# Survivorship and Tunneling Activity of *Reticulitermes flavipes* (Kollar) (Isoptera: Rhinotermitidae) in Response to Termiticide Soil Barriers With and Without Gaps of Untreated Soil[1]

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**ABSTRACT** In laboratory tests, survivorship and tunneling response of Eastern subterranean termite, *Reticulitermes flavipes* (Kollar), to termiticide soil barriers were dependent on active ingredient in the formulation and termiticide concentration. At 0.5 ppm, Pryfon® (isofenphos), Dursban TC® (chlorpyrifos), Tribute® (fenvalerate), Chlordane 8 EC® (chlordane), Dragnet® (permethrin), Torpedo® (permethrin), Prevail® (cypermethrin), and Demon® (cypermethrin) were ineffective in preventing termites from breaching a 5-cm wide soil barrier. Performance of these termiticides at 5 ppm was inconsistent. In contrast, all were effective at 50 ppm in preventing termite access to a protected food and aggregation substrate. The termiticides tested were placed into three categories based on termite survivorship and tunneling response after 7 d. Cypermethrin did not affect termite survivorship but did reduce termite tunneling activity after contact with treated soil. Permethrin and fenvalerate did not affect survivorship or tunneling activity in untreated soil. Chlordane, chlorpyrifos, and isofenphos affected survivorship and reduced tunneling activity. Termite location and exploitation of untreated gaps within a termiticide soil barrier appeared to be the result of random termite foraging behavior.

**KEY WORDS** Insecta, termiticide soil barrier, tunneling response, survivorship, Eastern subterranean termite, *Reticulitermes flavipes*.

Conventional control tactics for subterranean termites are mainly preventative. Termiticides applied to soil around the perimeter of a structure are intended to exclude termites from that structure. This requires application of a uniform and continuous termiticide soil barrier. Gaps of untreated soil within a termiticide soil barrier are thought to be one reason for the failure of a soil barrier treatment (Mampe 1990). Application techniques and equipment are being tested by the pest control industry to reduce the occurrence of untreated gaps within soil barrier treatments (Anderson and McMenemy 1991, Mampe and Bret 1992, Thomas 1993, Thoms et al. 1993). However, questions remain concerning responses of termites to soil barriers containing gaps of untreated soil.

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Laboratory evaluations of subterranean termite response to termiticides have been conducted by a variety of methods. Contact toxicity of treated soils to termites has been used as a measure of termiticide efficacy (Hetrick 1952, 1957, Ebeling and Pence 1958). However, because the goal of any soil termiticide treatment is exclusion of termites, efficacy of a soil barrier could be related to repellency and/or toxicity of a candidate termiticide. As a result, Smith (1979) devised a Petri dish assay to elucidate relative repellency of termites by termiticides. Su et al. (1982) emphasized the importance of recording termite behavior in evaluating termiticide efficacy. They list three criteria a test arena should provide to test termite response to termiticides, including maintenance of high humidity, isolation of treated and untreated substrates, and observation of termite behavior. Efforts to observe termite tunneling response in termiticide-treated substrates have resulted in test arenas which confine the treated substrate within glass tubes, glass sandwiches, or Petri dishes using both technical grade and commercially-formulated termiticides (Jones 1989, Smith and Rust 1990, Su and Scheffrahn 1990).

In this study, I evaluated tunneling response of the Eastern subterranean termite, *Reticulitermes flavipes* (Kollar), in a larger bioassay arena offering termites more freedom of movement compared to previous published reports (Jones 1989, Smith and Rust 1990, Su and Scheffrahn 1990). My tests were designed to be a microcosm of actual termiticide field applications. Eight commercially-formulated termiticides were tested as soil barriers with and without gaps of untreated soil. Termite survivorship and tunneling response to these termiticides were recorded and are reported in this paper.

## Materials and Methods

**Termites.** *Reticulitermes flavipes* were collected from infested logs found at the University of Georgia Westbrook Farm near Griffin, GA. Termites were extracted from logs brought into the laboratory using the technique described by La Fage et al. (1983). Alates associated with each colony were used to identify species (Weesner 1965). Eleven different colonies of *R. flavipes* were used. Termites removed from logs were maintained in 26 × 19 × 9 cm (L:W:H) clear plastic boxes containing moistened #1 Whatman filter paper and several 1-$cm^3$ blocks of white pine wood. Termites were maintained in an environmental chamber in total darkness at 24° C for no longer than one month before inclusion in a bioassay. Only undifferentiated workers and soldiers were used in the tests.

**Termiticides.** The eight formulations tested were isofenphos (Pryfon®, Miles Inc., Kansas City, MO), chlorpyrifos (Dursban® TC, DowElanco, Indianapolis, IN), fenvalerate (Tribute®, Rousell Bio Corp, Edgewood Cliffs, NJ), chlordane (Chlordane® 8 EC, Versicol Chemical Corp., Rosemont, IL), cypermethrin (Prevail® FT, FMC Corp., Princeton, NJ; Demon® 2 EC, ICI Americas Inc., Wilmington, DE), and permethrin (Dragnet® FT, FMC Corp.; Torpedo®, ICI Americas Inc.). Each termiticide was tested at: 0.5, 5, and 50 ppm.

**Test Arena/Bioassay.** All tests were conducted using 0.3-$m^2$ glass terrariums as test arenas (Fig. 1) which were constructed of 3-mm thick glass with side walls (15 cm high) held together with 100% clear silicone sealant (Dow Corning, Midland, MI) which is rated safe for food contact (FDA Reg. No. 21 CFR 177.2600).

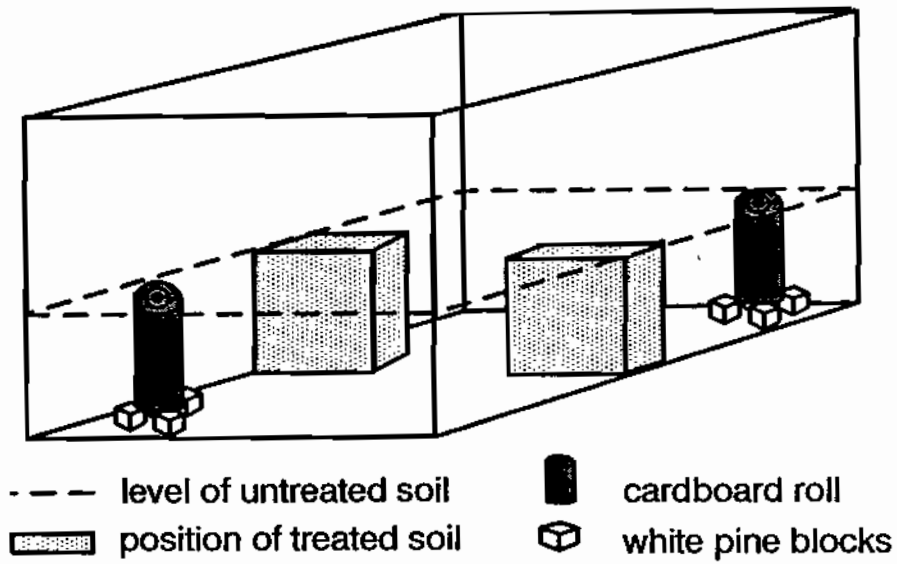


Fig. 1. Diagram of bioassay chamber and substrate arrangement from trials of termite response to termiticide soil barriers.

Before each test, arenas were prepared in the following manner: a termite aggregation substrate (single-faced 3 × 15 cm strip of corrugated cardboard) and food substrate (1-$cm^3$ cubes of white pine wood) were placed at opposite corners of the empty test arena (Fig. 1). The wood cubes were placed approximately 1 cm apart to provide a space under the aggregation substrate void of soil. The aggregation substrate was rolled around a wooden pencil leaving an 8-mm diam opening in the center. The opening in the aggregation substrate and void underneath were for receiving termites. This arrangement prevented termites from wandering across the soil surface following their introduction into the bioassay arena. It also placed termites at the bottom of the glass test arenas where tunneling activity could be observed.

Termiticide soil barriers were tested as either a complete barrier, which extended the entire width (30 cm) of the test arena between the two aggregation and food substrates, or as barriers containing 4.5- or 9-cm gaps of untreated soil in the center. Termiticide-treated soil was positioned within the center of each arena using clear fiberglass containment units. These containment units were 8 cm high, 5 cm wide, and constructed of 0.75-mm thick fiberglass sheets held together with 1.9 cm wide Scotch Brand Magic Tape (3M Company). Containment units were of three lengths (30, 12.75, or 10.5 cm) to provide for barriers with no, 4.5-, and 9-cm gaps in the center of the arena, respectively.

With the appropriate containment units in place, arenas were filled to a depth of 3 cm with autoclaved and oven-dried sandy loam soil (85:5:10, sand:silt:clay)

brought to 15% (w/w) moisture with distilled water. Commercial formulations of each termiticide concentration in ppm (g of active ingredient per g oven-dried soil) were prepared in a volume of distilled water necessary to bring the autoclaved and oven-dried treatment soils to 15% (w/w) soil moisture. The appropriate volume of termiticide solution was slowly poured into a measured amount of soil in clear plastic boxes [26 × 19 × 9 cm (L:W:H)] and mixed using a stainless steel teaspoon until, by visual inspection, an even distribution of soil moisture was achieved. Termiticide-treated soil was placed within the containment unit which was then removed to allow contact between treated and untreated soils. One termiticide was applied per arena.

Termites (700 undifferentiated workers plus 7 soldiers) were added to the center of an aggregation + food substrate arrangement using a Kimax glass funnel (60-mm internal diam). This was termed the introduction site with the opposite food and aggregation substrate termed the protected site. The number of termites was decided upon after several preliminary trials without termiticide treatment in which it was found that 700 termites consistently tunneled from the introduction site to the protected site in less than 30 h (Forschler, unpublished data).

To retard desiccation of the soil, each test arena was placed inside one of two chambers constructed of 8-mil plastic on a 2 × 3 m wooden frame. Greater than 90% relative humidity was maintained in each chamber by a cool water humidifier. Temperatures in these chambers ranged from 20° C at night to 33° C during the day throughout the tests.

**Data Collection and Analysis.** After 7 d, bioassay arenas were removed from the high humidity chambers, and five separate sets of data were collected. The bottom of each arena was examined, and the percentage area of the arena base excavated by foraging termites was visually estimated. Position of the tunnels in relation to termiticide barriers also was scored on a scale of 1-5. The scoring system was as follows: 1 = termite tunnels not to termiticide barrier, 2 = termite tunnels up to but not into termiticide barrier, 3 = termite tunnels into but not through termiticide barrier, 4 - termite tunnels through barrier but not to alternate food and aggregation site, 5 = termite tunnels through barrier or gap and to the alternate food and aggregation site.

After scoring tunneling activity, soil from each arena was excavated using garden trowels. First, termiticide-treated soils in the barriers were excavated, sifted by hand on aluminum baking pans; and numbers of living termites recorded. Next, untreated soil from the gap area (if present) were examined for live termites. Finally, soils from the introduction side of the termiticide barrier and then the protected side were excavated, sifted, and number of living termites recorded for each area. These data provided total number of surviving termites and their relative position in the arena after 7 d.

Five different temporally separate trials were conducted. Each trial consisted of a single termiticide concentration + barrier type combination. Three trials were conducted at 5 ppm concentration. These included three different barrier types: complete, 4.5-, and 9-cm gap barriers. The remaining two trials were conducted at 0.5 and 50 ppm concentrations using a 4.5-cm gap barrier. For each trial, a replicate consisted of seven or eight arenas, one arena per termiticide. Each replicate contained termites from a single colony source; all replicates

were conducted at the same time. In trials using a 4.5-cm gap the 0.5 ppm concentration was replicated four times, the 5 ppm concentration was replicated five times, and the 50 ppm concentration three times. Trials conducted using the 5 ppm concentration + complete barrier combination were replicated five times and the 5 ppm concentration + 9-cm gap combination were replicated three times. Pryfon was not included in the latter test because Miles Inc. Specialty Products had announced plans to phase out this termiticide from the marketplace at the time these tests were planned.

Before analysis, survivorship data were arcsine-transformed. Data from each trial were analyzed separately in a randomized complete block design. Data were subjected to analysis of variance (ANOVA, $P = 0.05$) with each replicate blocked for termite colony. Because there were no significant block effects, means were separated using the protected least significant difference procedure for each trial (SAS Institute 1988).

## Results

**4.5-cm Gap Barrier Tests.** Termites in control arenas located the food and aggregation substrates by day 7 in all tests and, therefore, yielded a mean penetration score of 5.0. All termiticides tested at the 0.5 ppm concentration failed to protect the food and aggregation substrates from termite attack. All but one termiticide tested at this concentration yielded a mean penetration score of 5.0 for all four replicates. In one replicate with Demon, termites breached the barrier in several locations, but by day 7 had not located the food and aggregation substrate. In contrast, all termiticides provided protection of the food and aggregation substrate at 50 ppm. Mean penetration scores for Pryfon (4.0), Tribute (3.8), and Chlordane (3.3) indicate termites were able to penetrate 5 cm of termiticide-treated soil, but they did not forage to the protected site. Mean scores for Dursban and Dragnet (2.7), Demon (2.3), Prevail (2.0), and Torpedo (2.0) indicate that termite tunnels touched or partially penetrated soil but did not breach the treated soil.

The 5 ppm rate was the discriminating concentration. As indicated by mean termiticide penetration scores, Pryfon (5.0), Tribute (4.8), and Chlordane (4.5) failed to protect the food and aggregation site in at least four of five replicates at 5 ppm. Scores for Demon (4.0), Dursban (4.0), Torpedo (3.8), and Dragnet (3.8) indicate that termites foraged to the food and aggregation site in one of the five replicates. The Dursban, Torpedo, and Dragnet failures in the 5 ppm + 4.5-cm gap tests were a result of termites tunneling through the treated soil. In one Demon treatment, termites exploited the 4.5-cm gap of untreated soil. This was the only observed instance of termites using the gap of untreated soil to breach a barrier of termiticide applied at 5 or 50 ppm.

Termite survivorship was not affected by any termiticides at the 0.5 ppm concentration (Table 1). At 5 ppm, only Dursban provided a mortality response significantly different ($F = 0.13$; df = 8, 22; $P < 0.05$) from the controls (Table 1). The 50 ppm concentration provided a statistical separation between those termiticides that acts as chemical barriers through contact toxicity or repellency. This separation is indicated by mean termite survivorship after 7 d in bioassay (Table 1). Survivorship means of 64% for Pryfon, 57% for Chlordane, and 41%

**Table 1. Mean number (± SEM) of surviving* *Reticulitermes flavipes*, by treatment and termiticide concentration, after one week in termiticide soil barrier bioassay, with a 4.5-cm gap of untreated soil in center of barrier.**

| Treatment | Termiticide Concentration† | | |
|---|---|---|---|
| | 0.5 ppm | 5 ppm | 50 ppm |
| Chlordane | 639 ± 27 A | 534 ± 45 B | 401 ± 78 BC |
| Control | 653 ± 14 A | 602 ± 22 AB | 628 ± 15 A |
| Demon | 626 ± 16 A | 656 ± 58 A | 628 ± 10 A |
| Dragnet | 627 ± 44 A | 591 ± 40 AB | 636 ± 23 A |
| Dursban | 626 ± 31 A | 221 ± 62 C | 289 ± 67 C |
| Prevail | 638 ± 40 A | 612 ± 42 AB | 595 ± 19 A |
| Pryfon | 613 ± 37 A | 580 ± 71 AB | 455 ± 51 B |
| Torpedo | 624 ± 29 A | 630 ± 83 AB | 621 ± 36 A |
| Tribute | 624 ± 17 A | 567 ± 22 AB | 572 ± 35 AB |

* Survivors of 707 initially introduced.
† Means within the same column followed by the same letter are not significantly different using LSD with $P < 0.05$ (SAS Institute 1985).

for Dursban were significantly lower ($F = 8.61$; df = 8, 18; $P < 0.001$) than survivorship in the control or other termiticide treatments (81-90%).

Mean percentage area of the arena base excavated by termites decreased with increasing concentration of termiticide (Table 2). This reduction in tunneling activity can be partially explained by efficacy of treatments excluding termites from the protected site in the arenas. Specifically, contact with cypermethrin reduced termite tunneling activity without increasing mortality. Even at the 0.5 ppm rate, cypermethrin showed significantly ($F = 1.00$; df = 8, 22; $P < 0.05$) less termite tunneling as compared to the controls (Table 2).

**Complete Barrier Tests.** Termiticides tested at 5 ppm in complete barriers provided mean penetration scores similar to scores from treatments with a 4.5-cm gap at the same concentration. The controls, Tribute, and Pryfon all scored 5.0 (Table 3). Chlordane scored 4.6 and failed in four of five replicates. The other mean penetration scores ranged from 4.1 for Dragnet to 3.5 for Demon and Dursban. Dragnet, Torpedo, Prevail, Demon, and Dursban all failed in one of five replicates to protect the food and aggregation substrate.

As indicated by survivorship, Dursban and Chlordane were the only termiticides to cause significant ($F = 16.55$; df = 8, 40; $P < 0.01$) mortality (Table 3). Mean percentage areas (± SEM) excavated were similar to 4.5-cm gap + 5 ppm trials with the exception of Dursban which dropped to 33.3 ± 5.6% compared to 59 ± 14% (Tables 2 and 3).

**Table 2. Mean (± SEM) percentage area of arena base excavated by *Reticulitermes flavipes*, by treatment and termiticide concentration, in termiticide soil barrier bioassay, with a 4.5-cm gap of untreated soil in center of barrier.**

| Treatment | Termiticide Concentration* | | |
|---|---|---|---|
| | 0.5 ppm | 5 ppm | 50 ppm |
| Chlordane | 90 ± 4 A | 88 ± 13 A | 20 ± 3 D |
| Control | 96 ± 8 A | 88 ± 8 A | 90 ± 10 A |
| Demon | 74 ± 7 B | 35 ± 6 B | 30 ± 6 CD† |
| Dragnet | 86 ± 4 AB | 54 ± 9 B | 40 ± 6 BC |
| Dursban | 88 ± 3 AB | 59 ± 14 B | 25 ± 2 D |
| Prevail | 73 ± 5 B | 39 ± 7 B | 21 ± 3 D |
| Pryfon | 84 ± 9 A | 95 ± 4 A | 40 ± 4 BC |
| Torpedo | 80 ± 4 AB | 55 ± 12 B | 47 ± 3 B |
| Tribute | 91 ± 4 A | 73 ± 4 AB | 49 ± 6 B |

* Means within the same column followed by the same letter are not significantly different using LSD with $P < 0.05$ (SAS Institute 1985).

† Termites utilized the gap of untreated soil to breach the termiticide soil barrier in at least one replicate.

**9-cm Gap Barrier Tests.** Mean penetration scores for controls was 5.0 ± 0. Both Tribute and Torpedo failed to protect the food and aggregation site in two of three replicates. Dragnet, Demon, and Prevail failed in one of three replicates because termites found and used the gap of untreated soil. Chlordane and Dursban each failed once even though the gap was not located by foraging termites.

Dursban was the only termiticide to show statistically lower survivorship ($F = 1.83$; df = 7, 16; $P < 0.05$) compared to controls (Table 4). However, percentage survivorship at 5 ppm with Dursban was higher (78%) in the 9-cm gap tests than in either the complete barrier (24%) or 4.5-cm gap (41%) trials. Percentage areas excavated were similar to other trials conducted at the 5 ppm concentration (Tables 2 - 4).

## Discussion

Foraging patterns of subterranean termites from the genera *Reticulitermes, Coptotermes,* and *Heterotermes* are random (Pickens 1934, Su et al. 1984, Jones et al. 1987). In my bioassay system, this random foraging behavior was evidenced by the low percentage of arenas in which termites used the gap of untreated soil to breach termiticide treatments. In trials at 5 ppm concentration with 4.5-cm gaps in the barriers, termites found and used the gaps to

**Table 3. Mean (± SEM) number of survivors* and mean percent area of arena base ± SEM excavated by *Reticulitermes flavipes*, by treatment at the 5 ppm concentration, after one week in termiticide soil barrier bioassay with complete termiticide barrier.**

| Treatment | Mean number of† termites recovered | Mean percent arena† base area excavated |
|---|---|---|
| Chlordane | 512 ± 61 B | 65.0 ± 8.4 BC |
| Control | 628 ± 18 A | 85.0 ± 5.6 A |
| Demon | 591 ± 19 AB | 48.3 ± 4.0 CDE |
| Dragnet | 522 ± 39 AB | 64.0 ± 4.0 BC |
| Dursban | 171 ± 26 C | 33.3 ± 5.6 E |
| Prevail | 616 ± 26 AB | 45.0 ± 3.4 DE |
| Pryfon | 560 ± 19 AB | 83.3 ± 7.1 AB |
| Torpedo | 548 ± 38 AB | 66.6 ± 3.3 ABC |
| Tribute | 581 ± 91 AB | 80.0 ± 8.6 AB |

* Survivors of 707 initially introduced.

† Means within the same column followed by the same letter are not significantly different using LSD with $P < 0.05$ (SAS Institute 1985).

reach protected food and aggregation substrates in 2.5% of the test arenas. When the gap was enlarged to 9 cm, this percentage increased to 12%. Although termites assayed at 5 and 50 ppm concentrations always contacted treated soil before changing the direction of their tunneling activity, there was no indication they purposefully searched for untreated soil along the termiticide-treated soil barrier. Termite contact with treated soil, tunneling contiguous with the barrier and then through the untreated gap, would have been an indication of purposeful exploitation of incomplete soil barriers.

Several authors have reported relative toxicity or repellency of various termiticides to rhinotermitid species (Su et al. 1982, Su and Scheffrahn 1990, Smith and Rust 1990). Of the products I tested, the pyrethroids (Tribute - fenvalerate; Demon and Prevail - cypermethrin; Dragnet and Torpedo - permethrin) acted as repellents in soil. These products did not affect termite survivorship at any concentration tested. However, the organophosphates (Pryfon - isofenphos; Dursban - chlorpyrifos) and chlorinated hydrocarbon (chlordane) could be considered toxic soil barrier termiticides. These termiticides did not deter termite tunneling into treated soils at any concentration tested, but all caused termite mortality at 50 ppm concentration. In these assays, no tunnels were blocked, and termite mortality occurred throughout the arenas, not just in the treated barrier.

**Table 4. Mean number (± SEM) of survivors* and mean percent area of arena base (± SEM) excavated by *Reticulitermes flavipes*, by treatment at the 5 ppm concentration, after one week in termiticide soil barrier bioassay with a 9.0-cm gap of untreated soil in center of barrier.**

| Treatment | Mean number of† termites recovered | Mean percent arena† base area excavated |
|---|---|---|
| Chlordane | 594 ± 21 AB | 66.7 ± 13.3 AB |
| Control | 636 ± 12 A | 83.0 ± 7.6 A |
| Demon | 644 ± 23 A | 35.0 ± 12.6 ‡ |
| Dragnet | 599 ± 31 AB | 43.3 ± 10.9 AB‡ |
| Dursban | 554 ± 27 B | 50.0 ± 10.4 AB |
| Prevail | 591 ± 27 AB | 36.7 ± 2.5 B‡ |
| Torpedo | 603 ± 18 AB | 51.7 ± 8.3 AB |
| Tribute | 650 ± 25 A | 60.0 ± 5.8 AB |

* Survivors of 707 initially introduced.
† Means within the same column followed by the same letter are not significantly different using LSD with $P < 0.05$.
‡ Termites utilized the gap of untreated soil to breach the termiticide soil barrier in at least one replicate.

Cypermethrin did not affect termite survivorship, but termites showed reduced tunneling activity in untreated soil after contact with the treated soil. These results agree with those of Smith and Rust (1990) who also found that termite tunneling was reduced. Percentage area excavated in cypermethrin arenas was significantly ($F = 1.75$; $df = 7, 24$; $P < 0.05$) lower than in the controls, even at the 0.5 ppm concentration, and was consistently 10% less than other pyrethroids in all trials (Tables 2-4). The reduced tunneling activity in those treatments could not be explained solely by mortality effects.

Permethrin and fenvalerate did not affect survivorship, and termite tunneling activity in untreated soil was not reduced following contact with soil treated with these termiticides. Tunneling activity was greater in the permethrin- and fenvalerate-treated soil relative to cypermethrin in all trials, with the exception of the 5 ppm + 9-cm gap tests (Tables 2 - 4). This indicates that both fenvalerate and permethrin are repellent, but termite foraging behavior following contact with treated soil is not reduced.

Chlordane, isofenphos, and chlorpyrifos reduced termite survivorship, but reduced tunneling activity was evident only at concentrations high enough to produce significant (>35%) mortality by day 7. Termite mortality was, therefore, the major factor in reduced termite tunneling activity (Tables 1, 3, and 4).

Smith and Rust (1990) showed no tunneling by *R. hesperus* at 50 ppm with either Pryfon (isofenphos), Chlordane, or Dursban (chlorpyrifos), although in

their tests there was evidence of termiticide movement into untreated soil. Beal and Smith (1971) reported that *R. flavipes* tunneled through 5 cm of soil treated with 25 ppm Chlordane, but tunneled only 1.7 cm in soil treated with 50 ppm of Chlordane. Su and Scheffrahn (1990) reported *R. flavipes* tunneling was stopped by technical grade chlorpyrifos and fenvalerate at 8 ppm and Chlordane at 40 ppm.

In my bioassay, *R. flavipes* tunneled into soil treated with those products at 50 ppm. Although these termiticides were effective in protecting the food and aggregation substrate, termites tunneled through the barrier in all three isofenphos replicates and in one of three Chlordane replicates. The termites did not tunnel the barrier of chlorpyrifos at the same rate. In my tests with these termiticides, dead termites were found in tunnels throughout the test arenas including under the introduction site. Despite this mortality, none of these termiticides killed all termites by day 7 (Tables 1, 3 and 4). This indicates that these products will not eliminate a termite colony in the field. Therefore, as with the repellent compounds, the remaining colony members would be free to continue probing and testing termiticide soil barriers over time, if the termite population is not adversely affected by the exposure.

Regardless of termiticide, termites always entered soils containing 5 ppm of the toxicant before changing the direction of their tunneling activity. This indicates that termites display avoidance behavior to cypermethrin, permethrin, and fenvalerate before toxic amounts of chemicals are obtained through contact with treated soil. In contrast, $LD_{50}$'s of ≤1 ppm were obtained in topical bioassys of technical grade permethrin, cypermethrin, and fenvalerate (Su and Scheffrahn) 1990). At 50 ppm, termite tunnels contacted soils treated with cypermethrin and permethrin and tunneled into fenvalerate-treated soils before tunneling was discontinued. This indicates that cypermethrin and permethrin were more repellent than fenvalerate. Su and Scheffrahn (1990) and Smith and Rust (1990) reported that *Reticulitermes* tunneling activity was reduced at concentrations of 1 ppm for permethrin and <10 ppm for cypermethrin and fenvalerate. My results showed that >5 ppm was required to elicit a similar response.

Differences in termite tunneling response to termiticides between my open microcosm bioassay and the closed-arena tests of Beal and Smith (1971), Su and Scheffrahn (1990), and Smith and Rust (1990) could be the result of several factors. Tests reported by Beal and Smith (1971) and Su and Scheffrahn (1990) were conducted with technical grade materials. It is possible that assays with formulated product are confounded by termite interaction with solvents and emulsifiers (Rust and Smith 1993) In addition, different soil types were used in each of these tests including a sandy loam (Beal and Smith 1971), a sand (Su and Scheffrahn 1990), and river sand (Smith and Rust 1990). I also used a sandy loam soil. Tests with different soil types indicate that termite $LD_{50}$ values, regardless of termiticide, are 10X greater on treated sand than on sandy loam soils (Forschler and Townsend, unpublished data).

The natural vigor and size of individual termites within the same species or genus also may account for differences in bioassay results. Mean worker body weight, though not an indication of termite health, may affect test results because size of the test animal is related to amount of toxicant needed to show effects. Worker body weight for *R. flavipes* used in my tests ranged from 3.38 to

4.25 mg/termite with a mean of 3.85 mg. The same species averaged 3.0-3.18 mg/termite in Beal and Smith (1971) and 2.3-2.4 mg in Su and Scheffrahn (1990).

These differences in findings also may be explained by differences in experimental design. Beal and Smith (1971) and Jones (1990) suggest that tunneling response of subterranean termites to termiticide soil barriers is a function of population pressure. The ratio of surface area of treated soil to numbers of termites in my test was 12.7 $mm^2$/termite. The ratios of Beal and Smith (1971) (0.63-1.04), Smith and Rust (1990) (3.18), and Su and Scheffrahn (1990) (1.9) were much lower, indicating that termiticide barriers in their tests were subjected to more termite population pressure. In those studies, termites tunneled less in soils treated with similar compounds at the same rates than in my tests. This indicates that factors other than treatment surface area to number of termites affect termite response to termiticide soil barriers.

Finally, because I did not attempt to partition treated and untreated soils, termiticide movement into untreated soil could explain some of these observed differences between laboratories. The soil absorption coefficient ($K_{OC}$) of a chemical has been related to a chemicals' mobility in soil (McCall et al. 1980). The $K_{OC}$ values for all termiticide active ingredients tested are >5000 and place them in the lowest (Immobile) mobility classification of Helling and Turner (1968). Smith and Rust (1990), however, indicated in their vertical tube assay that cypermethrin may have moved from treated to untreated zones. I am conducting a companion study to determine if termiticides moved from the treated zone in my bioassay.

In conclusion, these tests demonstrate termite location and exploitation of gaps of untreated soil within a termiticide soil barrier are the result of random termite foraging behaviors. All termiticides tested were effective at the 50 ppm concentration in protecting the food and aggregation substrate, regardless of termiticide type and formulation. Fifty ppm is 5-10 times less than the recommended application rates for currently registered termiticides (Su and Scheffrahn 1990). Therefore excluding decomposition rates and application techniques, any of the termiticides I tested should provide adequate protection from termite invasion as long as application provides a complete (unbroken) barrier.

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## References Cited

**Anderson, A. L. and H. McMenemy.** 1991. Termite rig evaluation: a way to reduce retreats? Pest Control Technology. 19: 46-51.

**Beal, R. H. and V. K. Smith.** 1971. Relative susceptibilities of *Coptotermes formosanus, Reticulitermes flavipes,* and *R. virginicus* to soil insecticides. J. Econ. Entomol. 64: 472-475.

**Ebeling, W. and R. J. Pence.** 1958. Laboratory evaluation of insecticide-treated soils against the western subterranean termite. J. Econ. Entomol. 51: 207-211.

**Hetrick, L. A.** 1952. The comparative toxicity of some organic insecticides as termite soil poisons. J. Econ. Entomol. 45: 235-237.

1957. Ten years of testing organic insecticides soil poisons against the eastern subterranean termite. J. Econ. Entomol. 50: 316-317.

**Helling, C. S. and B. C. Turner.** 1968. Pesticide mobility: determination by thin-layer chromatography. Science 162: 562-563.

**Jones, S. C., M. W. Trosset and W. L. Nutting.** 1987. Biotic and abiotic influences on foraging of *Heterotermes aureus* (Synder) (Isoptera: Rhinotermitidae). Environ. Entomol. 16: 791-795.

**Jones, S. C.** 1989. How toxic and repellent are soil insecticides to subterranean termites? Pest management 8: 16-19.

1990. Effects of population density on tunneling by Formosan subterranean termite (Isoptera: Rhinotermitidae) through treated soil. J. Econ. Entomol. 83: 875-878.

**La Fage, J. P., N. -Y. Su, M. J. Jones and G. R. Esenther.** 1983. A rapid method for collecting large numbers of subterranean termites from wood. Sociobiology 7: 305-310.

**Mampe, C. D.** 1990. Where are we with termite control? Pest Control 58 (2): 42-43, 46.

**Mampe, C. D. and B. Bret.** 1992. Rodding, soil type and application tips. Pest Control 60 (1): 48-50.

**McCall, P. J., R. L. Swann, D. A. Laskowski, S. M. Unger, S. A. Vrona and H. J. Dishburger.** 1980. Estimation of chemical mobility in soil from liquid chromatographic retention times. Bull. Environ. Contam. Toxicol. 24: 190-195.

**Pickens, A. L.** 1934. The biology and economic significance of the western subterranean termite, *Reticulitermes hesperus.*, Pg. 157-183. (In) Kofoid, C. A. [ed.] Termites and termite control. University of California Press. Berkely, CA.

**Rust, M. K. and J. L. Smith.** 1993. Toxicity and repellency of components in formulated termiticides against western subterranean termites (Isoptera: Rhinotermitidae). J. Econ. Entomol. 86: 1131-1135.

**SAS Institute Inc.** 1988. SAS users guide: statistics. SAS Institute Inc. Cary, N.C.

**Smith, V. K.** 1979. Improved techniques designed for screening candidate termiticides on soil in the laboratory. J. Econ. Entomol. 72: 877-879.

**Smith, J. L. and M. K. Rust.** 1990. Tunneling response and mortality of the western subterranean termite (Isoptera: Rhinotermitidae) to soil treated with termiticides. J. Econ. Entomol. 83: 1395-1401.

**Su, N. -Y., M. Tamashiro, J. R. Yates and M. I. Haverty.** 1982. Effect of behavior on the evaluation of insecticides for prevention of or remedial control of the Formosan subterranean termite. J. Econ. Entomol. 75: 188-193.

1984. Foraging behavior of the Formosan subterranean termite (Isoptera: Rhinotermitidae). Environ. Entomol. 13: 1466-1470.

**Su, N. -Y. and R. H. Scheffrahn.** 1990. Comparison of eleven soil termiticides against the Formosan subterranean termite and eastern subterranean termite (Isoptera: Rhinotermitidae). J. Econ. Entomol. 83: 1918-1924.

**Thomas, C.** 1993. Here comes the new termite application equipment. Pest Control 61(2): 70-71.

**Thoms, E., S. Nolen and L. Bodalbhai.** 1993. Termiticide foams fill slab treatment gaps. Pest Control 61(2): 47-51.

**Weesner, F. M.** 1965. The termites of the United States. A Handbook. The Nat'l. Pest Control Assoc., Elizabeth, N. J. 67 pp.