Mortality of Eastern Subterranean Termites (Isoptera: Rhinotermitidae) Exposed to Four Soils Treated with Termiticides

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ABSTRACT Termite survivorship was affected by soil type and termiticide tested in constant-exposure bioassay. Four soil types were tested at the same percentage soil moisture (15% wt:wt). Soil pH values were between 5.4 and 5.5 with organic matter contents ranging from <0.07 to 3.75%. Soils tested included a sand, sandy loam, sandy clay loam, and sandy clay. Six termiticide formulations were tested including chlorpyrifos (Dursban TC), fenvalerate (Tribute), cypermethrin (Prevail FT, Demon 2 EC), and permethrin (Dragnet FT, Torpedo). Estimated lethal concentrations for all termiticides were at least 7 times lower in sand compared with sandy loam or sandy clay loam soils. However, soil type alone could not be used to predict termite mortality with the termiticides tested.

KEY WORDS *Reticulitermes flavipes*, survivorship, termiticide, soil, bioavailability

CONVENTIONAL TERMITE TREATMENTS require application of termiticide solutions to the soil surrounding and beneath a structure. Studies with other soil insect systems have indicated that soil type, soil pH, insecticide type, moisture, temperature, microbial communities, and the target insect affect soil insecticide efficacy (Harris 1972, Tashiro and Kuhr 1978, Chapman et al. 1982, Macalady and Wolfe 1983, Felsot 1989). The conditions that may affect soil insecticide efficacy are numerous and insecticide interactions with the aforementioned factors are often complex. Each active ingredient–formulation combination must be tested individually, because efficacy in different soil types cannot be extrapolated from chemical structure alone (Harris 1972). Insecticides currently registered for use as termiticides have soil absorption coefficients (K_{oc} values) which place them in the immobile classification, implying they do not readily leach through the soil profile (Helling and Turner 1968, McCall et al. 1980). This indicates the potential for interactions between these compounds and components of the soil matrix that could affect the biological activity of these insecticides. We report here results from tests concerning the bioavailablity of selected termiticides in several soil types at the same percentage soil moisture using termites in a continuous-exposure bioassay system.

Materials and Methods

Termites. Eastern subterranean termites, *Reticulitermes flavipes* (Kollar), 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). Termites removed from logs were maintained in clear plastic boxes (26 cm long, 19 cm wide, 9 cm high) containing moistened No. 1 Whatman filter paper and several 1-cm^3 blocks of white pine wood (*Pinus* sp.). Termites were maintained in an environmental chamber in total darkness at 24°C for no longer than 1 mo before inclusion in a bioassay. Only undifferentiated *R. flavipes* workers from 4 different colonies were used in the tests.

Termiticides. The 6 formulations tested were chlorpyrifos (Dursban TC [termiticide concentrate], DowElanco, Indianapolis, IN), fenvalerate (Tribute, Rousell Uclaf, Montvale, NJ), cypermethrin (Prevail FT [for termite], FMC, Princeton, NJ; Demon 2 EC [emulsifiable concentrate], Zeneca, Wilmington, DE), and permethrin (Dragnet FT [for termite], FMC; Torpedo, Zeneca). Commercial formulations of each product were serially diluted to provide a range of concentrations. Each termiticide was tested at 7 of the following 11 rates: 0.001, 0.01, 0.05, 0.1, 0.5, 1, 5, 10, 50, 100, and 500 ppm (determined by weight of active ingredient per weight of oven-dried soil).

Soils. The soils tested included sand (play sand, Bosal, Charlotte, NC), a Cecil series sandy loam typical of A horizon soils (top soil) from the Piedmont region in Georgia, and 2 common Piedmont

Table 1. Analysis of the 4 soil types tested in constant-exposure termiticide bioassay

Soil type	% sand	% silt	% clay	% organic matter	pH	Cation ex-change capacity
Sand	100	0	0	<0.07	5.4	0.66
Sandy loam	71	21	8	3.75	5.4	13.11
Sandy clay loam	55	24	21	1.34	5.4	5.64
Sandy clay	52	12	36	0.07	5.5	4.11

region B horizon soil types (subsoil)—a Cecil series sandy clay and a Worsham series sandy clay loam. Soils were analyzed by the Soil Testing and Plant Analysis Laboratory at the University of Georgia, Athens. Soils were analyzed for structural composition (percentage sand:silt:clay), pH (w), cation exchange capacity, and percentage organic matter.

Bioassay and Data Analysis. Termiticide solutions were prepared to obtain the required concentration in a volume of distilled water necessary to bring 200 g of autoclaved and oven-dried soil to 15% (wt:wt) soil moisture. The appropriate volume of termiticide solution was slowly poured into soils in clear plastic boxes (26 cm long, 19 cm wide, 9 cm high). Solutions were mixed using a stainless steel teaspoon to obtain, by visual inspection, an even distribution of soil moisture. One replicate consisted of a container of soil mixed as previously described and divided into 4 petri dishes (100 by 15 mm) for each termiticide–soil type tested. Untreated control soils received distilled water only. Twenty-five termites were immediately added to each petri dish of moist soil for a total of 100 termites from 1 source colony for each replicate. Termite mortality was recorded at 48 h. Probit analysis was used to calculate LC_{50} from 4 replicates for each soil type–termiticide combination (SAS Institute 1988).

Results and Discussion

Soil pH ranged from 5.4 to 5.5 for each of the soils tested (Table 1). Differences in structural components of soils included higher percentage sand in the sandy loam (71%) top soil compared with the sandy clay loam (55%) and sandy clay (52%) subsoils (Table 1). There were similar percentages of silt between the sandy loam (21%) and the sandy clay loam (24%) (Table 1). Percentage clay was closest between the sandy clay (36%) and sandy clay loam (21%) subsoils compared with the sandy loam (8%) or sand (0%) (Table 1). Organic matter was highest with the sandy loam (3.75%) and lowest with sand (<0.07%), although barely detectable levels were found in sandy clay (0.07%) (Table 1). The sandy clay loam had a percentage organic matter (1.34%) intermediate between the aforementioned soils. Cation exchange capacity was highest in the sandy loam topsoil and lowest in the sand, whereas the two subsoils were similar (Table 1).

Data from constant-exposure bioassays can show general trends concerning toxic effects of termiticides; however, they do not measure soil termiticide efficacy (Su et al. 1982). All termiticides tested, with the exception of chlorpyrifos, are effective as repellents (Su and Scheffrahn 1990, Forschler 1994). Therefore, we cannot extrapolate these data directly relative to field efficacy of the termiticides tested. However, mortality data from these tests, expressed as LC_{50}, indicate there were interactions between the termiticides and soils tested (Table 2). At the same percentage soil moisture, the toxic effects of the formulations were reduced in certain soils (Table 2).

Bioassays in sand indicated a higher level of termiticidal activity versus the other soils tested. All of the termiticides regardless of soil type, with the exception of permethrin (Dragnet and Torpedo) and the cypermethrin Prevail in sandy clay, showed a statistically significant reduction in toxicity compared with sand as judged by the lack of 95% CI overlap (Tables 2 and 3). There was >7 difference in termiticide toxicity between sand and sandy loam or sandy clay within each termiticide tested (Tables 2 and 3).

There were no general trends in termite mortality attributable to soil type alone. For example, with the exception of sand, fenvalerate (Tribute)

Table 2. Lethal concentrations (LC_{50}) and 95% CIs by termiticide and soil type for *R. flavipes* from constant-exposure bioassays

Termiticide	Soil type							
	Sand		Sandy clay		Sandy loam		Sandy clay loam	
Demon[a]	0.14	(0.05–0.28)	0.55	(0.5–0.6)	2.88	(0.4–13.5)	2.85	(2.5–3.2)
Prevail[a]	0.10	(0.07–0.1)	0.32	(0.1–0.7)	1.50	(0.5–3.3)	3.41	(1.4–6.1)
Dragnet[b]	0.82	(0.47–2.4)	1.99	(1.2–4.4)	10.30	(8.4–12.1)	14.61	(10.5–20.3)
Torpedo[b]	0.68	(0.34–1.58)	1.48	(0.7–4.2)	4.37	(2.0–8.3)	9.10	(3.2–20.4)
Tribute[c]	1.26	(1.2–1.4)	32.73	(29–37.4)	27.27	(11–479)	35.4	(10–177)
Dursban[d]	0.005	(0.001–0.01)	0.01[e]		0.51	(0.4–0.6)	0.30[e]	

[a] Cypermethrin.
[b] Permethrin.
[c] Fenvalerate.
[d] Chlorpyrifos.
[e] Because of poor fit of data to probit analysis model, CLs could not be calculated (g > 0.5)

Table 3. Slopes ± SE for LC_{50} values by termiticide and soil type from constant-exposure bioassays

Termiticide	Soil type			
	Sand	Sandy clay	Sandy loam	Sandy clay loam
Demon[a]	2.03 ± 0.27	3.13 ± 0.02	2.52 ± 0.10	1.30 ± 0.02
Prevail[a]	3.51 ± 0.09	1.85 ± 0.06	2.25 ± 0.09	1.38 ± 0.10
Dragnet[b]	4.29 ± 0.85	2.58 ± 0.06	3.30 ± 0.11	1.96 ± 0.07
Torpedo[b]	2.33 ± 0.09	2.16 ± 0.09	1.23 ± 0.23	1.27 ± 0.16
Tribute[c]	3.81 ± 0.02	2.13 ± 0.03	2.14 ± 0.09	0.97 ± 0.23
Dursban[d]	1.69 ± 0.15	0.65 ± 0.44	2.94 ± 0.03	1.46 ± 1.19

[a] Cypermethrin.
[b] Permethrin.
[c] Fenvalerate.
[d] Chlorpyrifos.

probably had a greater affinity for components of the soil matrix than the other termiticides tested. This is indicated by the 22 times higher LC_{50} estimates when comparing fenvalerate in sand with the other soils. The effect of soil type on termite mortality varied between different termiticides. LC_{50} for both cypermethrin products (Prevail and Demon) and the permethrin Dragnet showed at least a 4.5 times difference in activity between the sandy clay and the sandy loam soils. However, only Dragnet provided statistically different LC_{50} in this soil comparison. Comparing the same soils, differences were 2.9 times for the permethrin Torpedo, 50 times for chlorpyrifos (Dursban), and no difference for fenvalerate (Table 2). In contrast, there was <2 times difference in the LC_{50} between any of the termiticides when comparing the sandy loam and the sandy clay loam soils, none of which were statistically significant (Table 2).

Comparisons between soil types may indicate which individual soil components affect soil termiticide toxicity in constant-exposure bioassays. The sand and sandy clay soils had low percentage organic matter but major differences in amounts of silt and clay. The soil structural components (silt and clay) affected the termiticide Tribute (fenvalerate) most and Dursban (chlorpyrifos) and the permethrins Torpedo and Dragnet least (Table 2). Comparing the sandy loam soil, which had 50 times the organic matter but 4 times less clay than the sandy clay, only Dragnet provided significantly lower toxicity (Table 2). However, all other termiticides, with the exception of Tribute (fenvalerate), provided LC_{50} values at least 3 times higher in the same soils, indicating a trend toward reduced toxicity. A comparison between the sandy clay and the sandy clay loam is also indicative of the effect of organic matter on termiticide activity. These soils had similar percentage soil structural components (percentage sand:silt:clay) but the sandy clay loam had 19 times more percentage of organic matter (Table 1). With the exception of Tribute and Torpedo, all termiticides were significantly less active in the sandy clay loam (Tables 2 and 3). Therefore, of the termiticides tested, all but fenvalerate (Tribute) appear to interact more strongly with the organic matter content in soil than with the other soil structural components. Comparisons of percentage silt and clay are less clearly defined because of confounding influences that each of the other soil components may have on potential interactions. Cation exchange capacity, however, was not related to termite mortality.

Results of these tests illustrate the importance of stating soil physical characteristics when reporting results from soil termiticide bioassays. Smith and Rust (1993) reported differences in toxicity and repellency of termiticides tested in sand amended with cellulose or kaolin clay. Although our bioassays in natural soils were not designed to define which specific components of the soil matrix affected termite mortality, they can help explain differences reported from past studies concerning termiticide efficacy (Forschler 1994). Termite mortality between soil types within termiticide indicates that physical or chemical affinity by the active ingredient for portions of the soil matrix affected the percentage of toxin available for biological interactions. This phenonemon (bioavailability) may affect the field performance of a termiticide used in different soils. Therefore, termiticide soil bioassay efficacy must be reported in relation to soil type.

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References Cited

Chapman, R. A., C. M. Tu, C. R. Harris, and Carol R. Harris. 1982. Biochemical and chemical transformations of phorate, phorate sulfoxide, and phorate sulfone in natural and sterile mineral and organic soils. J. Econ. Entomol. 75: 112–117.

Felsot, A. S. 1989. Enhanced biodegradation of insecticides in soil: implications for agroecosystems. Annu. Rev. Entomol. 34: 453–476.

Forschler, B. T. 1994. Survivorship and tunneling activity of *Reticulitermes flavipes* (Kollar) (Isoptera: Rhinotermitidae) in response to termiticide soil barriers with and without gaps of untreated soil. J. Entomol. Sci. 29: 43–54.

Harris, C. R. 1972. Factors influencing the effectiveness of soil insecticides. Annu. Rev. Entomol. 17: 177–198.

Helling, C. S., and B. C. Turner. 1968. Pesticide mobility: determination by thin-layer chromatography. Science (Washington, DC) 162: 562–563.

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.

Macalady, D. L., and N. L. Wolfe. 1983. New perspectives on the hydrolytic degradation of the organophosphorothoate insecticide chlorpyrifos. J. Agric. Food Chem. 31: 1139–1147.

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.

SAS Institute. 1988. SAS users guide: statistics. SAS Institute, Cary, NC.

Smith, J. L., and M. K. Rust. 1993. Cellulose and clay in sand affects termiticide treatments. J. Econ. Entomol. 86: 53–60.

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.

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.

Tashiro, H., and R. J. Kuhr. 1978. Some factors influencing the toxicity of soil applications of chlorpyrifos and diazinon to European chafer grubs. J. Econ. Entomol. 71: 904–907.

Weesner, F. M. 1965. The termites of the United States. A handbook. National Pest Control Association, Elizabeth, NJ.

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