Historical Review of Termite Activity at Forest Service Termiticide Test Sites from 1971 to 2004

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J. Econ. Entomol. 100(2): 488–494 (2007)

ABSTRACT The U.S. Forest Service has a long history of providing termiticide efficacy data used for product registration and labeling. Four primary test sites (Arizona and Florida, Mississippi, and South Carolina [hereafter southeast]) have been used for this purpose. Various parameters of termite attack at water-only control plots were examined in this study to assess the relative pressures of termites at each site. Termiticide studies installed between 1971 and 2001 by using ground board (GB) and concrete slab (CS) test methods were included. GB control plots were attacked 85% of the time in the southeast, about twice the rate observed in Arizona (43%). CS plots were attacked 59–70% of the time in the southeast, significantly higher than in Arizona (43%). Termites were slower to initiate attack at control plots in Arizona compared with the southeast, and they were up to twice as slow at GB controls. Once initial attack began, GB plots were reattacked at higher percentages in the southeast (89–90%) than in Arizona (67%). Reattack at CS plots ranged from 65% in Arizona and South Carolina to 76% in Mississippi. Termites caused less damage to wooden blocks in control plots in Arizona than the southeast. Attack rates at controls generally declined during the 1990s, but these rates have rebounded since 2000, except at CS plots in Arizona and South Carolina. Statistical analysis of attacks at plots treated with chlorpyrifos, cypermethrin, fenvalerate, and permethrin also was undertaken. Time to initial termite attack (failure) of the organophosphate chlorpyrifos was generally shorter in Arizona than in the southeast, whereas time to initial attack in plots treated with one of three pyrethroids (cypermethrin, fenvalerate, and permethrin) was generally longer in Arizona.

KEY WORDS termite, termiticide efficacy testing, termite attack and damage

Termiticides are one of two remaining categories of insecticides that require efficacy data for registration by the U.S Environmental Protection Agency (EPA). Typically, 6 yr of field efficacy testing is required for registration of a termiticide—1 yr to install and five subsequent years of evaluation. Once a product receives federal registration, most states require similar action before the distribution and sale of the product. Indeed, some states have the authority to not register the termiticide, or may issue a label that is more restrictive than EPA's label. Thus, termiticide registration is a lengthy and complicated process that has been debated among registrants, regulators, and the pest management industry for years. Not surprisingly, efficacy testing and standards are among the most contested issues.

Federal policy directing termiticide efficacy evaluation and testing is described in EPA's Product Performance Test Guidelines, OPPTS 810.3600 (EPA 1998) and Pesticide Registration Notice 96-7 (EPA 1996). These documents serve as guidelines that enable EPA to consider efficacy as a factor in registration along with toxicology and environmental data consistent with their primary mission—to protect human health and the environment. For example, OPPTS 810.3600 states, "The effectiveness of prophylactic termite treatments is measured by the time over which the toxic barrier remains effective in resisting penetration by the termites." "Data derived from [concrete slab, ground board, or stake tests] should provide complete resistance to termite attack for a period of five years, based on annual reinspection. The tests should be in at least three geographic areas that provide year-around pressure (usually in the southern U.S.)." A general interpretation of the guidelines can be restated as follows: for a candidate termiticide to be successful it *should* be 100% effective for at least 5 yr in 10 replicated concrete slab (CS) plots at each of four southern test sites. Because EPA places a higher priority on toxicology and environmental data, this policy is not an absolute rule. Product performance can vary somewhat among candidate termiticides under the guidelines.

The U.S. Forest Service has the oldest federal termite project in the country, initiated in the mid-1930s. It began testing chemicals as novel soil treatments for

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termite control in 1939 (Beal 1984). Standardized field methods were developed at this time, and they included the stake and ground board (GB) tests. During the 1940s, termiticide testing was conducted largely for the U.S. military, and the ground board test became the principal method for evaluating chlorinated hydrocarbons. The stake test was discontinued in 1958, because it produced similar results to the ground board test. In 1967, the ground board test took on a secondary role, because the emerging termiticides (e.g., organophosphates, pyrethroids, and carbamates) were prone to degradation and leaching in the exposed plots. The concrete slab test was introduced at this time to simulate preconstruction treatments, and it has become the principal test method used in registration.

Forest Service tests have been conducted at numerous field sites over the years, including those in Arizona, Florida, Louisiana, Maryland, Mississippi, South Carolina, Midway Island, and the Republic of Panama (Beal 1980, Mauldin et al. 1987). Currently, termiticides are evaluated at four primary sites in Arizona and Florida, Mississippi, and South Carolina [hereafter southeast]. These sites represent semiarid (Arizona), temperate (South Carolina), and subtropical climates (Florida and Mississippi). Soil pH ranges from approximately neutral (6.9, Arizona) to moderately acidic (4.8, Florida). *Reticulitermes* Holmgren species are found at the southeastern sites, and *Heterotermes aureus* (Snyder) is found in Arizona. Climatic conditions, soil characteristics, and termites at each site were described by Beal (1980, 1986).

Virtually all restricted-use termiticides have undergone Forest Service testing before registration. In field trials, termite pressure at treated plots is an inherent assumption of the test because a lack of pressure equates to an invalid assessment of product performance. Thus, control plots are installed to estimate the relative pressure of termites at treated plots. Termite pressure is not easily assessed, e.g., it can be estimated as the percentage of attacks at control plots, calculated as the cumulative attack among all replicates and years or as the number of replicates attacked at least once over all years. The latter approach will produce higher percentages than the former, especially at sites with minimal pressure, but it is unclear which estimate provides a better indicator of relative pressure. Furthermore, there is no recognized percentage below which a test is declared "invalid." The present federal regulatory "standard" is very high (e.g., no attacks at any treated plot over 5 yr), and low attack at control plots does not eliminate the possibility of attacks at treated plots. Although termite pressure at test plots is an important issue, the validity of tests based upon attacks at control plots has been left to the regulators to decide.

Detailed historical estimates of termite attacks at wooden test blocks in Forest Service plots have not been compared among test sites; yet, this information is used to assess product performance and ultimately registration. Thus, we evaluated termite attacks at control plots from the four test sites over the past several decades. The time to failure (longevity) of selected termiticides also was compared at each site. Information from this evaluation can be used by regulatory officials, registrants, the pest control industry, and the general public to assess differences in termite pressure among test sites under which termiticides are evaluated.

Materials and Methods

GB and CS tests are currently used by the EPA and thus the Forest Service to evaluate soil-applied termiticides. In the GB test, a known concentration of chemical solution is applied at an equivalent preconstruction volume of 4.07 liters/m^2 (or 1 gallon/square foot) to a 43.2- by 43.2-cm area of soil (plot) that has been cleared of vegetation and leaf litter. After the chemical has soaked into the soil, an untreated sapwood pine board (14.0 cm in length by 14 cm in width by 1.9 cm in thickness) is centered on top of the treated soil and weighed down with a brick. Termites must penetrate the treated soil in these plots to attack the wood.

The CS test is designed to simulate conditions under a structure with a concrete slab foundation (Beal 1986). This test was previously known as the modified ground board test (Beal 1986). Soil is treated as in the GB test and then covered with a polyethylene vapor barrier. A 10-cm-diameter capped plastic pipe is centered in the plot and serves as an inspection port. The soil and vapor barrier surrounding the inspection port are covered with concrete. The vapor barrier is removed from inside the pipe and a piece of southern yellow pine board (6.4 cm in length by 8.9 cm in width by 3.8 cm in thickness) is placed on the soil inside the pipe (Kard et al. 1989).

Each treatment concentration and a water-only control are replicated 10 times per test method. Plots (replicates) are set out in a randomized complete block design. Boards are examined annually and, for control plots, replaced if attacked by termites.

Attack and Damage at Control Plots. Termite attack and damage to boards in GB and CS control plots were obtained from 20 field studies installed between 1971 and 2001. Each study consisted of several concentrations of from one to three termiticides plus water-only controls applied to CS and GB plots.

Termite attack was defined as the presence of termites or damage to pine boards in control plots at the time of annual inspection. Time to initial attack was computed for each plot in each study. This represents the number of years it took termites to first attack a wooden block in a plot. The percentage of years that each plot was attacked over all years also was computed for each study, as was the percentage of years that each plot was attacked from first attack. Termite damage was rated according to the U.S. Forest Service "Gulfport" scale, where 0 is no damage, 1 is nibbles to surface etching, 2 is light damage with penetration, 3 is moderate damage, 4 is heavy damage, and 5 is destroyed. Average damage was computed for each attacked control plot (e.g., excluding years with no damage).

A mixed model analysis of variance (ANOVA), PROC MIXED (SAS Institute 2001), was used to compare sites with respect to time to initial attack, percentage of time (years) attacked, average damage, and percentage of years attacked from first attack. Random effects in the model include study, replication within study, and interactions between site and study as well as site, study, and replicate. Weighting was used to account for differing study lengths. Least square means were separated using the PDIFF option (SAS Institute 2001).

The percentage of control plots attacked in each study was computed by calendar year and chronological year (e.g., years from installation), and these values were averaged across all studies by like year at each site. Mean percentage of attacks by calendar year between 1972 and 1979 were dropped because of small sample sizes (e.g., <4). Mean percentage of attacks by chronological year for Arizona and the combined southeastern sites was plotted using SigmaPlot version 9.0 (Systat, Inc., Point Richmond, CA).

Trend analysis was conducted to investigate termite attack over time at each test site. Using PROC MIXED (SAS Institute 2001), the percentage of CS and GB plots attacked in each study was computed for each calendar year, and these percentages were subjected to regression analysis to evaluate trends over time. A fourth order polynomial was fitted to the data. If not significant at the 0.05 level, the model was then refit with the next lower order polynomial. This process was continued until a significant fit was achieved; thus, the final model chosen to represent the trend was that with the coefficient for the highest order term significant at the 0.05 level. Study was taken to be a random effect in the model, and a first order autoregressive correlation structure was used to account for repeated sampling of study plots over time (Littell et al. 2006). Mean percentage of attacks over all studies was plotted by calendar year for each site, and model results were overlaid for trend comparisons (note that models were not fit to the plotted data).

Attack at Treated Plots. Termite attack on wood in treated CS plots from selected studies was analyzed to provide an indication of termite pressure on organophosphate and pyrethroid test plots at each test site. The three selected studies each contained multiple compounds applied at multiple rates; however, only the compounds and rates listed below were included in the evaluation: chlorpyrifos (Dursban) initiated in 1971 and applied at 0.1, 0.25, 0.5, 1.0, and 2.0% (AI); fenvalerate (Pydrin) and permethrin (Pounce) initiated in 1977 and applied at 0.125, 0.25 and 0.5% (AI); and cypermethrin (Cymbush) (1982) and permethrin (Ectiban) (1980) applied at 0.125, 0.25, and 0.5% (AI).

Survival analyses based on Kaplan–Meier survival curves by using PROC LIFETEST (SAS Institute 2001) compared the times of attack at treated concrete slab plots in these studies. Attack was defined as the presence of termites or wood damage to blocks at the time of inspection. PROC LIFETEST includes censored observations in the analysis which, in this case, are treated plots that were never attacked. Because some plots were never attacked (e.g., those at higher rates), the 25th percentile of attack times was chosen to represent typical performance. Comparisons, however, are based on the entire survival curve. Differences between sites were tested for each concentration within a chemical. Sites within concentrations were subjected to pairwise tests of equality in the event of an overall site effect in the above-mentioned test. Wilcoxon tests were used in PROC LIFETEST to test for significant differences among sites both in overall site comparisons as well as pairwise comparisons (SAS Institute 2001). A significance level of 0.05 was used for all hypothesis tests.

Table 1. Mean number of years to initial termite attack at CS and GB control plots in termiticide studies at Forest Service test sites between 1972 and 2004

Site	CS	GB
Arizona	2.4 ± 0.2a	3.1 ± 0.3a
Florida	1.6 ± 0.2b	1.4 ± 0.1b
Mississippi	1.3 ± 0.2b	1.3 ± 0.1b
South Carolina	1.6 ± 0.2b	1.4 ± 0.1b

Means in a column not followed by the same letter are significantly different ($P \leq 0.05$) as determined by PDIFF (SAS Institute 2001).

Results and Discussion

Attack at Control Plots. Significant differences in the mean number of years to initial termite attack at CS ($F = 7.62$; df = 3, 49; $P = 0.0003$) and GB ($F = 47.90$; df = 3, 50; $P < 0.0001$) control plots were found among sites (Table 1). Termites in Arizona were slower to attack boards in CS plots and twice as slow to attack wood in GB plots as termites in the southeast. Times to initial attack at CS and GB plots among sites in the southeast were not different.

Attack rates at Arizona and the combined southeastern sites during the first 10 yr of studies are given in Fig. 1. Attacks at control plots occurred much more rapidly and generally reached a higher asymptote in the southeast compared with Arizona. For example, attack at CS plots in the southeast peaked at ≈68% in the second year, but attack was protracted over 10 yr in Arizona, only achieving ≈59% at the end of this period. The difference in the attack sequence for GB was even greater between regions, with ≈88% of plots attacked in the southeast by the third year, compared with a steady increase in attacks over the 10-yr period in Arizona, culminating at 64%.

The mean percentage of years control plots were attacked (among years) was significantly lower in Arizona than the southeastern sites for CS plots ($F = 11.10$; df = 3, 54; $P < 0.0001$) and GB plots ($F = 58.46$; df = 3, 51; $P < 0.0001$) (Table 2). The frequency of attacks at CS plots was significantly greater in Mississippi (70%) than in South Carolina (59%), whereas Florida (62%) fell between the two sites. GB plots in the southeast were attacked ≈85% of the time versus 43% in Arizona.

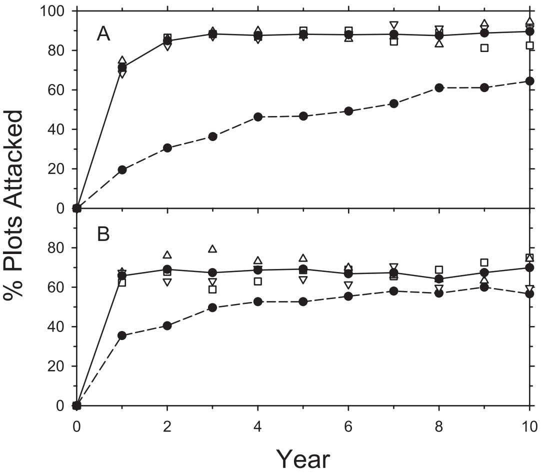

Fig. 1. Mean percentage of (A) ground board and (B) concrete slab control plots attacked by termites by chronological year for the first 10 yr of studies in Arizona (circles, dashed line), Florida (squares), Mississippi (triangles), South Carolina (inverted triangles), and the combined southeastern sites (closed diamonds, solid line).

Persistence of attack at each site was evaluated using the percentage of years control plots were attacked from first attack (Table 2). Termites in Mississippi (76%) were more persistent in reattacking CS plots ($F = 3.06$; df $= 3, 53$; $P = 0.0361$) than termites in Arizona (65%) and South Carolina (65%). Reattacks at CS plots in Florida (69%) were not statistically different from Mississippi or Arizona and South Carolina. Termites in the southeast (89–90%) were more persistent in reattacking GB plots ($F = 28.85$; df $= 3, 51$; $P < 0.001$) than termites in Arizona (67%).

The mean percentages of CS plots attacked by calendar year in Arizona ranged between 60 and 80% ($\bar{x} = 70\%$) from 1980 to 1990 (Fig. 2A). Attacks peaked at 90% in 1991, declined sharply to 19% by 2000, and recovered somewhat thereafter. In Florida (Fig. 2B), mean attacks at concrete slabs also ranged between 60 and 80% ($\bar{x} = 72\%$) through 1994, declined to 45% by 2001, and rebounded through the present. Mississippi (Fig. 2C) experienced two unusually low years of attack in 1981 (42%) and 1991 (47%) but otherwise remained relatively stable through 1996, ranging between 64 and 83%. Attacks declined from 80 to 34% during the next 4 yr but have rebounded sharply since. Peak attack in South Carolina (Fig. 2D) occurred in 1981 at 85%. Attacks declined slowly but steadily during the next 23 yr, reaching a low of 26% in 2004. Unlike other sites, no recent recovery in attacks at CS plots has been observed in South Carolina. The fourth order polynomial fitted to percentages of CS plots attacked in individual studies accurately reflects the trends in mean attacks over all studies (Fig. 2A–D; Table 3).

Table 2. Mean percentage of time concrete CS and GB control plots were attacked over all years and from first attack in termiticide studies at Forest Service test sites between 1972 and 2004

Site	CS		GB	
	Over all years	From first attack	Over all years	From first attack
Arizona	43.1 ± 3.7a	65.4 ± 3.4a	42.8 ± 2.8a	67.2 ± 2.1a
Florida	61.5 ± 3.9bc	69.0 ± 3.4ab	84.9 ± 3.0b	89.6 ± 2.1b
Mississippi	70.2 ± 3.7c	76.0 ± 3.2b	84.7 ± 2.8b	90.0 ± 2.0b
South Carolina	59.3 ± 3.8b	64.9 ± 3.3a	85.0 ± 2.9b	89.3 ± 2.1b

Means in a column not followed by the same letter are significantly different ($P \leq 0.05$) as determined by PDIFF (SAS Institute 2001).

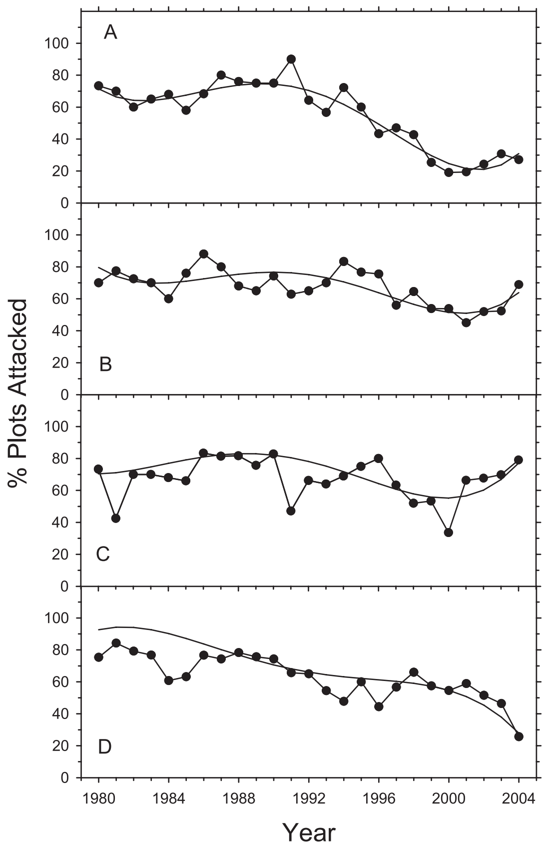

Fig. 2. Mean percentage of concrete slab control plots attacked by termites over all studies (closed circles) for each calendar year in (A) Arizona, (B) Florida, (C) Mississippi, and (D) South Carolina. Solid line represents polynomial regression fitted to the percentage of concrete slab control plots attacked in each study per year.

Mean percentages of GB plots attacked by calendar year in Arizona increased from 32% in 1982 to 77% in 1991 (Fig. 3A). Attacks declined 28 percentage points the following year (1992), and remained relatively stable for the next 7 yr, only to decline sharply again in 2000 to 23%. Attacks have recovered since. In Florida (Fig. 3B), mean attacks generally increased from 67 to 97% over an extended period between 1980 and 1996, declined to 74% by 1999, and recovered somewhat erratically thereafter. Attacks at Mississippi (Fig. 3C) GB plots started at 73% in 1981, stabilized between 93 and 96% during 1984–1995, declined from 93 to 54% over the next 5 yr, and rebounded sharply thereafter. Attacks in South Carolina (Fig. 3D) were more uni-

Table 3. Statistics of highest order coefficient of regressions of percentage attack on years for each test site

Site	Coefficient	*F* value	df	*P* value	R^2
		Concrete slab			
Arizona	Quartic	10.93	1,180	0.0011	0.52
Florida	Quartic	8.59	1,183	0.0038	0.17
Mississippi	Quartic	3.93	1,178	0.0490	0.09
South Carolina	Quartic	4.05	1,175	0.0457	0.22
		Ground board			
Arizona	Cubic	12.04	1,176	0.0007	0.03
Florida	Quadratic	14.28	1,180	0.0002	0.09
Mississippi	Cubic	15.03	1,174	0.0001	0.14
South Carolina	Cubic	3.95	1,170	0.0485	0.12

form than other sites, ranging from 80 to 96% between 1980 and 2002. Attacks at GB plots dropped to 67% in 2003, but rose to 78% in 2004. Second and third order polynomials fitted to percentages of GB plots attacked in individual studies accurately describe the trends in mean attacks over all studies, although in Arizona the model under predicted the mean values throughout most of the time period (Fig. 3A–D; Table 3).

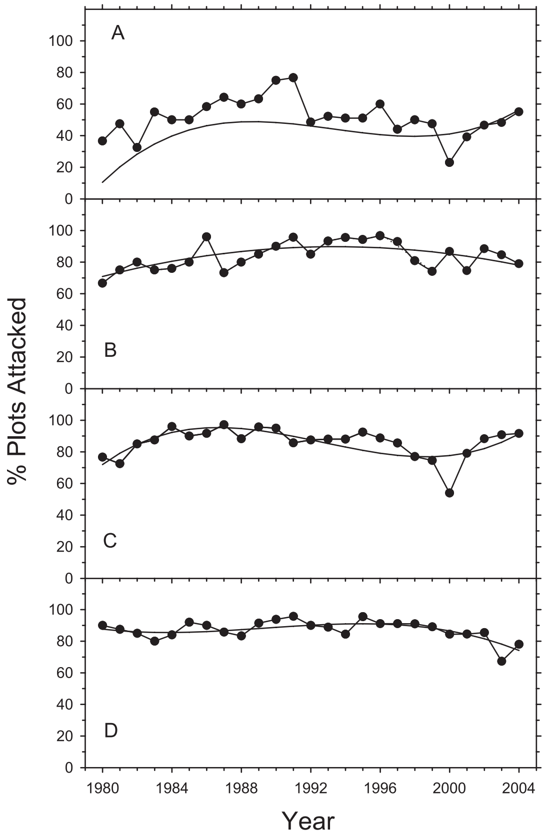

Fig. 3. Mean percentage of ground board control plots attacked by termites over all studies (closed circles) for each calendar year in (A) Arizona, (B) Florida, (C) Mississippi, and (D) South Carolina. Solid line represents polynomial regression fitted to the percentage of ground board control plots attacked in each study per year.

Table 4. Mean termite damage (Gulfport scale) to test blocks at attacked CS and GB control plots in termiticide studies at Forest Service test sites between 1972 and 2004

Site	CS	GB
Arizona	2.6 ± 0.07a	2.6 ± 0.07a
Florida	3.4 ± 0.07bc	3.2 ± 0.06b
Mississippi	3.5 ± 0.06c	3.5 ± 0.06c
South Carolina	3.3 ± 0.06b	3.2 ± 0.06b

Means in a column not followed by the same letter are significantly different ($P \leq 0.05$) as determined by PDIFF (SAS Institute 2001).

With the exception of Arizona, the annual percentage of GB attacks was generally higher and less variable among years than CS plots (Figs. 2 and 3). These results are consistent with those from Table 2. GB plots are larger and have more surface area in contact with the soil than boards found in concrete slabs (195 versus 34 cm^2); thus, GB plots may be more apparent to foraging termites. Because GB plots are directly exposed to the weather, higher humidity and temperatures in the southeast may keep GB plots attractive to termites most of the year. Conversely, the hot, arid conditions in Arizona may limit attacks at GB plots. Termite species, species abundance, and behavior also may explain differences in attacks at CS and GB plots as well as the lower attack rates between Arizona and the southeast (Table 2). For example, Jones et al. (1987) showed that the primary termite species in Arizona, *H. aureus,* prefers to attack baits around vegetation. Ettershank et al. (1980) hypothesized that foragers may detect subsurface thermal variation between vegetated and nonvegetated sites, and they suggested that potential food on the soil surface casts thermal shadows to which termites respond. Concrete slabs in Arizona may produce larger thermal shadows that *H. aureus* prefers compared with the exposed wood in GB plots. In addition, colony size of *Reticulitermes* species in the southeast tends to be larger than *H. aureus* in Arizona (Howard et al. 1982, Jones 1990), and greater colony sizes could result in higher attack probabilities (Table 2) and greater damage (Table 4) in the southeast.

Discounting differences in the magnitude of attack at GB and CS plots, annual trends in attacks within and among sites were fairly consistent between the two plot types (Figs. 2 and 3). For example, attacks at control plots began to decline in Arizona, Florida, and Mississippi between 1991 and 1996 and subsequently began to recover between 2000 and 2001. These trends were less apparent in South Carolina, where attacks at CS plots underwent a long decline not observed in GB plots.

Damage to Control Plots. Termites in Arizona not only took longer to attack control plots (Table 1) but also the degree of damage to wood at both CS (F = 33.40; df = 3, 53; $P < 0.0001$) and GB (F = 52.13; df = 3, 51; $P < 0.0001$) was less than in the southeast (Table 4). The amount of damage to wood in CS and GB plots was similar for all sites, although statistical comparisons were not made. Average damage at CS plots in Mississippi was greater than that observed in South

Table 5. Kaplan–Meier estimates (95% CI) of 25th percentile attack times (years) at concrete slab plots treated with chlorpyrifos (initiated in 1972), fenvalerate and permethrin (initiated in 1977), cypermethrin (1982), and permethrin (1980) in termiticide studies at Forest Service test sites

Compound	% (AI)	Arizona	Florida	Mississippi	South Carolina
Chlorpyrifos	0	1 (†–†)b	1 (†–†)b	1 (†–†)b	2 (1–4)a
	0.1	3 (†–†)c	5 (3–6)b	3 (2–3)c	6 (5–8)a
	0.25	4 (3–5)b	7 (4–10)a	7 (5–8)a	8 (7–9)a
	0.5	7 (5–9)a	9 (8–11)a	8 (4–9)a	10 (8–11)a
	1.0	9 (7–9)c	17 (9–†)a	16 (12–17)a	13 (13–16)b
	2.0	13 (12–15)c	23 (20–†)a	19 (16–22)b	23 (22–25)a
Fenvalerate	0	2 (2–3)a	1 (1–2)b	1 (†–†)b	1 (1–2)b
	0.125	8 (8–9)a	3 (2–†)a	2 (2–4)b	3 (2–5)a
	0.25	12 (9–†)a	6 (2–8)bc	4 (3–5)c	8 (5–10)b
	0.5	14 (8–17)a	9 (4–†)a	10 (8–†)a	14 (5–18)a
Permethrin	0	2 (2–3)a	1 (1–2)b	1 (†–†)b	1 (1–2)b
	0.125	9 (7–12)a	3 (2–6)b	2 (†–†)c	2 (†–†)c
	0.25	14 (9–16)a	5 (3–8)b	2 (†–†)c	2 (1–3)c
	0.5	20 (14–†)a	5 (4–21)b	7 (6–8)b	9 (5–11)b
Cypermethrin	0	1 (†–†)a	1 (†–†)a	1 (†–†)a	1 (†–†)a
	0.125	6 (2–8)a	4 (2–†)a	4 (2–†)a	4 (3–5)a
	0.25	6 (5–†)b	15 (12–†)a	7 (4–†)b	5 (5–†)b
	0.5	6 (2–†)b	13 (6–†)ab	16 (8–†)a	13 (13–†)ab
Permethrin	0	1 (†–†)a	1 (†–†)a	1 (1–2)a	1 (†–†)a
	0.125	11 (6–†)a	3 (3–6)b	1 (1–2)c	1 (†–†)c
	0.25	11 (10–†)a	10 (4–14)a	3 (3–5)b	1 (1–4)b
	0.5	17 (12–†)a	14 (7–†)a	5 (4–7)b	5 (2–9)b

Estimates in a row not followed by the same letter are significantly different ($P \leq 0.05$).
† Insufficient data to calculate confidence interval(s).

Carolina but not different from that of Florida. Damage in Florida and South Carolina was not significantly different. Average damage at GB plots was greatest in Mississippi, identical in Florida and South Carolina, and least in Arizona.

Attack at Treated Plots. CS plots treated with chlorpyrifos (Dursban) at 0.25% ($\chi^2 = 24.42$, df = 3, $P < 0.0001$), 1.0% ($\chi^2 = 38.04$, df = 3, $P < 0.0001$), and 2.0% (AI) ($\chi^2 = 52.67$, df = 3, $P < 0.0001$) had shorter 25th percentile attack times in Arizona than other sites (Table 5). At 0.1% ($\chi^2 = 21.25$, df = 3, $P < 0.0001$) and 2.0% (AI) ($\chi^2 = 52.67$, df = 3, $P < 0.0001$), Arizona and Mississippi had significantly shorter times than Florida and South Carolina. There were no significant differences among sites at the 0.5% rate. Termites in the chlorpyrifos study took significantly longer ($\chi^2 = 12.7341$, df = 3, $P = 0.0052$) to attack 25% of the control plots in South Carolina compared with other sites.

Fenvalerate (Pydrin) and permethrin (Pounce) were installed in the same study in 1978. For fenvalerate, Mississippi had the shortest ($\chi^2 = 19.26$, df = 3, $P < 0.0001$) time to 25% failure at the 0.125% rate (Table 5). Mississippi had a shorter ($\chi^2 = 25.78$, df = 3, $P < 0.0001$) time than Arizona and South Carolina at 0.25% (AI); however, there was no significant difference between Mississippi and Florida. No significant differences were observed among sites at 0.5% (AI). For permethrin, Mississippi and South Carolina had significantly shorter first quartile attack times than Arizona and Florida at 0.125% ($\chi^2 = 30.95$, df = 3, $P < 0.0001$) and 0.25% (AI) ($\chi^2 = 26.44$, df = 3, $P < 0.0001$), and times were significantly shorter ($\chi^2 = 11.30$, df = 3, $P = 0.0102$) for Mississippi, Florida, and South Carolina than for Arizona at the 0.5% rate. Termites in the fenvalerate/permethrin study took significantly longer ($\chi^2 = 24.04$, df = 3, $P < 0.0001$) to attack 25% of the control plots in Arizona compared with the other sites.

No significant differences were observed among sites in the 25th percentile attack times at plots treated with 0.125% cypermethrin (Table 5). At 0.25% (AI), Florida had a significantly longer ($\chi^2 = 11.21$, df = 3, $P = 0.0106$) time than the other sites, which were not significantly different from one another. Treated with 0.5% cypermethrin, plots in Arizona reached the first quartile attack time significantly faster ($\chi^2 = 13.74$, df = 3, $P = 0.0033$) than Mississippi. There was no significant difference in these times between Mississippi, Florida, and South Carolina at the 0.5% rate. For permethrin, Mississippi and South Carolina had the shortest ($\chi^2 = 34.94$, df = 3, $P < 0.0001$) time at 0.125% (AI), Florida was intermediate, and Arizona had the longest time. At 0.25% ($\chi^2 = 34.56$, df = 3, $P < 0.0001$) and 0.5% (AI) ($\chi^2 = 19.38$, df = 3, $P = 0.0002$), Mississippi and South Carolina again had significantly shorter times than Arizona and Florida. There was no difference ($\chi^2 = 3.5657$, df = 3, $P = 0.3123$) in 25% attack times among control plots in the cypermethrin/permethrin study (Table 5).

These results indicate differences in times to failure of termiticide chemistries between Arizona and southeast. For example, 25th percentile attack times of the organophosphate, chlorpyrifos, was shorter in Arizona than other sites at three of the five rates (0.25, 1.0, and 2.0%), whereas attack times of the pyrethroids (cypermethrin, fenvalerate, and permethrin) were generally longer in Arizona. Control data from the individual studies suggests that these differences are not related to differences in termite pressure among sites (Table 5). The higher soil pH and a hotter arid climate in Arizona compared with the southeast certainly contributed to the faster degradation of the organophosphate compared with the pyrethroids (Racke et al. 1988). Termite penetration through termiticide treatments is not only due to termite pressure but also to environmental factors that affect the behavior of termiticides in the soil. Unfortunately, termite pressure cannot be separated from environmental influences on termiticides by using these field results.

The U.S. Forest Service's Termiticide Testing Program has provided data on product performance of termiticides for decades. Although recent attack rates at control plots were at or near historic low levels, these rates have rebounded to more normal levels during the past few years. Exceptions include attacks at concrete slab control plots in Arizona and South Carolina. Because of the many and dynamic factors that regulate attack at test plots, most beyond human control, fluctuations will surely continue. Nevertheless, there is an expectation that adequate termite pressure at treated plots will continue at these test sites, ensuring viable test results into the future.

Acknowledgments

We thank Craig Bell and Don Fye for digitizing data from termiticide studies. We also acknowledge those who have contributed to the testing program in the past: Ray Beal, V. A. Cachot, R. E. Daniel, J. L. Etheridge, G. N. Johnson, H. R. Johnson, B. M. Kard, E. J. Mallette, J. K. Mauldin, N. M. Rich, E. L. Scruggs, and K. E. Tynes. We thank Brad Kard and Jeff Willers for helpful reviews of the manuscript.

References Cited

Beal, R. H. 1980. New materials for termite control. Pest Control 48: 11, 46, 48, 50, 52, 54.

Beal, R. H. 1984. Termiticide research update. Pest Control Technol.. 12: 71–72, 74.

Beal, R. H. 1986. Field testing of soil insecticides as termiticides. *In* Proceedings of the 17th Annual Meeting International Research Group on Wood Preservation, Working Group 1b, 26–30 May 1986, Avignon, France. IGR Secretariate, Stockholm, Sweden. Document IRG/WP/1294.

[EPA] Environmental Protection Agency. 1996. Environmental Protection Agency's pesticide registration notice 96-7. EPA 730-N-96-006. Environmental Protection Agency, Washington, DC.

[EPA] Environmental Protection Agency. 1998. Environmental Protection Agency's product performance test guidelines (OPPTS 810.3600). EPA 712-C-98-424. Environmental Protection Agency, Washington, DC.

Ettershank, G., J. A. Ettershank, and W. G. Whitford. 1980. Location of food sources by subterranean termites. Environ. Entomol. 9: 645–648.

Howard, R. W., S. C. Jones, J. K. Mauldin, and R. H. Beal. 1982. Abundance, distribution, and colony size estimates for *Reticulitermes* spp. (Isoptera: Rhinotermitidae) in southern Mississippi. Environ. Entomol. 11: 1290–1293.

Jones, S. C. 1990. Delineation of *Heterotermes aureus* (Isoptera: Rhinotermitidae) foraging territories in a Sonoran desert grassland. Environ. Entomol. 19: 1047–1054.

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

Kard, B. M., J. K. Mauldin, and S. C. Jones. 1989. Evaluation of soil termiticides for control of subterranean termites (Isoptera). Sociobiology 15: 285–297.

Littell, R. C., G. A. Milliken, W. W. Stroup, R. D. Wolfinger, and O. Schabenberger. 2006. SAS for mixed models, 2nd ed. SAS Institute, Cary, NC.

Mauldin, J. K., S. C. Jones, and R. H. Beal. 1987. Gulfport termiticide study: viewing termiticides. Pest Control 55: 1–7.

Racke, K. D., J. R. Coats, and K. R. Titus. 1988. Degradation of chlorpyrifos and its hydrolysis product, 3,5,6-trichloro-2-pyridal, in soil. J. Environ. Sci. Heath B. 23: 527–539.

SAS Institute. 2001. User's guide, version 8e. SAS Institute, Cary, NC.

Received 7 April 2006; accepted 18 December 2006.