Five-Year Soil Concentrations of Seven Termiticides in Two Mississippi Soil Types¹

James H. Jarratt,² Jim Haskins³ and Reba Ingram⁴

Extension Entomologist, Department of Entomology and Plant Pathology, Box 9775, Mississippi State University, Mississippi State, MS 39762 USA

Abstract Two Mississippi soil types were treated with seven termiticides representing six active ingredients. Soil locations and types were Gulfport, MS (Poarch fine sandy loam) and Mississippi State University (Faulkner silt loam). Active ingredients used in the study are cypermethrin-D, permethrin-Dr, chlorpyrifos, isofenphos, fenvalerate, cypermethrin-Pr, and bifenthrin. The lowest registered label concentration was used for the treatments. Treatments were applied to the outside and inside walls of test foundations. Test foundations were covered after treatment to provide a simulated crawl space area and the areas were sampled independently of each other. Treated soils were sampled on day of treatment and at 3, 6, 9, 12, 18, 24, 36, 48, and 60 months post treatment, with the exception of isofenphos. This treatment was not sampled at 24 and 36 months. Soil samples were extracted with acetone and analyzed by gas liquid chromatography. Initial soil residue concentrations for all products were high and related to the dilution rate at which the compounds were mixed. Dilutions varied from a low of 0.06% (bifenthrin) to a high of 1.0% (chlorpyrifos). The products showed a gradual decline over time, with the exception of isofenphos. Most of the isofenphos degraded within the first 9 months.

Key Words Termiticide, soil concentration, soil type, cypermethrin, permethrin, chlorpyrifos, isofenphos, bifenthrin

For the past 55 years, termite control has relied on the establishment of an insecticide barrier between the structure and foraging termites in the form of a horizontal or vertical barrier. Chlordane was one of the first products used as a soil barrier. Shelford (1949) and Hetrick (1957) later published the results of a 10-year laboratory study that showed the effectiveness of other chlorinated hydrocarbons, including chlordane. Results of small plot field tests showed effective termite control for periods ranging from 24 to 34 yrs (Mauldin 1986).

More recently, Beal and Smith (1971) and Mauldin et al. (1987) have shown the effectiveness of a number of compounds for termite control in laboratory tests, as well as in small plot field trials. A variety of active ingredients were present in these studies, including chlorinated hydrocarbons, pyrethroids, and organophosphates.

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²To whom offprint requests are addressed (email: jjarratt@entomology.msstate.edu or bperrigin@ entomology.msstate.edu).

³Pesticide Division Director, Retired, Bureau of Plant Industry, Mississippi Department of Agriculture and Commerce, P. O. Box 5207, Mississippi State, MS 39762.

⁴Director of Industrial and Agricultural Services, Mississippi State Chemical Laboratory, P. O. Box 9572, Mississippi State, MS 39762.

Prior to 1988, chlorinated insecticides were widely used; however, materials such as chlordane and heptachlor became illegal to use after April 1988. Following the removal of these materials, six products filled the void in the termite control market, two organophosphates and four pyrethroids. Research continued to show that these latter insecticides were effective termite control agents (Kard et al. 1989).

The above data indicate the toxicity of various materials to termites and the efficacy of the products over time; however, they do not address concentrations that may be in the soil at various times post treatment for either a horizontal or vertical type treatment. Soil concentrations could be important in determining the reason for control failures (i.e., was the proper concentration applied during the treatment or did some factor cause an accelerated rate of degradation of the product?). This latter factor would be important, especially with the newer classes of termiticides. Two studies (McDaniel and Kard 1994, Gold et al. 1996) have addressed the concentration issue with pyrethroid and organophosphate termiticides. In these studies representing a vertical type treatment, soil was removed from a to-be-treated site, sieved, placed in a cement mixer; and treatments were applied during rotation of the cement mixer.

Soil samples taken from commercially treated structures for regulatory purposes added to the information on termiticide concentrations at various times post treatment. These concentrations were, however, variable—concentrations varied from almost non-existent to what would be termed an acceptable amount (Haskins, Mississippi Department of Agriculture, Bureau of Plant Industry, unpubl. data). For example, the samples taken by Haskins showed chlorpyrifos concentrations ranging from less than 1 ppm (4 mo in field) to 2000 ppm (4 mo in field). Concentrations of isofenphos were even lower. In one set of buildings (8 units), concentrations of isofenphos (4 mo in field) were less than 1 ppm for all samples taken around this group of buildings. Variation of this magnitude can make the assessment of an application problem suspect. Is this the norm for commercial treatments or are these samples an anomaly?

In an attempt to answer this question, the following experiment was designed and implemented. The objectives were to determine initial termiticide concentrations of registered termiticides on different soil types, to evaluate the concentrations in an unprotected vs a protected environment, and to follow these concentrations over time. Rather than using a cement mixer as an application device, treatments were made in a manner similar to a commercial application, albeit on a smaller scale.

Materials and Methods

Study sites. Locations representing two soil types were used in this study. Location one, designated GLF, is located at Gulfport, Harrison Co., MS. This site is on a Poarch fine sandy loam (clay 4.3%, silt 22.4%, sand 73.3%) with an organic matter content of 2.46% and a pH of 4.9. Cation milliequivalents per 100 gm soil are: hydrogen 5.30, potassium 0.5, calcium 0.51, and magnesium 0.12 for a total of 5.98. Site two, designated MSU (Mississippi State Univ.), is located at Starkville, Oktibbeha Co., MS. The soil at this site is a Falkner silt loam (clay 26%, silt 64%, sand 10%) with an organic matter content of 2.73% and a pH of 4.5. Cation milliequivalents per 100 gm of soil are: hydrogen 12.70, potassium 0.31, calcium 2.36, and magnesium 4.16 for a total of 19.53. Soil characteristics were determined by the Mississippi Extension Service Soil Testing Laboratory, Mississippi State University, from samples taken at

each site. A sample consisted of pooling and mixing 40 to 50 soil cores (2 \times 10.1 to 12.7 cm) and withdrawing 491 cm³ for analysis.

The soil characteristics are a general description of the site and may or may not be indicative of the characteristics in soil cores used for termiticide analysis.

Termiticides. Seven termiticides representing six active ingredients were used in the study. The products and dilution rates were: chlorpyrifos, 1.0%, (Dursban TC®, Dow AgroSciences, Indianapolis, IN); isofenphos, 0.75% (Pyfron 6®, (Miles) Bayer Environmental Science, Montvale, NJ); cypermethrin-D 0.25% (Demon TC®-D, Syngenta, Wilmington, DE); permethrin-Dr, 0.5% (Dragnet®, FMC Corporation, Princeton, NJ); fenvalerate 0.5% (Tribute®, Bayer Environmental Science); cypermethrin-Pr, 0.3% (Prevail®-Pr FMC); and bifenthrin 0.6% (Biflex®, FMC). The concentrations were the lowest allowed by the label. Treatments were applied in a completely randomized design around test foundations described below and were replicated five times at each site.

Test foundations and application. In an effort to simulate a concrete wall, test foundations measuring $76.2 \times 76.2 \times 35.56$ cm were constructed of concrete with a wall thickness of 5 cm. Foundation blocks were placed in the ground to a depth of 20.32 cm. The outside (O.S.) foundations were trenched along each of the four sides—each trench measured $72.2 \times 15.24 \times 10.16$ cm. The soil in the bottom of each trench was loosened to a depth of approximately 5 cm. A continuous trench measuring $203.2 \times 15.24 \times 10.16$ cm was dug around the inside (I.S.) of the foundation walls. Roots and small rocks were removed from the soil as it was dug from the trench; however, it was not sieved. This was done to represent a treatment as it might be done by a pest control service.

Liquid insecticides were applied (as to a shallow foundation) at a volume equivalent to 15.1-liter per 304.8 linear cm per 30.48 cm of depth, as described on the termiticide labels. The manner of application consisted of applying an appropriate volume to the loose soil in the bottom of the trench and then treating and backfilling until all trenched soil had been returned to the trench and the specified volume of insecticide solution had been used. Treatments were made with a CO_2 pressurized sprayer calibrated to deliver 3.79 L of spray per min. After the applications, the blocks were covered with a piece of plywood measuring 81.28 × 81.28 cm and weighted with a cinder block. This was done to provide protection for the inside treated surface. The inside/outside samples became the data that are reported as "position" in subsequent discussions.

Sampling time and procedures. Foundation treatments were sampled on the day of treatment (time 0: 6/91), and thereafter at 3, 6, 9, 12, 18, 24, 36, 48, and 60 months (6/96), with one exception—isofenphos was not sampled at 24 and 36 months. Samples were taken with a standard soil-sampling probe with an inside diameter of 2 cm. Two samples were taken from each foundation—one inside and one outside. A sample consisted of four pooled cores, one from each side of the block. Core depth was 12.7 cm and the top 2.54 cm was discarded according to protocols established by several state regulatory agencies during the early to mid-80s (Haskins, pers. comm.). Collected cores were placed in 266-mL clear glass jars with Teflon™ lined lids for transportation to the laboratory. The jars were kept out of direct sunlight while in the field; however, they were not stored over ice while in transit. Gulfport samples were usually taken in the afternoon and transported to the laboratory the next morning; time from the end of sampling to the laboratory was approximately 18 h. MSU samples were usually taken in the morning and were in the laboratory.

ratory by 1300 h on the day of sampling. Once they arrived at the laboratory, samples were placed in a freezer (\sim -10.0°C) until analysis.

Chemical analysis. The Mississippi State Chemical Laboratory utilized a modification of EPA Method 3550 (acetone was used as the extracting solvent rather than hexane) for analysis of all samples. Analysis was performed using a Varian 3600 gas chromatograph with an 8100 autosampler (1-microliter injections), DS-654 data station and dual columns. The primary column (0.53 mm i.d. \times 30 m) was a DB-5 (41.5 μ film thickness) and the confirmatory column (0.53 mm i.d. \times 30 m) was a DB-608 (0.83 μ film thickness). Spiked samples were run at each sample time for each treatment. Average percent recovery fell between 99.2%, S.E. 1.9, for bifenthrin and 90.3%, S.E. 2.6, for isofenphos.

Data analysis. Chemical degradation over time and differences in a protected versus a non-protected position were analyzed using linear regression and slope comparison (CoHort 6.2 Software 1998-2002, Monterey, CA) between the protected and non-protected position. All concentration (ppm) values were transformed to their corresponding natural logarithm (In) and averaged. The regression was performed using the average concentration (dependent variable) for each chemical at its corresponding sampling time (independent variable), location and position. T-tests for independent samples (SAS Inst. Inc., SAS OnlineDoc[®], Ver. 8, Cary, NC: SAS Inst. Inc., 1999) were used to evaluate differences between locations for each position and chemical with respect to initial concentrations as well as concentrations across all time periods.

Results and Discussion

Initial concentrations. Depending on dilution rate, the initial concentrations for all products were high at both locations, with concentrations tending to be higher at MSU than at GLF (Figs. 1-7). A t-test for independent samples of the initial concentrations (Table 1) between the two sites showed that the means were higher at MSU, with one exception. Cypermethrin-Pr at the inside position was significantly higher at GLF by 125.0 ppm (Table 1) than at MSU. The concentrations for two products, cypermethrin-D and chlorpyrifos, were significantly higher for both positions at MSU when compared to GLF, while three products, permethrin-Dr, isofenphos and bifenthrin had one position that was significantly higher. Although fenvalerate concentrations for both positions were higher at MSU, neither value was significant. If means were averaged over time, concentrations were higher at MSU for six of the seven compounds in the study, with the exception being isofenphos (Table 2). A highly significant difference was noted at both positions for chlorpyrifos and fenvalerate. Two compounds, permethrin-Dr and cypermethrin-Pr, had a highly significant difference for the O.S. positions at MSU, and one compound cypermethrin-D had a highly significant difference at the inside position (Table 2). P-values for the other positions and compounds varied from 0.2550 to 0.6991.

A number of studies and reviews (Chiou 1989, Hassett and Banwart 1989, Zielke et al. 1989, Sheng et al. 2001, Cox et al. 1998) have focused on soil organic matter and clays as these soil components relate to sorption of a wide range of compounds. If the soil organic matter were contributing to higher termiticide concentration at MSU, it would appear that the GLF site would have similar levels, given the similarity of organic matter content at both sites. A major difference between the two sites was the higher percent clay at MSU. Not only is the percent clay higher, the Falkner soil series



Fig. 1. Mean concentration of cypermethrin-D, 0.25% at the indicated times post treatment. Error bars represent standard error.



Fig. 2. Mean concentration of permethrin-Dr, 0.5% at the indicated times post treatment. Error bars represent standard error.



Fig. 3. Mean concentration of chlorpyrifos, 1.0% at the indicated times post treatment. Error bars represent standard error.



Fig. 4. Mean concentration of isofenphos, 0.75% at the indicated times post treatment. Error bars represent standard error.



Fig. 5. Mean concentration of fenvalerate, 0.5% at the indicated times post treatment. Error bars represent standard error.



Fig. 6. Mean concentration of cypermethrin-Pr, 0.3% at the indicated times post treatment. Error bars represent standard error.



Fig. 7. Mean concentration of bifenthrin, 0.6% at the indicated times post treatment. Error bars represent standard error.

present at MSU has an approximate montmorillonite composition of 35%, which gives the soil a high cation-exchange capacity (Glenn 1973). Montmorillonite is also classified as a 2:1 clay that is characterized by a single octahedral sheet between two tetrahedral sheets (Brady and Weil 1999). This greatly increases the surface area available for sorption. Given the differences in clay content between the two sites, it would appear that this could account for the higher concentrations recorded at MSU.

Time effects. Regression data (Ln) for all treatments are shown in Table 3 and, with one exception, all regressions were significant ($P \le 0.05$); isofenphos (MSU, O.S.) was non-significant, P = 0.1491. As hypothesized, all products exhibited negative slopes (Table 3) and the transformation of the data to natural logarithms showed a good linear fit for three of the compounds in the test. These were cypermethrin-D, cypermethrin-Pr, and bifenthrin (Table 3). The R² values ranged from 0.938 (cypermethrin-Pr, GLF, I.S.) to 0.987 (cypermethrin-D, GLF, I.S.) for these three compounds. R² values for permethrin-Dr, chlorpyrifos, and fenvalerate were lower with values ranging from 0.631 (permethrin-Dr, GLF, I.S.) to 0.912 (chlorpyrifos, GLF, O.S.) (Table 3). Concentrations for these three products were erratic (Figs. 2, 3 and 5, respectively) between sampling periods. Some post-treatment values were higher than the initial values through 18 months for all three compounds and the standard errors were higher for these compounds. These factors had an effect on the linearity of these compounds. The lowest R² values were recorded for isofenphos (Table 3) with values ranging from 0.339 (MSU, O.S.) to 0.857.

Regression slopes (Table 3) for isofenphos indicated a higher rate of degradation than for other compounds in the study, and it is the only treatment that was not higher at MSU (Table 2) over the 5-yr period. A mean difference of -230.1 (inside) and -27.3

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		Loca	ttion				
		MSU	GLF	Mean			
Treatment	Pos*	conc. ± S.E.	conc. ± S.E.	difference	đf	t-value	<i>P</i> -value
Cypermethrin-D	I.S.	370.4 ± 15.3	322.4 ± 10.3	48.0	8	2.61	0.0312
	0.S.	407.2 ± 20.7	297.8 ± 10.9	109.4	8	4.69	0.0016
Permethrin-Dr	S.	894.6 ± 67.5	805.2 ± 54.9	89.4	8	1.03	0.3344
	0.S.	1086.4 ± 36.4	717.2 ± 68.4	369.2	8	4.77	0.0014
Chlorpyrifos	<u>.</u> Si	2210.4 ± 264.3	1496.0 ± 40.1	714.4	8	2.67	0.0283
	O.S.	2343.2 ± 191.8	1515.0 ± 91.0	828.2	8	3.90	0.0045
lsofenphos	.S.I	1692.0 ± 242.9	1157.4 ± 97.9	534.6	8	2.04	0.0755
	0.S.	1855.6 ± 248.2	1102.0 ± 92.5	753.6	8	2.84	0.0217
Fenvalerate	.S.I	1228.8 ± 207.2	674.0 ± 135.1	554.8	8	2.24	0.0552
	O.S.	931.2 ± 156.7	617.2 ± 103.9	314.0	8	1.67	0.1334
Cypermethrin-Pr	.s.I	458.2 ± 28.8	583.2 ± 45.5	-125.0	8	-2.32	0.0488
	O.S.	573.6 ± 28.8	509.8 ± 25.4	63.8	8	1.66	0.1348
Bifenthrin	I.S.	157.8 ± 12.7	108.4 ± 7.7	49.4	8	3.33	0.0104
	0.S.	150.8 ± 11.9	108.2 ± 18.0	42.6	8	1.98	0.0837

* I.S. = Inside and O.S. = Outside.

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		Loca	tion				
		MSU	GLF	Mean			
Treatment	Pos*	conc. ± S.E.	conc. ± S.E.	difference	df	t-value	P-value
Cypermethrin-D	I.S.	200.3 ± 19.9	191.9 ± 13.3	8.4	ω	0.42	0.6822
;	0.S.	220.7 ± 21.0	147.8 ± 14.0	72.9	ω	7.73	<0.0001
Permethrin-Dr	.S.I	783.2 ± 39.8	737.6 ± 22.2	45.6	ω	1.23	0.2550
	0.S.	797.2 ± 41.0	600.9 ± 28.1	196.3	æ	6.56	0.0002
Chlorpyrifos	.S.I	1913.8 ± 66.2	1367.2 ± 33.0	546.6	œ	5.46	0.0006
	0.S.	2092.4 ± 76.5	1148.5 ± 50.9	943.9	ω	8.13	<0.0001
Isofenphos	.S.	320.7 ± 95.5	550.8 ± 70.7	-230.1	œ	-3.71	0.0060
	O.S.	251.2 ± 101.3	278.5 ± 60.6	27.3	80	-0.77	0.4648
Fenvalerate	<u>.</u> S	817.5 ± 40.8	551.0 ± 25.7	266.5	œ	4.37	0.0024
	0.S.	811.5 ± 38.7	584.6 ± 22.0	226.9	8	4.13	0.0033
Cypermethrin-Pr	<u>.</u> S.	379.9 ± 29.2	359.9 ± 20.8	20.0	8	0.84	0.4244
:	0.S.	404.8 ± 30.6	290.5 ± 21.6	114.3	ω	4.10	0.0035
Bifenthrin	.S.	64.5 ± 6.6	62.0 ± 4.4	2.5	8	0.40	0.6991
	0.5.	64.2 ± 6.5	55.3 ± 5.5	8.8	ω	1.85	0.1014

Table 2. t-test (for independent samples) of termiticide concentration (Conc. ppm) means (±S.E.), averaged over 10 sampling poriode between MSII (Mississinni State Ilniversity) and GLE (Gulfnort Mississinni) P < 0.05

* I.S. = Inside and O.S. = Outside.

Treatment	Location*	Position**	Slope (±S.E.)‡	R ²	P-value‡‡
Cypermethrin-D	GLF	I.S.	-0.032 (0.0013)a	0.987	<0.0001
	GLF	O.S.	-0.054 (0.0023)b	0.986	<0.0001
	MSU	I.S.	-0.044 (0.0027)a	0.97	<0.0001
	MSU	O.S.	-0.045 (0.0028)a	0.969	<0.0001
Permethrin-Dr	GLF	I.S.	-0.007 (0.0019)a	0.631	0.0060
	GLF	O.S.	-0.016 (0.0023)b	0.855	0.0001
	MSU	I.S.	-0.017 (0.0021)a	0.883	<0.0001
	MSU	O.S.	-0.016 (0.0022)a	0.881	0.0004
Chlorpyrifos	GLF	I.S.	-0.007 (0.0014)a	0.789	0.0006
	GLF	O.S.	-0.018 (0.0019)b	0.912	<0.0001
	MSU	I.S.	-0.009 (0.0013)a	0.853	0.0001
	MSU	O.S.	-0.011 (0.0019)a	0.802	0.0004
lsofenphos	GLF	I.S.	-0.112 (0.0195)a	0.857	0.0010
	GLF	O.S.	-0.102 (0.0299)a	0.660	0.0142
	MSU	I.S.	-0.102 (0.038)a	0.463	0.0369
	MSU	O.S.	-0.067 (0.04)a	0.339	0.1491
Fenvalerate	GLF	I.S.	-0.009 (0.0017)a	0.803	0.0004
	GLF	O.S.	-0.010 (0.0023)a	0.714	0.0021
	MSU	I.S.	-0.018 (0.0023)a	0.845	0.0003
	MSU	O.S.	-0.014 (0.0026)a	0.802	0.0029
Cypermethrin-Pr	GLF	I.S.	-0.024 (0.0021)a	0.938	<0.0001
	GLF	O.S.	-0.034 (0.002)b	0.973	<0.0001
	MSU	I.S.	-0.035 (0.0026)a	0.951	<0.0001
	MSU	O.S.	-0.038 (0.002)a	0.973	<0.0001
Bifenthrin	GLF	I.S.	-0.032 (0.0026)a	0.951	<0.0001
	GLF	O.S.	-0.048 (0.0021)b	0.985	<0.0001
	MSU	I.S.	-0.044 (0.003)a	0.973	<0.0001
	MSU	O.S.	-0.045 (0.0031)a	0.97	<0.0001

 Table 3. Regression line slopes (In), R² and probability values for the indicated termiticides at two locations and two within location positions

* GLF = Gulfport, MS; MSU = Mississippi State University; ** I.S. = Inside; O.S. = Outside; \ddagger Test for significance compares inside and outside slopes within a location and chemical; slopes followed by the same letter are not significantly different from each other; $\ddagger P \le 0.05$.

(outside) was recorded at GLF (Table 2). The higher concentration remaining at GLF is related to the high initial degradation that isofenphos underwent at the MSU 3 months post-treatment (Fig. 4). This compound (applied at 0.75%) had high initial concentrations (Table 1) ranging from 1102 ± 92.5 ppm (GLF, outside) to 1855.6 ± 248.2 ppm (MSU, outside). By month three, concentrations at MSU (outside) had fallen to 57.2 ± 27.2 ppm. While concentrations fell at GLF, they remained relatively high compared to the outside position at MSU. By month twelve, both positions at MSU were under 10 ppm (Fig. 4). Utilizing similar techniques, Gold (1996 et al.)

reported losses in isofenphos concentrations over time on five different soil types; percent degradation ranged from a low of 58.51 to a high of 88.04 one yr post-treatment.

Isofenphos was introduced in 1981 and was originally labeled for corn rootworm control as Amaze[®]. By 1983, control failures were being reported. It was shown that in cases of repeat applications, the product degraded much faster than the first year of use (Abou-Assaf et al. 1986, Chapman et al. 1986). Subsequent research showed that microbial (*Pseudomonas,* sp.) degradation was responsible for isofenphos control failures (Racke and Coats 1987).

If a "pre-conditioning" treatment is required for bacterial build-up, the high 3 month degradation at MSU was somewhat surprising because soil samples collected prior to treatment were negative for isofenphos or any of the other insecticides used in the test. Both study areas were undisturbed, heavily forested (MSU mixed pine and hardwood) to open pineland (GLF), and years of duff had accumulated on the surface of the soils. It is probable that high levels of soil microorganisms were present in these soils and were responsible for the steep 3-month decline in isofenphos at MSU.

Degradation over time appears to be dependent on the pesticide load that is being applied to the soil. Agricultural rates degrade at a much faster rate than those applied at termiticide rates or are applied at higher than label rates for experimental purposes. Racke et al. (1994) showed that nearly all chlorpyrifos applications made at a rate of 1000 μ g g⁻¹ (in a Florida soil) had a half-life that exceeded 24 months. In the same soil type, an application rate of 10 μ g g⁻¹ had half-lives that ranged from 3 to 24 months. Half-life expectancy varied greatly in this experiment based on soil type. In similar experiments (Wolfe et al. 1973), parathion persisted for up to 5 yrs in an accidental spill scenario of a 45.6% concentrate. Initial values ranged from 30,000 to 95,000 ppm (0 to 7.6 cm depth) and by the end of 5 yrs, concentrations were approximately 11,000 to 35,000 ppm. Field concentrations of parathion, which might have been dumped on the ground after an application, showed much quicker degradation. For example, a 0.03% parathion concentration had initial soil concentrations of about 11 ppm (2.54 to 7.6 cm depth) and at the end of 5 yrs, levels were less than 1 ppm.

The current data support these findings, in that products applied at the higher concentration lasted longer than those applied at lower concentrations, excluding isofenphos. Depending on position, initial chlorpyrifos (1.0% dilution rate) concentrations ranged from 2343.2 ± 191.8 ppm to a low of 1496.0 ± 40.1 ppm (Table 1), while bifenthrin, with the lowest tank mix concentration (0.06%), had initial concentrations from 157.8 ± 12.7 ppm to 108.2 ± 18.0 ppm (Table 1). Over the course of the 5 yrs, chlorpyrifos concentrations (Fig. 3) remained fairly stable through the first year at both locations. From this point, there was a slow decline through 60 months, with the lowest value at 481.0 ± 59.1 ppm (Table 4) and the highest ending value at 1417.2 ± 125.4 ppm (Table 4). From the initial values, bifenthrin dropped almost continually through most of the recording points. The highest ending value for this compound was 15.8 ± 3.7 ppm (Table 4) and the lowest was 6.0 ± 0.3 ppm (Table 4). Steepness of slope also was higher for bifenthrin (Table 3). Values for chlorpyrifos ranged from -0.007 ± 0.0014 (GLF, I.S.) to -0.018 ± 0.0019 (GLF, O.S.) while those of bifenthrin ranged from -0.032 ± 0.0026 (GLF, 1.S.) to -0.045 ± 0.0031 (MSU, O.S.).

Effects of treatment position. The inside of the treatment foundations received some protection due to the plywood cover, and it was thought that this protection might reduce the degradation rate; however, inside/outside slope comparisons gave

Table 4. Fifth yr concentrations of seven termiticides at Gulfport (GLF) and Mississippi State University (MSU) as compared to threshold concentrations for two termite species, *Coptotermes formosanus* and *Reticulitermes flavipes*. Threshold values taken from Su and Scheffrahn. 1990. J. Econ. Entomol. 83: 1918-1924

		Fifth yr concentrations		Threshold conc. for termite species in ppm	
		(ppm)	(ppm) ± S.E.		R.
Treatment	Pos	GLF	MSU	formosanus	flavipes
Chlorpyrifos	I.S.*	1012.0 ± 40.7	1417.2 ± 125.4	40,100	0
	O.S.**	481.0 ± 59.1	1365.6 ± 78.1	40-100	0
Permethrin-Dr	I.S.	553.0 ± 47.6	389.2 ± 47.0	-	0400
	0.S.	329.6 ± 45.5	378.6 ± 28.8	1	0.4-0.8
Fenvalerate	I.S.	370.6 ± 58.0	471.8 ± 23.0	10.90	o
	0.S.	339.6 ± 19.3	454.6 ± 8.7	40-60	0
Cypermethrin-Pr	I.S.	147.6 ± 52.0	86.8 ± 5.9	6 10	16
	0.S.	74.0 ± 9.7	85.4 ± 9.9	0-12	1-0
Cypermethrin-D	I.S.	53.2 ± 6.0	33.0 ± 5.4	6 10	16
	0.S.	10.4 ± 1.7	41.0 ± 6.2	0-12	1-0
Bifenthrin	I.S.	15.8 ± 3.7	7.6 ± 1.2	6 10	16
	0.S.	6.2 ± 1.4	6.0 ± 0.3	0-12	1-0
Isofenphos	I.S.	2.4 ± 0.5	4.3 ± 1.5	—	—
	0.S.	3.1 ± 2.0	4.3 ± 1.5	_	

* I.S., Inside; ** O.S., Outside.

mixed results (Table 3). Outside slopes were significantly steeper for treatments at GLF than the inside slopes for five of the treatments in the test—cypermethrin-D, permethrin-Dr, chlorpyrifos, cypermethrin-Pr and bifenthrin. The outside slope for fenvalerate was numerically higher than the inside, but there was not a significant difference between the two slopes. Isofenphos, the remaining product at GLF, had a steeper slope for the inside, -0.112 versus -0.102, but the values were not significantly different.

There was no significant difference between slopes for any of the treatments at MSU; however, O.S. slopes were numerically steeper for four of the compounds—cypermethrin-D, chlorpyrifos, cypermethrin-Pr and bifenthrin (Table 3). Slopes for the I.S. were steeper for permethrin-Dr, isofenphos and fenvalerate.

Given that a relatively cool dry environment exists in crawl spaces, termiticide residues might be expected to remain higher than they would around the outside perimeter of a structure. In this latter area, insecticides would be subjected to greater fluctuations in environmental factors, and concentrations might be expected to decrease at a faster rate than in the crawl space. The GLF data would appear to support this hypothesis; however, the MSU data are not in agreement. In a similar study, McDaniel and Kard (1994) did not find any differences between the inside and outside treatments. The test foundations were similar to the current study in that there was 15 to 18 cm of air space between the treatment and the bottom of the cover. Gold et al.

(1996) also reported no difference between a protected versus a non-protected area of treated soil with several termiticides; however, there was no air space involved in their study.

Based on the current data, there does not appear to be an explanation for the observed differences or lack of differences in a protected area versus a non-protected area. In a horizontal barrier study using sandy soil, Su et al. (1999) found that there was a difference in chlorpyrifos degradation between small plot versus large plots. Chlorpyrifos degraded faster in the small plots and at the edges of the larger plots, showing that the larger slabs afford a certain level of protection for chlorpyrifos. It is possible that concentrations might tend to remain higher in larger protected areas that exist in actual crawl space construction. The small space covered by the plywood (approximately 0.58 m²) does not offer the same degree of protection as would a single-family dwelling measuring 12.2×15.2 m. A structure with these dimensions would provide a covered surface of 185.4 m² which would give more separation between crawl space treatments and external environmental conditions.

Conclusions. Prior to 01 October 1996, conventional wisdom held that a liquid termiticide treatment should give at least 5 yrs control to be registered. This presumption was thought to center around the fact that HUD (Department of Housing and Urban Development) required a 5-yr pre-treatment warranty against termite infestation. On 01 October 1996, the Environmental Protection Agency issued Pesticide Regulation (PR) Notice 96-7 (EPA 730-N-96-006) which stated, "termiticide products should demonstrate efficacy for at least five yrs against termites." The above document referenced "Pesticide Assessment Guidelines, Subdivision G, Product Performance, Section 95-12 (b) (i) (C)." This notice added the strength of regulation to the 5-yr period. HUD has since dropped the 5-yr warranty in favor of a 1-yr warranty (Apgar 1999). This was done in conjunction with the National Pest Control Association (now the National Pest Management Association) and the building industry. Given the stipulations in PR 96-7, the question arises, "Do the five year termiticide concentrations in this test meet the five yr stipulation?"

In tunneling studies, Su and Scheffrahn (1990) established a range of concentrations that they termed "threshold concentrations" for a number of termiticides and defined this concentration as "the lowest concentration to totally stop termite penetration." The threshold concentrations are used for comparison with the Mississippi 5-yr concentrations; however, it must be pointed out that the Su and Scheffrahn (1990) study did not state the percentage of soil components (sand, silt and or clay) present in the tunneling chambers. Silt and clay appear to decrease the toxic affect of termiticides (Smith and Rust 1993, Forschler and Townsend 1996) when added to sand or when present in native soils. These soil components may bind with certain termiticides thereby making them less available as a toxic agent to foraging worker termites. Therefore, a true comparison may be difficult as the soil components are unknown; however, it does present a baseline that may have to be scaled up or down depending on the percentage of silt and clay.

These concentrations are reproduced in Table 4, along with the 5-yr concentrations for each product in the current study. When comparing our data with Su and Scheffrahn (1990), it would appear that the only compound close to being suspect at 5 yrs is bifenthrin. Low averages ranged from 7.6 to 6.0 ppm and the threshold concentrations are 6 to 12 and 1 to 6 ppm for *Coptotermes formosanus* Shiraki and *Reticulitermes flavipes* (Kollar), respectively. Of the ten values recorded at each site, the minimum value at GLF was 2 ppm and at MSU it was 5 ppm. When using this product in areas of known *C. formosanus* activity, the higher label rate should be used. With the exception of isophenphos, all other compounds in the study were well above threshold and should meet the 5-yr requirement. Chlorpyrifos may be an exception, as it is now registered for use at 0.5% in most states.

Isophenphos was not included in the study by Su and Scheffrahn (1990); however, it was included in another series of experiments conducted by Su et al (1993). Weathered soil cores from isophenphos treated plots were completely penetrated by both *C. formosanus* and *R. flavipes* workers 1 yr post-treatment—mortality ranged from 5.2 to 8.8%, respectively, for the two species. It is probable that termites would be able to penetrate the 5-yr isofenphos concentrations at both GLF and MSU.

If soil sampling is to be used as a measurement of a "by the label treatment," soil pH, as well as clay/organic matter measurements, should be recorded for the sampled site. As can be seen by these data, there can be a considerable difference in concentrations based on soil characteristics. High pH soils appear to cause significant degradation when compared to lower pH soils. For example, chlorpyrifos lost almost 85% (1-yr post-trt.) of the original concentration on a pH 8.2 soil at Dallas, TX (Gold et al. 1996). If pH were not taken into account, one might conclude that an inadequate application had been made.

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