other 3 cm). The device was modified from that described by Tamashiro et al. (1987). Two wooden applicators and a piece of paper (1 cm by 5 cm) were placed into a 5-cm void adjacent to the 3-cm agar. Eighty workers and one soldier were introduced into the 5-cm void at one end of the tube; paper was placed in a 1-cm void at the opposite end. Both ends were closed with metal fixture caps. Soil samples were treated with acetone solutions of each termiticide at selected concentrations before testing. A preliminary test with 0, 0.01, 0.1, 1, 10, and 100 ppm (wt [AI]/wt soil) was done to determine concentration ranges resulting in partial penetration (vertical distance >0 or <5 cm). Five to 10 concentrations (plus control) within that range were then tested for each termiticide. Two subsamples were tested for three colonies each of both termite species. A total of 2,244 tubes (792 for the preliminary study and 1,452 for the narrow-range tests) were prepared for the experiment. The tubes were mounted vertically with termites at the bottom. The experimental units were held at 28 ± 1°C. Observations were made daily for up to 1 wk. The vertical distance of soil penetrated by termites and termite mortality were recorded at the end of the experiment.

Results and Discussion

Topical Toxicity. Mortality in control groups was <10%. Of the 11 termiticides tested, the experimental pyrethroid deltamethrin was the most

toxic. Chlordane was the least toxic. Deltamethrin was approximately 2,000 and 370 times more toxic than chlordane against *R. flavipes* and *C. formosanus*, respectively (Table 1). Chlordane acted most slowly (3 d versus 1–2 d for other termiticides). Among the four commercially registered termiticides, cypermethrin was substantially more toxic than either chlorpyrifos, fenvalerate, or permethrin.

Reticulitermes flavipes was more susceptible to termiticides than *C. formosanus*. The relative susceptibility of the two species (*C. formosanus* LD₅₀ ÷ *R. flavipes* LD₅₀) ranged from 2.0 (chlorpyrifos) to 12.9 (bifenthrin). These results agree with those of Beal & Smith (1971), who reported that cyclo-dienes were more toxic to *Reticulitermes* spp. than *C. formosanus*. Our LD₅₀ for chlorpyrifos against *C. formosanus* (3.39 µg/g; 95% FL, 2.99–3.58) was comparable with those reported by Khoo & Sherman (1979) (2.22–3.18 µg/g). Hutacharern & Knowles (1974) reported an LD₅₀ of 15.4 µg/g for chlorpyrifos against *R. flavipes*. This higher value may reflect counting paralyzed termites as alive and using a different application technique.

Penetration of Treated Soil by Termites. Soil treated with chlordane was most vulnerable to termites' tunneling activity. Both termite species penetrated the entire 5 cm soil treated at 10 ppm (Fig. 1). The threshold concentration, which is defined as the lowest concentration to totally stop termites' penetration, was between 80 and 100 ppm for chlordane against *C. formosanus*, and 40 ppm against *R. flavipes*. Our results agree with the report of Beal & Smith (1971) that *C. formosanus* was less deterred from tunneling through soil treated with chlordane than was *R. flavipes*.

With a threshold concentration of 1 ppm, permethrin was most effective in preventing penetration by *C. formosanus* (Fig. 1). For tunneling of *C. formosanus*, threshold concentrations for tralomethrin, bifenthrin, cypermethrin, or deltamethrin ranged from 6 to 12 ppm (approximately 0.1 that of permethrin). The performance of fenvalerate (threshold concentration, 8–80 ppm) against *C. formosanus* ranged between those of tralomethrin and fenvalerate (threshold concentration, 6–20 and 40–80 ppm, respectively). Chlorpyrifos, silaneophane, and fenvalerate inhibited tunneling by *C. formosanus* at 40–100 ppm.

Both deltamethrin and cyhalothrin were as or more effective than permethrin in inhibiting tunneling of *R. flavipes* (threshold concentration, 0.4–0.8 ppm). Bifenthrin and cypermethrin (threshold concentration, 1–6 ppm) were only slightly less effective than permethrin (Fig. 1). Groups of *R. flavipes* in 10 or 100 ppm treatments with tralomethrin were killed before reaching the soil–agar interface (Fig. 2), indicating movement of this pyrethroid into the agar. Although *R. flavipes* did not move into the treated soil, high mortalities were also observed from groups exposed to 10 and 100 ppm deltamethrin (Fig. 2). Because deltamethrin

Table 1. Response of *C. formosanus* and *R. flavipes* to selected termiticides

Termiticide ^a	<i>C. formosanus</i>				<i>R. flavipes</i>			
	Mean body wt. (mg/worker ± SE)	n	Slope ± SE	LD ₅₀ (95% FL) ^b	Mean body wt. (mg/worker ± SE)	n	Slope ± SE	LD ₅₀ (95% FL) ^b
CLD	3.7 ± 0.3	432	0.046 ± 0.006	45.34 (40.01-50.07)	2.4 ± 0.1	426	0.074 ± 0.016	20.10 (12.83-24.73)
SIL	3.5 ± 0.5	580	0.258 ± 0.029	5.24 (4.46-5.93)	2.4 ± 0.1	293	3.010 ± 0.399	0.95 (0.86-1.03)
CPF	3.5 ± 1.1	406	0.613 ± 0.052	3.39 (2.99-3.58)	2.3 ± 0.1	388	1.125 ± 0.101	1.74 (1.58-1.89)
FNV	3.3 ± 0.9	542	0.379 ± 0.036	2.14 (1.66-2.52)	2.4 ± 0.1	433	4.240 ± 0.424	0.40 (0.37-0.44)
PER	3.4 ± 0.7	408	0.835 ± 0.096	2.03 (1.77-2.26)	2.3 ± 0.1	466	2.970 ± 0.451	0.62 (0.54-0.72)
BIF	3.4 ± 1.0	331	1.980 ± 0.228	0.73 (0.66-0.81)	2.3 ± 0.1	406	19.517 ± 4.083	0.06 (0.04-0.08)
CYP	3.4 ± 0.9	550	1.771 ± 0.155	0.64 (0.57-0.71)	2.3 ± 0.1	628	7.642 ± 0.996	0.13 (0.10-0.15)
SNV	3.3 ± 0.9	513	2.357 ± 0.373	0.56 (0.47-0.64)	2.4 ± 0.1	340	14.592 ± 3.567	0.09 (0.06-0.11)
CYH	3.7 ± 0.4	448	6.539 ± 0.808	0.29 (0.26-0.32)	2.4 ± 0.0	311	33.299 ± 6.700	0.04 (0.03-0.05)
TRL	4.4 ± 1.1	404	13.810 ± 1.573	0.14 (0.13-0.16)	2.3 ± 0.1	326	118.078 ± 12.001	0.04 (0.03-0.04)
DLT	3.9 ± 0.3	590	11.980 ± 1.166	0.12 (0.11-0.14)	2.3 ± 0.1	366	244.374 ± 24.076	0.01 (0.01-0.11)

^a CLD, chlordane; SIL, silanophane; CPF, chlorpyrifos; FNV, fenvalerate; PER, permethrin; BIF, bifenthrin; CYP, cypermethrin; SNV, esfenvalerate; CYH, cyhalothrin; TRL, tralomethrin; DLT, deltamethrin.

^b Dose is µg/g body weight.

was extremely toxic to *R. flavipes* (Table 1), many termites were killed by slight contact with treated soil near the agar-soil interface. The threshold concentration for esfenvalerate against *R. flavipes* is between 4 and 8 ppm. Esfenvalerate was only slightly more effective than fenvalerate (threshold concentration, 8 ppm), while chlorpyrifos and silanophane were approximately as effective as fenvalerate (Fig. 1).

Tunneling responses of *R. flavipes* in soil treated with permethrin, fenvalerate, bifenthrin, and cypermethrin were similar to those of the western subterranean termite, *R. hesperus* (Smith & Rust 1990). Chlorpyrifos at 8 ppm completely stopped tunneling of *R. flavipes*, while *R. hesperus* penetrated 1.5 cm of soil treated with 10 ppm. Chlordane inhibited tunneling by *R. hesperus* more than by *R. flavipes*. Dose-dependent penetration responses to termiticides have also been reported for *Heterotermes indicola* (Wasmann) and *R. lucifugus santonensis* (Feytaud) by Cymorek & Pospischil (1984).

Topical toxicity data (Table 1) did not quite correspond with the ability of termiticides to inhibit termite tunneling. For example, deltamethrin was the most toxic against *C. formosanus*, but its ability to stop penetration by this termite was one tenth of that of permethrin (threshold concentration 10 ppm versus 1 ppm). Permethrin, which was less toxic, was apparently more repellent than deltamethrin.

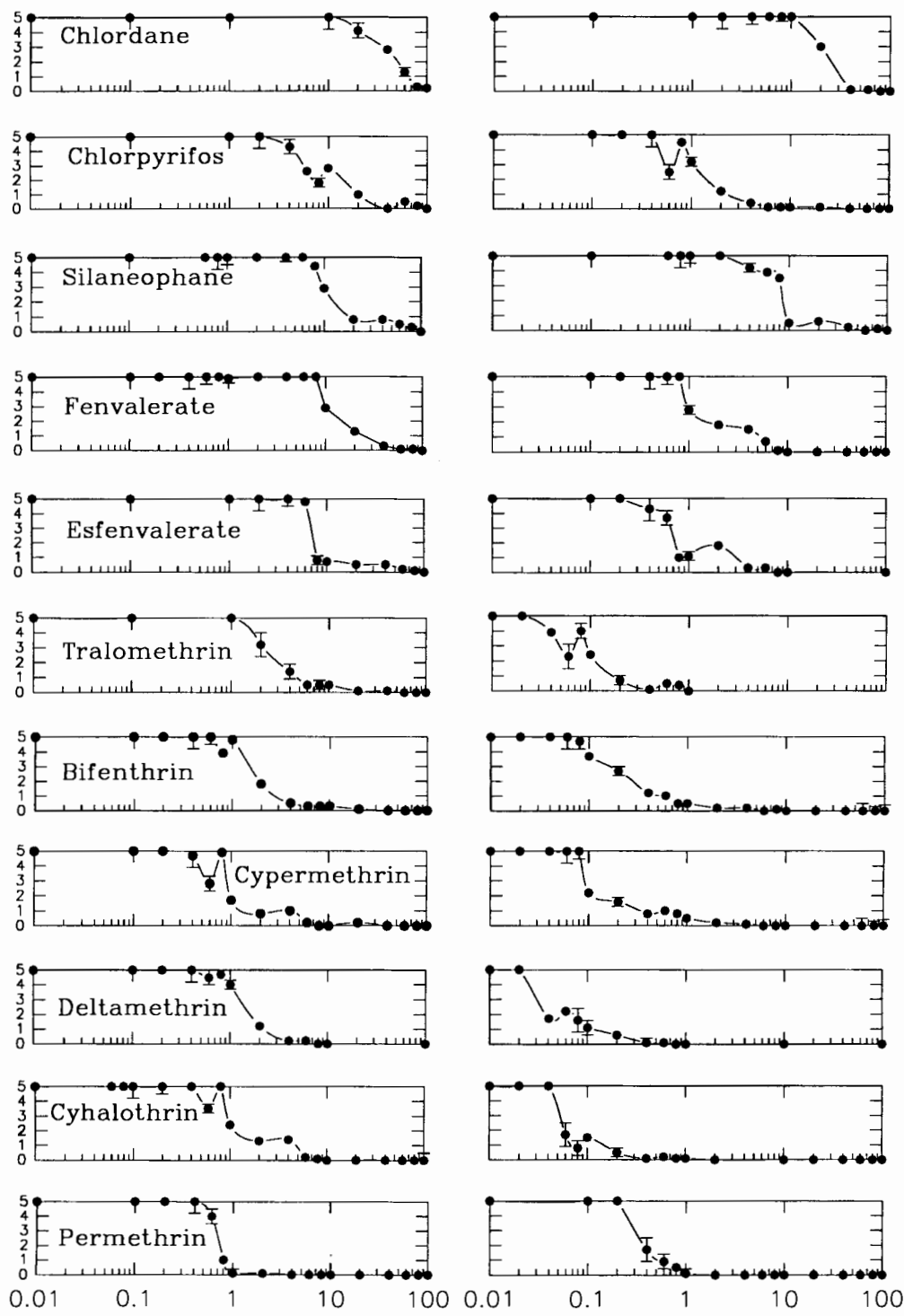
Su et al. (1982) demonstrated that pyrethroids are repellents. This conclusion was confirmed by mortality data shown in Fig. 2. Only the two chemicals that are not pyrethroids, chlordane and chlorpyrifos, produced concentration-dependent mortality. For these two termiticides, no penetration was recorded (Fig. 1) only when 100% mortality occurred (Fig. 2). Thus, the termites surviving an initial exposure did not avoid treated soil but ultimately contacted a lethal dose. In contrast, many surviving termites did not penetrate soil treated with one of the nine pyrethroids at mid- to high-concentration ranges (Fig. 1). Dethier et al. (1960) defined a repellent as "a chemical which causes insects to make orientated movements away from its source." Our data indicated that the nine pyrethroids were repellents at the concentrations tested.

Beal & Smith (1971) concluded that chlordane was a repellent. This observation was based on the failure of termites to penetrate a layer of treated soil in a Petri dish. The procedure, however, did not permit termites to avoid the treated soil. Termites probably failed to penetrate the substrate because the toxicity, not the repellency, of chlordane disabled their tunneling behavior. When Smith (1979) improved the test procedure by dividing the soil into treated and untreated sections, significant numbers of termites stayed on the untreated soil. His test did not demonstrate repellency because chlordane vapor in these open-air experiments might have affected the test insects. The tubing test

Formosan Sub. Termite

Eastern Sub. Termite

Distance Tunneled by Termites (cm)



Concentration (ppm)

Fig. 1. Vertical distance tunneled by the Formosan subterranean termite and eastern subterranean termite 1 wk in soil treated with one of the 11 termiticides within concentration ranges between 0.01 and 100 ppm.

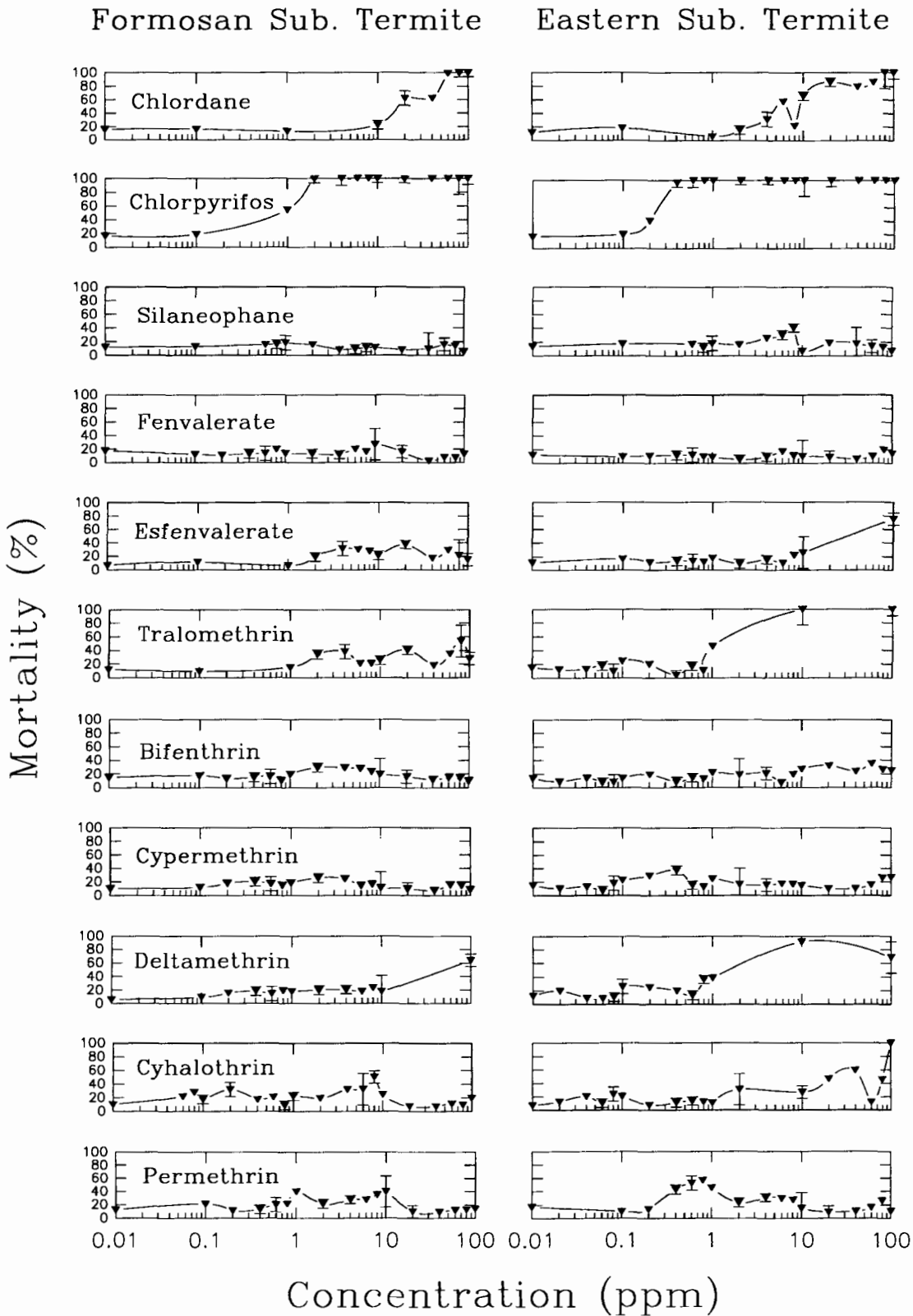


Fig. 2. Mortality of the Formosan subterranean termite and eastern subterranean termite 1 wk after placed in the tunneling tubes.

in which termites were placed in an isolated chamber connecting a tube filled with treated soil (Beal & Smith 1971) showed that termites penetrated soil treated with cyclodienes. Their results agree with our soil penetration data for chlordane. In a tunneling experiment, Jones (1988) also reported that termites penetrated into soil treated with chlordane and chlorpyrifos (with resultant high mortalities), while many termites survived by avoiding soil treated with permethrin. We conclude that chlordane is not repellent for termites.

Repellency of pyrethroids was clearly demonstrated in termites exposed to silaneophane, fenvalerate, bifenthrin, or cypermethrin. No significant mortality of either species was recorded for any concentration tested (Fig. 2). At higher concentrations, termites avoided soil treated with these pyrethroids. They penetrated the soil only when the concentration was below mortality thresholds. The concentration thresholds for repellency were apparently lower than those that induced mortality after termites encountered the treated soil.

Different responses were observed when termites were exposed to other groups of pyrethroids (esfenvalerate, cyhalothrin and tralomethrin for *C. formosanus* and permethrin for both species). In this group, the highest mortalities were recorded from the mid-range concentrations. At these concentrations, termites did not enter the treated soil, but left the agar-soil interface open. Mortality occurred when termites contacted the treated soil at the interface. At higher concentrations, termites sealed the interface gallery and were effectively protected from the pyrethroids. Similar behavior of termites toward high concentrations of pyrethroids were also observed by Su et al. (1982).

The third group of pyrethroids (i.e., esfenvalerate, cyhalothrin, and tralomethrin for *R. flavipes*, and deltamethrin for both species) was so toxic that many termites succumbed on brief initial contact. Substantially higher mortality was observed at higher concentrations (Fig. 2). At the middle concentrations, significant numbers of termites survived because they were repelled, resulting in minimal exposure.

Current labels for the four commercially registered termiticides (chlorpyrifos, permethrin, cypermethrin, and fenvalerate) prescribe application of 0.25–1% solutions at a rate of 4.1 liter/m² for overall treatment under the slab, and approximately 5.0 liter per m along the foundation walls (NPCA 1985). When the recommended rate is sprayed onto the soil, the resulting concentrations in the soil are approximately 125–500 ppm. This recommended rate exceeds the threshold concentrations for all of the 11 compounds tested in this study. If properly applied, therefore, all of these termiticides should provide an effective barrier to prevent invasion by subterranean termites. Indeed, studies have shown that these termiticides remained effective 6–19 yr under field conditions (Mauldin et al. 1987).

With the withdrawal of chlordane from the market, many pest control operators have expressed opinions that currently available termiticides are not as effective as chlordane. Cyclodienes are generally more persistent in the soil than organophosphates or pyrethroids. However, our data show that the four registered termiticides that we tested are more effective (toxic or repellent) than chlordane. Failure of these new termiticides to control termites may be related to factors other than the efficacy of the active ingredient itself. Possible factors may be rapid decomposition, improper formulation, or inadequate application techniques.

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