

# EVALUATION OF TERMITICIDES RESIDUES AND BIOAVAILABILITY FROM FIVE SOIL TYPES AND LOCATIONS IN TEXAS

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**Abstract**—The results of a four year study with six termiticides including: bifenthrin, chlorpyrifos, cypermethrin, fenvalerate, permethrin, and isofenphos indicate significant differences in effectiveness among products applied to different soil types in Texas. Each of the five field test locations represents very different soil types and environmental conditions. Test locations within Texas included: Lubbock, Dallas, Overton, Corpus Christi and College Station. Termiticides were applied in 1990 with soil samples taken from the replicated treatment plots at 1 and 6 months, and then annually through four years. Soil residues of termiticides were measured with gas chromatography. The amount of pesticide remaining in each sampling period indicates a significant loss of termiticide by the fourth year of the test. The bioavailability of termiticide remaining in the soil was estimated through bioassays utilizing field collected subterranean termites (*Reticulitermes flavipes* (Kollar)). Both tunneling distance and mortality were used as indicators of termiticide activity and availability. The results of the bioassays confirm the findings of the residue analysis portion of the project. The most stable termiticides, through four years, were permethrin and fenvalerate. Isofenphos was the least stable with significant loss of activity within 24 months post-application. The most challenging conditions, in terms of effective termiticide residuals retained through time, were alkaline soils with high clay content and organic compositions greater than 1%. The most favourable soils were those that are acidic with low clay content and low organic content.

## INTRODUCTION

This research project was initiated at the request of representatives of the Texas Pest Control Association, based on their perspective that termiticides available in 1988–90 were not as effective in controlling termites as were pesticides used in the past including aldrin, chlordane and heptachlor. The professional pest control industry apparently believes that retreatment rates during the first year were higher with the modern termiticides than they had been in the past with chlorinated hydrocarbons. Efforts to decrease the need for retreatments have been made (Potter, 1994), but the problem persists. Unfortunately, records which we examined were incomplete and direct comparisons between retreatment rates were not possible. It was agreed that we would undertake a research project to examine the efficacy and residual activity of termiticides under Texas conditions.

Subterranean termites have been collected from all regions of Texas (Howell *et al.*, 1987). They are considered to be of major economic importance in terms of the damage they do, the cost of repairs and the costs associated with termite prevention and control. McLlveen *et al.* (1993) estimated that the value of termites to the economy of Texas exceeded \$250 million/year based on a survey of 3000 licensed pest control companies. Total loss due to termites in the United States was estimated at \$1.7 billion/year (Gold *et al.*, 1993). It has been estimated that termites do more damage than all tornadoes, hurricanes and wind storms combined and involve five times as many houses as fire (Granovsky, 1983; Granovsky, 1979; Granovsky and Sadberry, 1983). Along the coastal regions of Texas, by the time a structure is 40 years old the probability of infestation with one or more species of termites exceeds 90%. Kamble *et al.* (1984) reported that in colder climates, such as represented by Nebraska, that approximately 5% of structures were infested with termites at any point in time.

The modern prevention and control of termite damage has relied primarily on the use of termiticides (Gold *et al.*, 1994). There have been relatively few changes associated with the chemical control of termites for over 50 years. The basic concept of establishing a chemical barrier around a structure apparently is as effective today as it has been in the past. There is considerable information available about the merits of soil applied termiticides which act as barriers to tunneling termites (Su and Scheffrahn, 1990; Su *et al.*, 1995; Jones, 1990; Smith and Rust, 1990, 1991, 1992; Grace, 1991; Gold *et al.*, 1994; and Forschler, 1994). The major changes have come in the form of different chemical groups of termiticides, particularly organophosphates (chlorpyrifos and

isofenphos) and pyrethroids (bifenthrin, cypermethrin, fenvalerate, and permethrin). These pesticides were originally developed for soil applications in agricultural situations where they were effective for a single season. It was believed that with an increase in application rate that they would be effective as termiticides. The first of the new generation of termiticides registered with the United States Environmental Protection Agency (EPA) was chlorpyrifos (Dursban TC™), which by 1991 had an estimated 65.1% of the termiticide market share (Mix, 1991). With a total market value exceeding \$100 million/year, it was no surprise that other pesticides were labeled and marketed for termite control (Gold *et al.*, 1994).

In order to register a pesticide as a termiticide, the EPA has required efficacy data from field tests conducted by the United States Department of Agriculture, Forest Service (FS). It was assumed that five years of data were required to register a pesticide as a termiticide. The testing was done at the Southern Forest Experiment Station in Gulfport, Mississippi or on their other test sites (Kard *et al.*, 1989). In these tests, proposed termiticides were to provide 100% control (protection) of subterranean termites for five years in at least three of five field sites. Different types of testing were done as part of the Forest Service program (Stanley, 1994) including concrete slabs and ground boards. The results of the testing have been made available to the public (Kard *et al.*, 1989; Kard and McDaniel, 1993; and Kard and Mauldin, 1994). It appears that there are differences in the persistence and efficacy of the termiticides included in their tests.

State regulatory agencies have demonstrated a great deal of interest in sampling soils treated with termiticides to determine the residues remaining through time (Kard and McDaniel, 1993; Mix, 1995). The Association of Structural Pest Control Regulatory Officials (ASCPRO) sponsored research involving soil sampling from structures treated with termiticides. They determined that through proper sampling procedures it is possible to use results from soil sampling for regulatory actions if sufficient pesticide is not present following treatment. Again, there were differences in termiticide concentration through time, indicating that within 180 days all pesticides included in the tests had significantly decreased in concentration.

Independent studies which compare the persistence and efficacy of pesticides in field trials used for termite control are somewhat limited; however, Su *et al.* (1993) and Gold *et al.* (1994) both reported that termiticides lost effectiveness through time. The present study was conducted to carefully compare termiticide persistence and efficacy under varying soil types and environmental conditions.

## MATERIALS AND METHODS

### Study sites

The termiticide tests were conducted at five locations in Texas, each of which represented a specific soil type and climatic condition (Tables 1 and 2). All test locations are on properties owned and managed by the Texas A&M University System. It was initially anticipated that the tests would be conducted for a 15 year period. The specific locations in Texas are: Lubbock Research and Extension Centre; Dallas Research and Extension Centre; Overton Research and Extension Centre; College Station (Easterwood Airport); and the Corpus Christi Research and Extension Centre. All of the termiticides included in these tests were included in replicated test plots at each of the five locations.

Table 1. Site characteristics

Site	pH	% OM <sup>1</sup>	% Sand	% Silt	% Clay	Series
Dallas	8.2	3.9	3.2	32.8	64.0	Austin silty clay
Lubbock	7.7	0.8	51.6	18.1	30.0	Acuff loam
Corpus Christi	7.8	1.3	37.7	15.1	47.2	Victoria/Olerlia clay complex
College Station	7.1	1.2	53.7	33.7	12.5	Lufkin series
Overton	6.4	0.8	73.4	11.5	15.1	Libert loamy

<sup>1</sup>Organic matter

Table 2. Meteorological data by site.

Site	Mean maximum temperature for July	Mean minimum temperature for January	Annual precipitation
Dallas	35.0°C	-2.2°C	911 mm
Lubbock	33.3°C	-4.4°C	421 mm
Corpus Christi	34.4°C	7.8°C	1189 mm
College Station	35.0°C	3.9°C	993 mm
Overton	34.4°C	0.6°C	1095 mm

### Termiticide applications

At each test location, the termiticides were applied as per the recommendations of the manufacturers including: isofenphos (Pryfon 6 insecticide<sup>TM</sup>: Bayer @ 0.75% A.I.); bifenthrin (Biflex TC<sup>TM</sup>: FMC @ 0.062% A.I.); chlorpyrifos (Dursban TC<sup>TM</sup>: DowElanco @ 1.0% A.I.); cypermethrin (Demon TC<sup>R</sup>: Zeneca @ 0.25% A.I. and Prevail FT<sup>R</sup>: FMC @ 0.30% A.I.); fenvalerate (Tribute<sup>R</sup>: AgroEvo @ 0.50% A.I.); and permethrin (Dragnet FT<sup>R</sup>: FMC @ 0.50% A.I. and Torpedo<sup>R</sup>: Zeneca @ 0.50 % A.I.). Each termiticide and recommended test concentration was replicated three times at each of the five locations. Each replication consisted of four applications arranged in a cluster. The clusters were formed by auguring soil out of four holes each was 25 cm in dia. and 30.5 cm deep. All four holes per cluster were dug at the same time. The soil removed was batched, screened through a 1 cm hardware cloth, and placed in a concrete mixer. The same weight of soil was used in each treatment batch (approximately 58 kg). With the mixer turning, termiticides was applied uniformly to the soil. The mixing process continued until thorough mixing had been accomplished (15 minutes per batch). Care was taken to clean the mixer between batches to minimize carry over of termiticide between treatments.

The amount of termiticide applied to the soil in the mixer was calculated to provide the same concentration as would be found in a post-construction treatment at the concentration and rate recommended by the manufacturer. A layer of white sand was placed in the bottom of each hole. This contrasting band was used during sampling as an indication of the boundaries for the treatments. After the soil and termiticide had been thoroughly mixed, the holes were refilled with the treated soil, tamped (to a density of approximately 3 g/cm<sup>3</sup>), and leveled to surrounding grade levels. Into the fourth hole in the cluster was placed a 20 cm pine stake; into the second, a pine stake was driven, but in addition the hole was covered with a precast concrete block (5×30.5×30.5 cm); the third hole was left exposed and was used for residue analysis; and the fourth hole was covered with a similar concrete block and was also used for soil sampling. A metal spike (25.4 cm) was driven in the centre of each filled hole to facilitate finding the centre of the plot at each sampling period. The pine stakes were used to monitor termite activity and efficacy of the treatments. Records were kept of these pine stakes as to which were infested by termites since the prior sampling period. Control (non-treated) plots were included in equal numbers with treatments at all of the five test sites. Soil from the control clusters were handled and analyzed as were the termiticide treated soils.

### Soil samples

Soil sampling was done with a 2.5 dia. cm soil probe pushed 30.5 cm in the sampling site. The resulting core was carefully placed in a plastic specimen bag. Soil sampling was done at specific times: pretreatment (time 0), 1, 6, 12, and 18 months, and then annually through 4 years. As each sample was taken, the resulting hole was filled with a contrasting color of sand to insure that the area was not resampled at a later time. Soil samples were frozen and transported to the analytical laboratory in College Station, Texas, where they were held at -5°C until extraction, chromatographic analysis, and bioassay.

### Sample preparation

In the laboratory, the soil core was separated into three distinct sections made from the top, middle and bottom. Each section was blended to produce an homogeneous mixture. Three 5 g subsamples were taken from each sample, and each subsample was then placed in individual 25 mL plastic scintillation vials to which was added 20 mL of acetone or other appropriate solvent. All samples were then agitated for 30 min on a horizontal shaker, after which time they were allowed to settle over night. The following day supernatant was then diluted with the appropriate solvent to an acceptable level for electron capture detection (ECD) on a gas chromatograph. Extraction efficiencies and moisture determinations were also performed and incorporated into the concentration calculations.

### Chemical analysis

A series of Perkin Elmer Gas Chromatographs (Model 9000) fitted with ECD detectors and auto injectors were used in this work. Carrier gas was Zero grade helium, and make up gas was a mixture of 5% methane:95% argon. The capillary column used for all samples was a Restek XTI-5, megabore 0.53 mm I.D., 30 meters long, 1.5  $\mu$ M df, 5% diphenyl-95% dimethyl polysiloxane. Data collection and analysis was performed on a Perkin Elmer model 1020S digital data analysis system. Performance of the methods and instrumentation was monitored through the use of analytical standards (ChemServices, West Chester, Pa.) inserted before each successive plot number, and linear regression curves were constructed for each termiticide used. The overall method and instrument sensitivity was 0.1  $\mu$ g/g with an extraction efficiency of 91.4% based on spiked soil samples.

Instrument conditions for bifenthrin, permethrin, fenvalerate, and chlorpyrifos were as follows: Carrier gas=7 ml/min; make up gas=23 ml/min; attenuation=32; temperatures=injection port @ 250°C, detector @ 375°C, column (isothermally) @ 225°C. Instrument conditions for cypermethrin were as stated above except that the injector temperature was 270°C and column temperature was 245°C. Instrument conditions for isofenphos were the same as permethrin, except that the column was thermally programmed from an initial temperature of 160°C and then ramped at +5°C/minutes to 220°C and held for 5 minutes, then ramped at +30°C/min to 240°C and held for 5 minutes.

### Bioassay analysis

Two types of bioassays were used to evaluate termiticide effectiveness. The first involved determining if the termiticide afforded protection to wood. At the time termiticides were mixed and placed in the ground, pine stakes were placed in each of the treatment plots. With each soil sampling period, the pine stakes were removed and examined for evidence of termite infestation or feeding. If a stake was attacked by termites, the termiticide applied to the surrounding soil failed to protect the wood from termites. If the stake was not attacked, the termiticide may have protected the wood from attack, or the wood may have been missed by termites.

The second type of bioassay tested the effects of termiticides directly on termite behavior. The soil bioassays presently being used were derived from earlier work by Su *et al.* (1993) and Gold *et al.* (1994). It involved taking ca. 12 g of soil from each sample bag (a soil core) which represented one replication of termiticide per time interval. All soil samples were air dried overnight. The following day 1 ml of distilled water was added to each soil sample and then thoroughly mixed. A 2 cm agar plug was placed ca. 3 cm from one end of a 1.6 cm O.D.  $\times$  15 cm glass tube and was designated the top. The moistened soil was carefully placed in the bottom of the tube and lightly packed to remove air pockets within the soil. After 5 cm of soil was packed into the tube, a second 2 cm agar plug was inserted and pushed into the bottom of the glass tube until it contacted the soil. Once the soil and agar plugs were in place, a 3 cm pieces of wooden applicator stick was placed in the bottom of the tube. The end of the tube was then covered with a piece of aluminum foil. To the top of the glass tube, 30 pseudergates (*Reticulitermes flavipes*) were added and then sealed with another piece of aluminum foil. Pieces of aluminum foil were held in place by orthodontic rubber bands. After assembly, bioassay tubes were placed in an upright position in a rack and held at 25°C with a 12:12 (L:D) photoperiod.

Each bioassay tube was checked for termite tunneling after 24 hours. Termite tunneling was record from 0 mm (soil/agar interface at the top of the bioassay tube) to 50 mm (soil/agar interface at the bottom of the tube). After 5 days, final termite tunneling was recorded and the bioassay tubes were carefully dissembled to determine the number of surviving termites. All values presented are means of three replications.

Controls were performed in conjunction with the bioassay tests and involved using untreated soil from the same geographical location as the test plots. All controls were set up similarly to treated soils. Control soils were used to indicate whether the termite tunneling and survival could be attributed to the termiticides being tested instead of the behaviour of the termites themselves. Bioassay results for both 36 and 48 months are reported.

### Statistical Analysis

Pesticide residue data are expressed as  $\mu\text{g/g}$  remaining at each test site per time period. Data were analyzed by analysis of variance (SAS Institute, 1987). Significant differences in treatment means were calculated by LSD at  $p=0.05$ .

## RESULTS

### Chemical Analysis

The methods and procedures developed for this research project proved to be effective in the extraction, detection and quantification of the termiticides applied to soils in the field plots. Extraction efficiencies varied slightly between pesticides, but had an overall mean of  $91.4 \pm 3.2\%$  with limits of detection at  $0.10 \mu\text{g/g}$ . We recognize that it is possible to develop procedures which are even more sensitive to individual pesticides; however, the methods used allowed us sufficient data to draw conclusion from this work. The methods were consistent throughout the four years of the study, making it possible to compare data from year to year. The results of the pretesting of soils indicated that there were no residues of pesticides in the plots at initiation of the study.

The results of the soil analysis are presented in Figures 1–8. It is apparent from these summaries that all of the termiticides were significantly degraded through the four years of the study. There were differences between termiticide products in terms of residues remaining in the fourth year. Part of these differences are explained by the chemical makeup of the individual products used in these trials, while other differences may have been due to soil type, pH, and organic content (Table 1). Weather may also have played a role in affecting termiticide degradation (Table 2). Rainfall varied from 421mm/year in Lubbock to 1189 mm/year in Corpus Christi. Mean temperatures, particularly in the winter months, varied markedly. The ground was frozen in Lubbock while the mean temperature in Corpus Christi was relatively warm (Table 2).

There were no significant differences in residues remaining in the top, middle and bottom of the soil samples, so the data present were combined (Figures 1–8). There were no significant differences between those plots that were covered with concrete as compared to those that were exposed to the elements. It was determined there was a difference between covered and uncovered for isofenphos at 24 months in the Lubbock plots, but this difference was not noted in later sampling periods, or from other locations (Gold *et al.*, 1994).

Estimates of the half-life of the termiticides in these tests varied markedly, but with all products less than 50% of the active ingredients were present at 1 year post-treatment. Isofenphos had the shortest half-life (less than 90 days) as compared to the other termiticides (estimated at 9 months overall). By 36 months isofenphos had degraded (both isofenphos and isofenphos oxon) to undetectable levels at all five sites. All other termiticides had detectable residues at least through 48 months posttreatment. Degradation was the slowest at the Lubbock and Overton sites, and was most rapid at the Corpus Christi and Dallas locations. The College Station site was most similar to Corpus Christi and Dallas, but had a slightly slower rate of degradation.

The most persistent of the termiticides tested were permethrin (Figures 7 and 8) and fenvalerate (Figure 5). Both of these pyrethroids were recovered at consistently higher levels than the other termiticides through 48 months. The least persistent was isofenphos (Figure 6), which as indicated

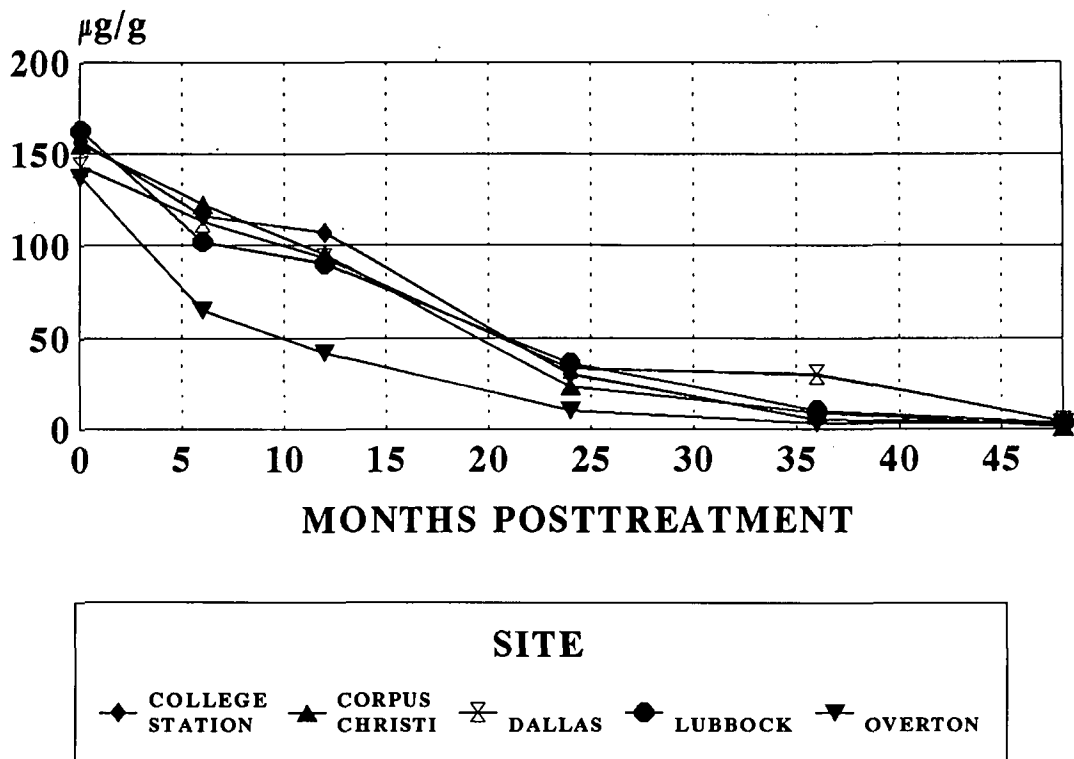


Figure 1. Bifenthrin (Biflex®).

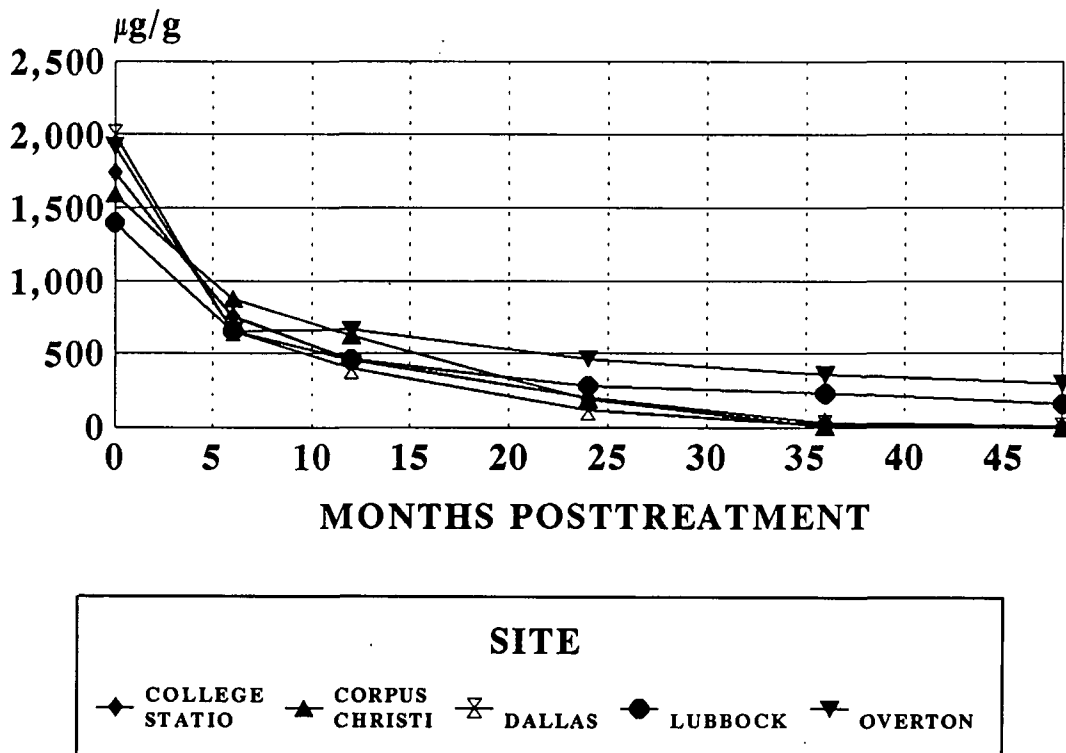


Figure 2. Chlorpyrifos (Dursban TC®).

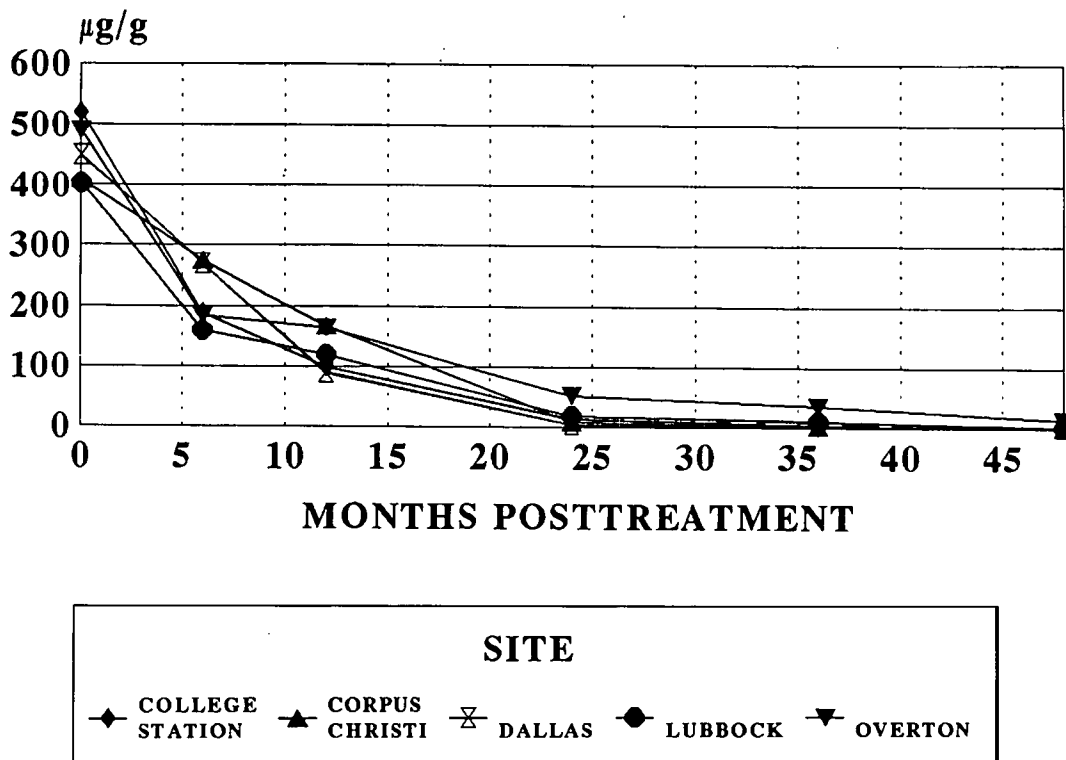


Figure 3. Cypermethrin (Demon TC®).

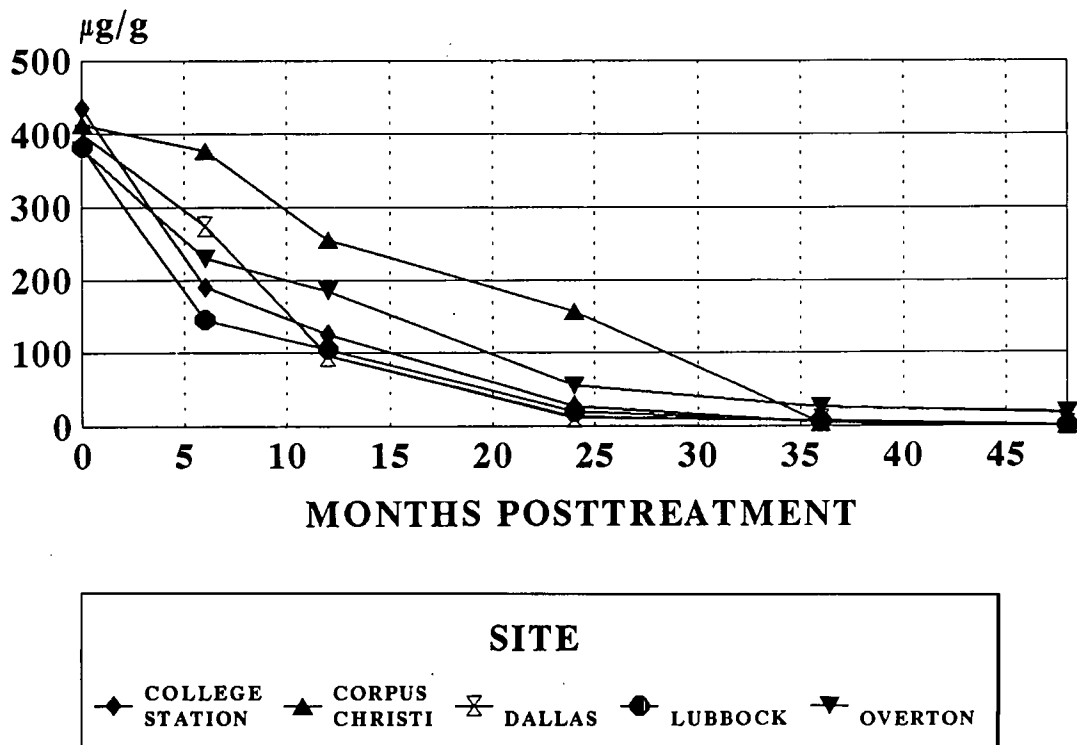


Figure 4. Cypermethrin (Prevail®).

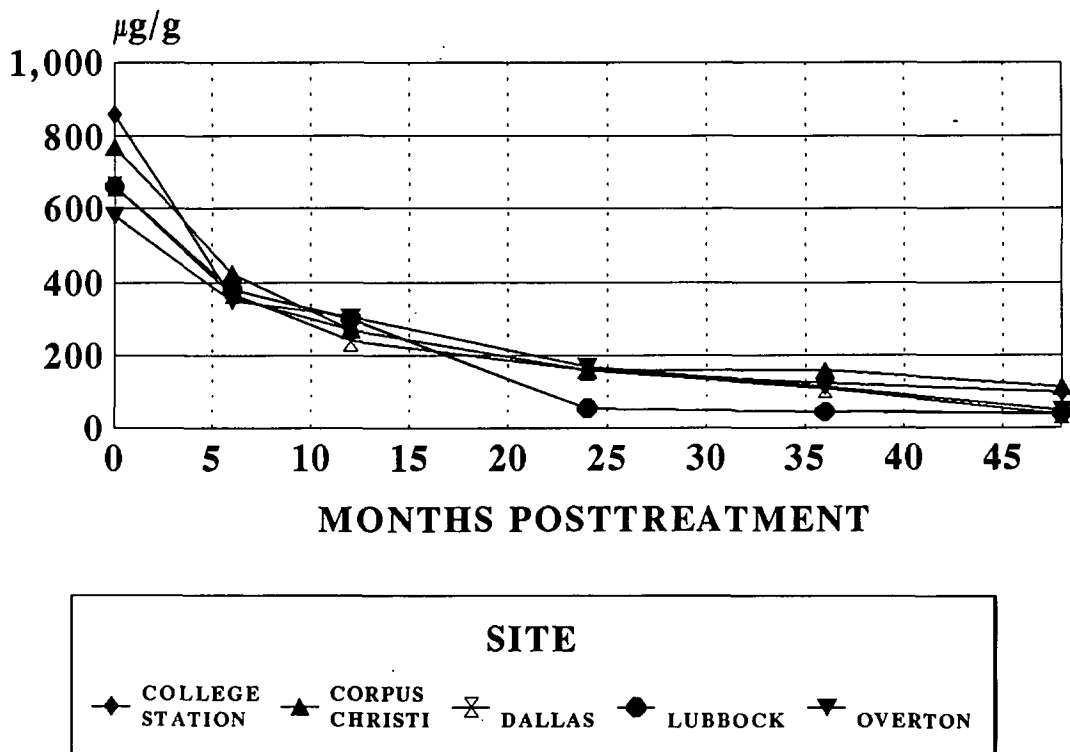


Figure 5. Fenvaletrate (Tribute®).

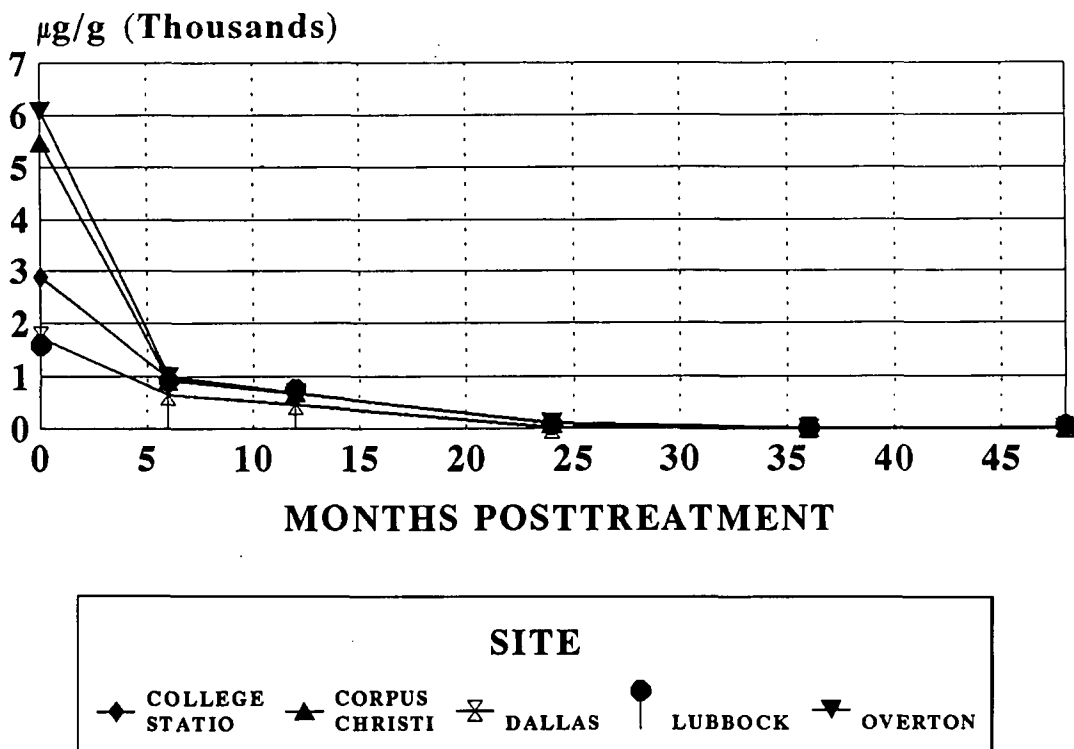


Figure 6. Isufenphos (Pryfon®).



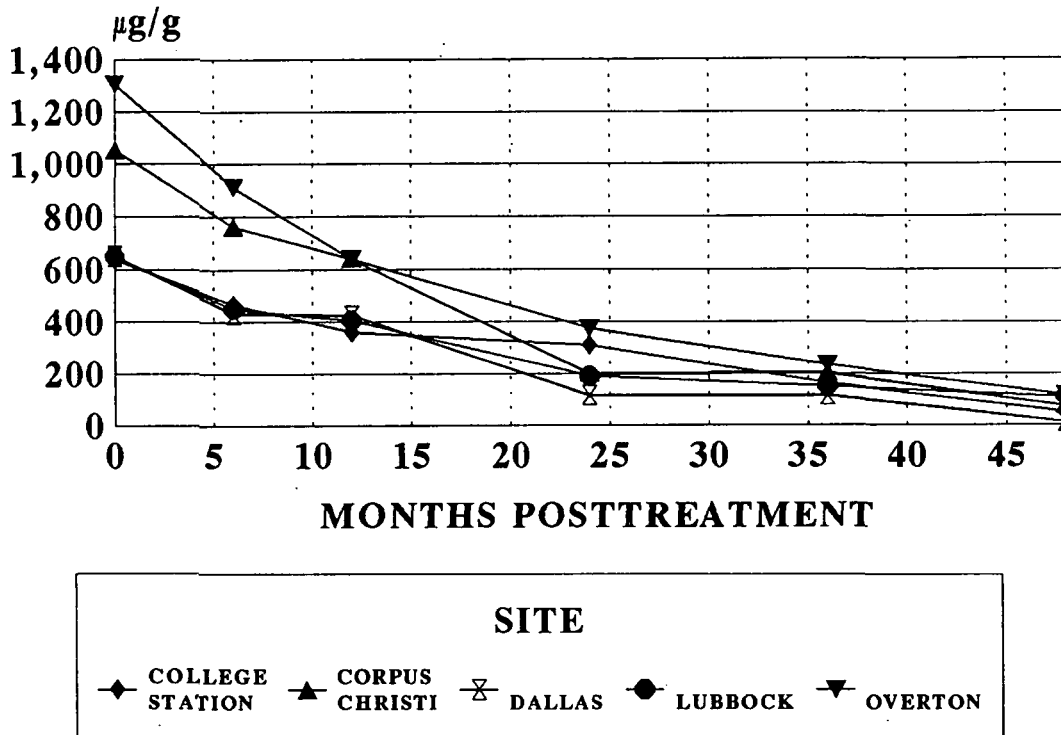


Figure 7. Permethrin (Dragnet®).

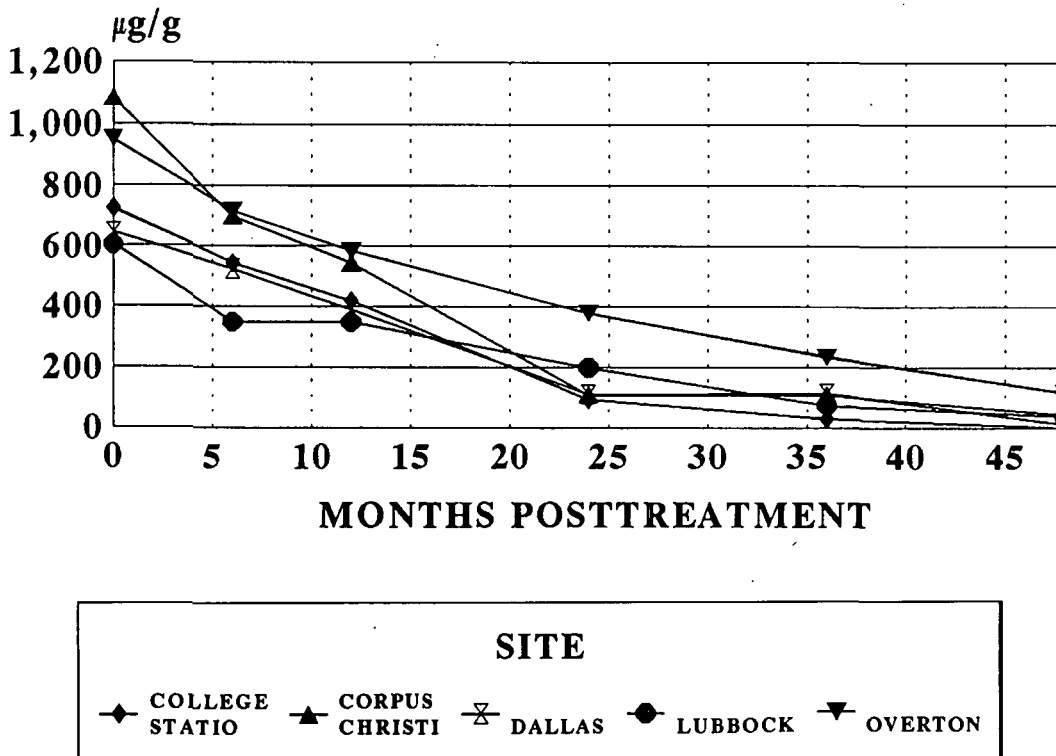


Figure 8. Permethrin (Torpedo®).

Table 3. % Termiticide remaining by site (4th year data).

	College Station	Corpus Christi	Dallas	Lubbock	Overton
Biflex	1.00	0.30	2.50	3.50	2.50
Dursban	0.60	0.02	0.08	11.50	16.00
Tribute	12.00	22.00	6.00	6.00	9.00
Dragnet	7.00	7.00	2.00	16.00	9.00
Torpedo	0.25	4.00	4.50	7.00	7.00
Demon	0.15	0.30	0.15	0.40	3.00
Prevail	0.20	0.00	0.00	0.30	5.00
Pryfon	0.00	0.00	0.00	0.00	0.00

above, was undetectable at 36 months. Chlorpyrifos appeared to be more persistent at the Lubbock and Overton sites (Figure 2) as compared to Corpus Christi and Dallas where the soils had higher clay contents (Table 1).

There were variations in the initial concentration (time 0) of the termiticides at all sites. We made every effort to keep the variations to a minimum, but the results show that certain products were more difficult to measure, mix and apply than others (Figures 1–8). The most variation occurred with isofenphos and the two permethrin termiticides, part of this was due to formulations differences which made it difficult to agitate the products in the original containers and get consistent and uniform technical product to measure and apply. Certain soils were generally more difficult to treat, particularly those in Corpus Christi and Dallas which were rich in clays. It proved to be difficult to get even mixing of termiticide with the heavier soil throughout the study.

The interest in the results of this work has been both gratifying and troubling. In order to present the results in an understandable way we prepared the summary which appears as Table 3. In this table only the results of the fourth year are presented, but they are expressed as the percentage of termiticide remaining at 48 month based on 100% of the termiticide being recoverable at Time 0. This presentation indicates that there has been a dramatic decrease in all of the termiticides within a relatively short period of time (4 years).

### Bioassay analysis

Termite bioassay results for 36 and 48 months have been grouped by test locations for ease in comparisons (Figures 9–13). Termiticide effectiveness in the different soil types tested was variable. Bifenthrin (Biflex TC™ applied at 0.062% A.I.) created a barrier which prevented termite tunneling at all five test locations for 36 months. After 48 months, bifenthrin continued to degrade as indicated by increased termite tunneling activity. *R. flavipes* was capable of tunneling completely through the treated soil at Lubbock and Overton. In general, termite survival was higher during the 36-month bioassays than during the 48-month bioassays. During the 36-month bioassays, termites were able to detect the termiticides within the soil and were deterred from tunneling. However, during the 48-month bioassays, the bifenthrin residue failed to inhibit termite tunneling. Because enough bifenthrin residue still existed in the soil, some termites were killed after coming into contact with the treated soil.

The mode of action for chlorpyrifos is different than that for bifenthrin (Su and Schaffrahn, 1990). When soil is treated with chlorpyrifos, a toxic but non repellent zone is created in the treatment area. Termites are killed when they enter this zone. Since the mode of action for chlorpyrifos is not repellent, more tunneling into the treated soil should be seen with chlorpyrifos, but at the same time, termite mortality in the treated soil should increase. Bioassay results for chlorpyrifos for 36 and 48 months reflect this mode of action. As with bifenthrin, chlorpyrifos (Dursban TC™ applied at 1.0% A.I.) was effective at preventing termites from tunneling through treated soil at all five locations through the 36 month test point (Figures 9–13). Although the termites were capable of tunneling at least 40% of the way through the soil at three locations (College Station, Corpus Christi and Dallas), termite survival at four of the five locations was

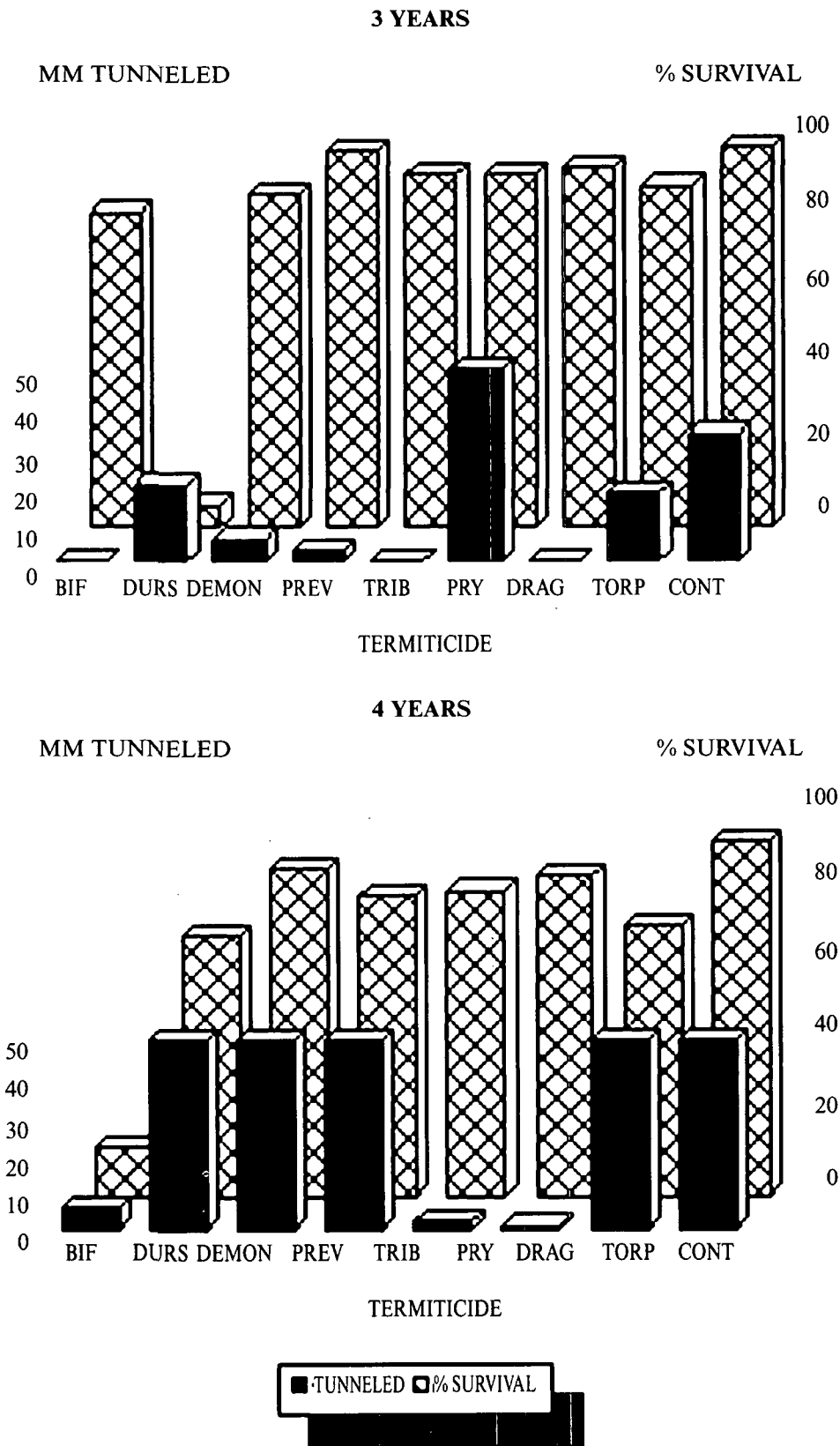


Figure 9. College Station bioassay results.

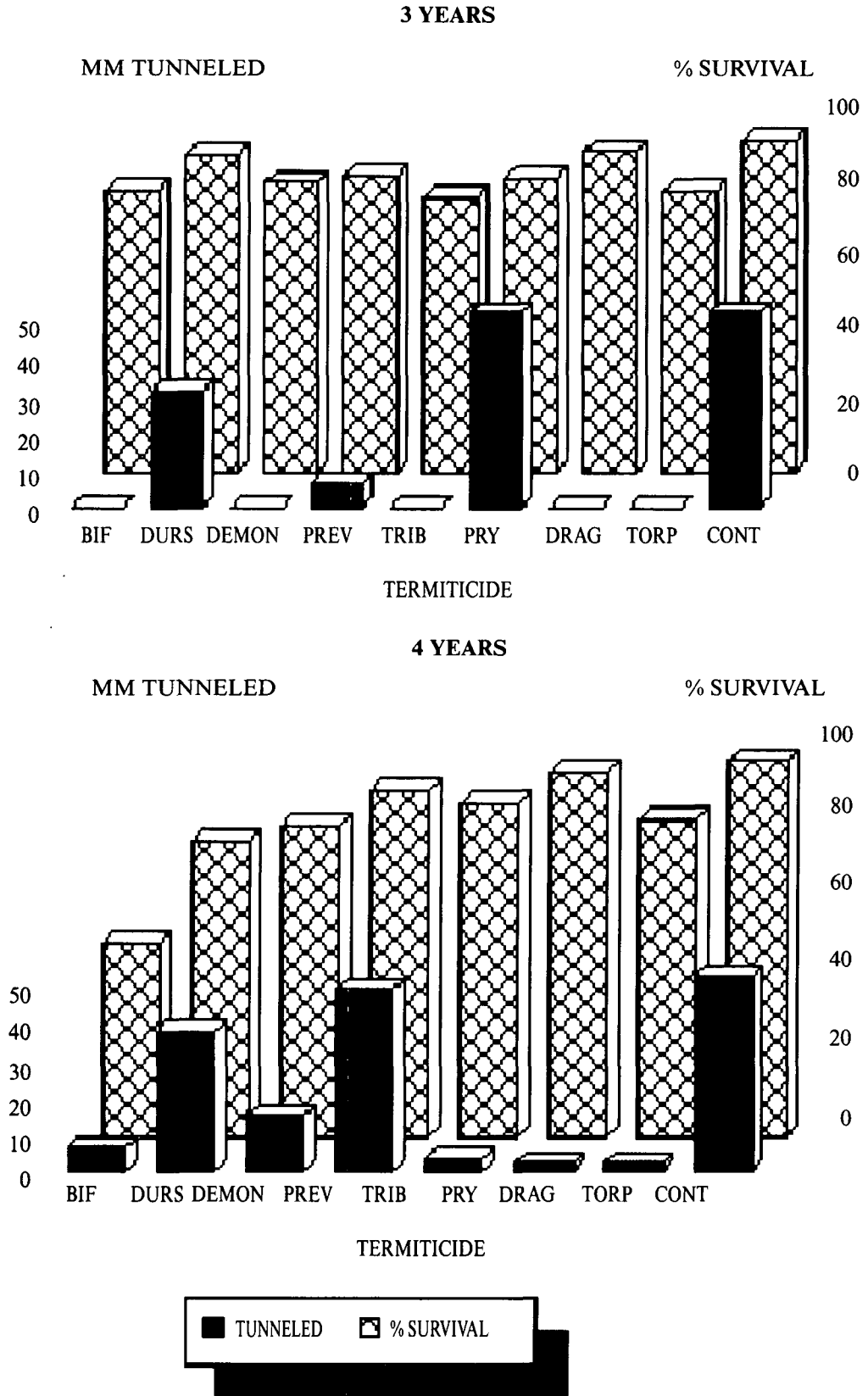


Figure 10. Corpus Christi bioassay results.

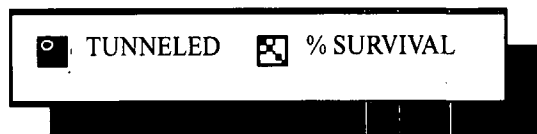
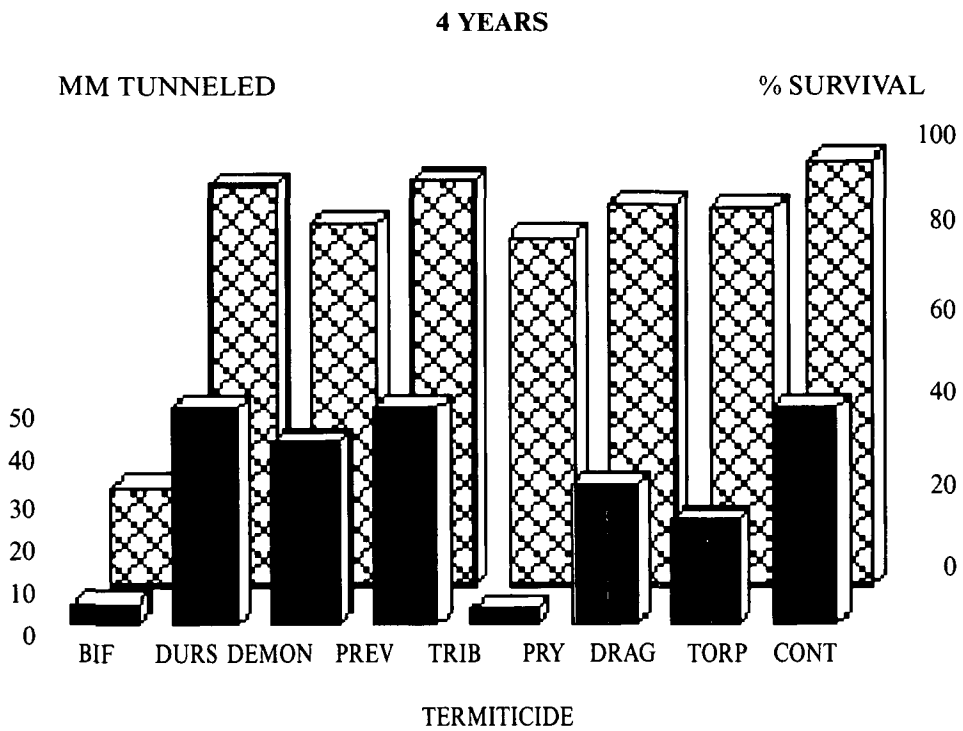
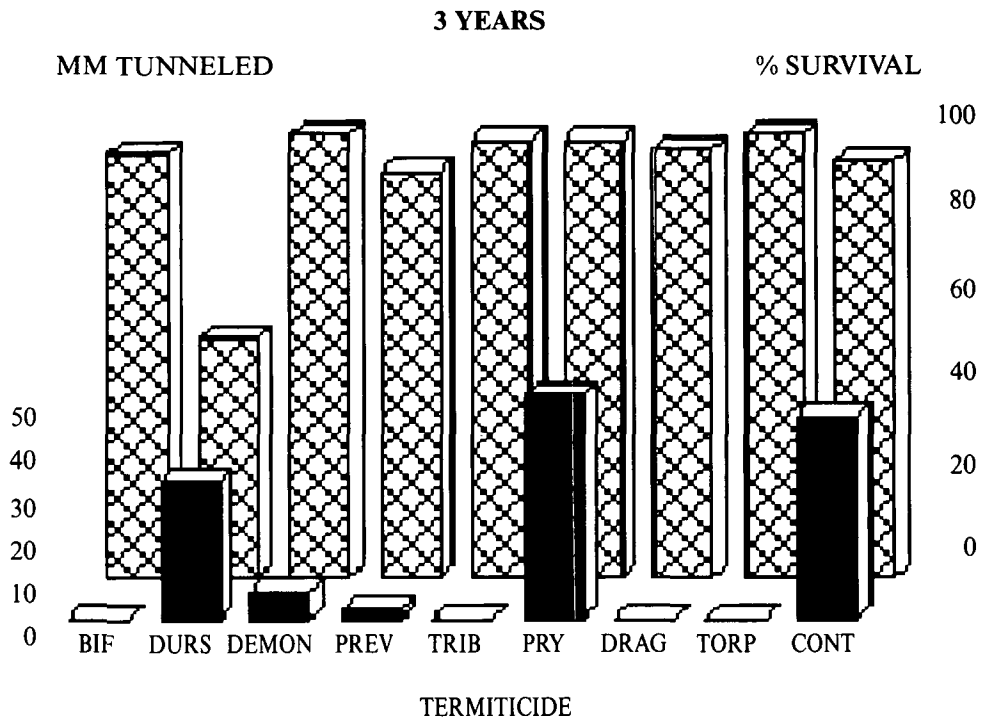


Figure 11. Dallas bioassay results.

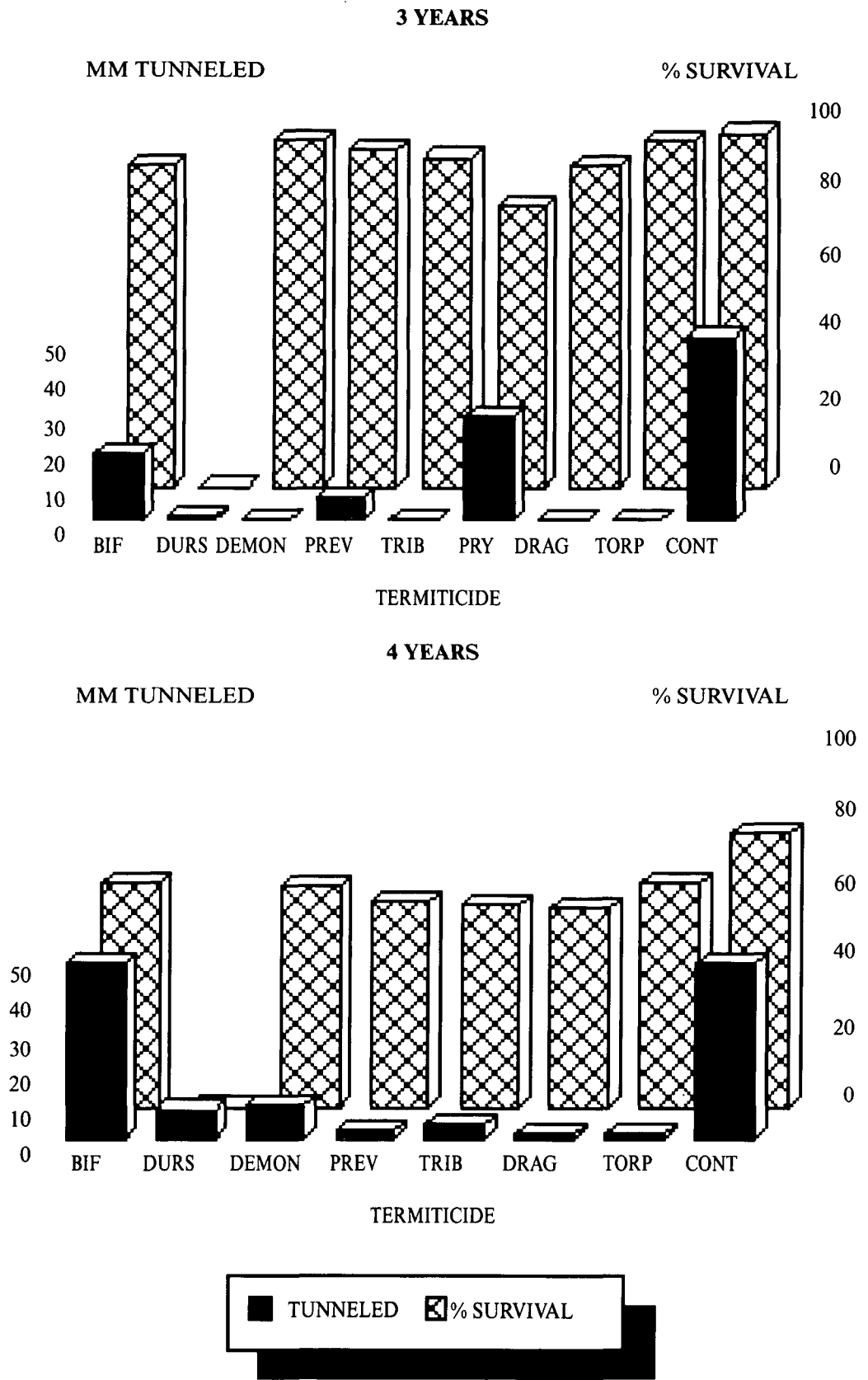


Figure 12. Lubbock bioassay results.

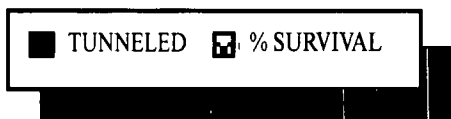
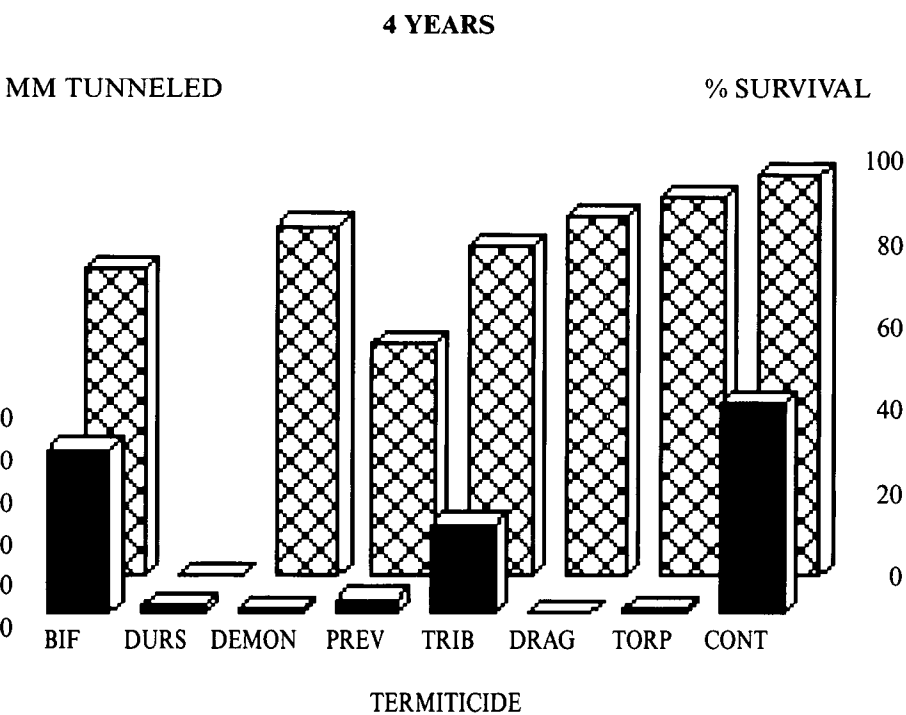
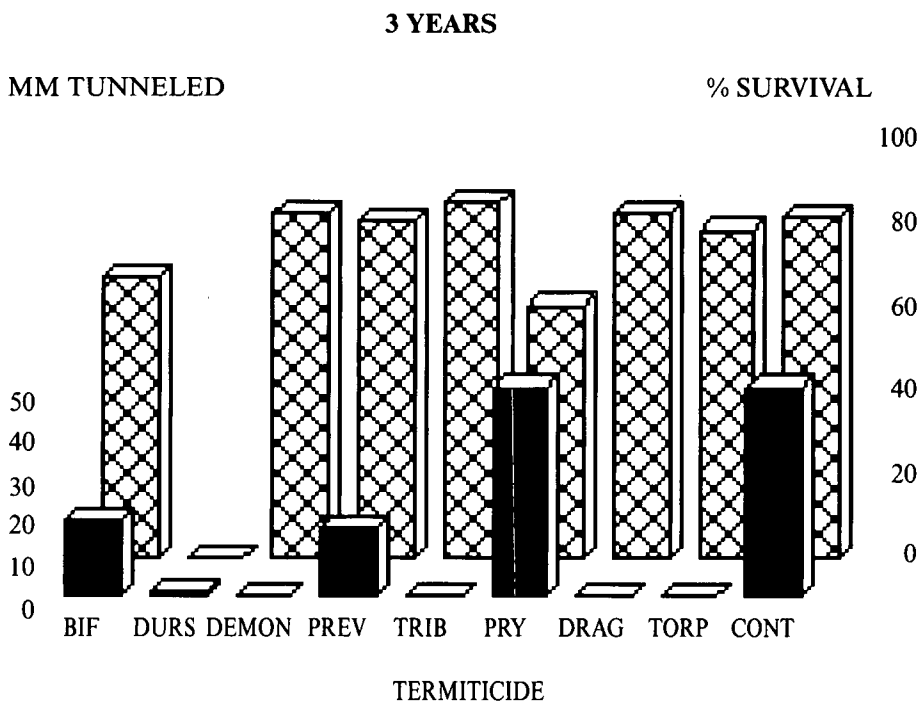


Figure 13. Overton bioassay results.

significantly lower than termite survival in the control bioassays. For the 48-month bioassay, chlorpyrifos was effective in preventing termite tunneling at only the Lubbock and Overton locations. In addition, all termites were killed during the (bioassay) test period. Chlorpyrifos failed to prevent termite tunneling at College Station, Corpus Christi and Dallas. At all three locations, termites tunneled 100% through treated soils and termite survival was in excess of 60%.

Two cypermethrins were tested in this study: Demon TC<sup>®</sup> applied at 0.25% A.I., and Prevail FT<sup>®</sup> applied at 0.50% A.I. Little to no differences were observed in the bioassay results between the two cypermethrins among the five test locations during either the 36 or 48 month bioassays (Figures 9–13). Soils treated with both cypermethrins repelled termites for at least 36 months at all five test locations. Termite survival in bioassay tubes with cypermethrins was similar to the survival of termites in the control bioassay tubes. Cypermethrin degraded more quickly in the College Station, Corpus Christi and Dallas soils than at the Lubbock and Overton sites. After 48 months, the cypermethrin treated soils were effective at preventing termite tunneling at the Lubbock and Overton locations, while termites were capable of tunneling completely through the treated soils at the College Station and Dallas locations. And, although termites did not tunnel 100% through treated Corpus Christi soil, distance tunneled after 48 months was much greater than the distance termites tunneled after 36, months indicating a gradual breakdown in protection by both cypermethrins.

Fenvalerate (Tribute<sup>®</sup> applied at 0.50% A.I.) was effective as a termiticide in preventing termite tunneling across all five soil types (Figures 9–13). Fenvalerate prevented termite tunneling during the 36 month bioassays, and very little tunneling occurred during the 48 month bioassays. The survival of termites exposed to fenvalerate treated soils was similar to the survival of termites in control bioassays at 36 months. Termite survival during the 48 month bioassays was lower in fenvalerate treated soils than in control soils indicating some termites began tunneling into the treated soil and were killed.

The other organophosphate in the study was isofenphos (Pryfon at 0.75% A.I.). Results from the 36 month bioassays supported the results obtained from the chemical analysis. Soils treated with isofenphos from the five test locations failed to prevent termites from tunneling nor did it kill them. (Figures 9–13). *R. flavipes* tunneled completely through all but one location, Lubbock, and high survival occurred in the bioassays from all five locations. Because isofenphos was not detected at 36 months, 48 month bioassays were not performed.

As with the cypermethrins, two permethrins (Dagnet FT<sup>®</sup> applied at 0.50% A.I. and Torpedo<sup>®</sup> applied at 0.50% A.I.) were tested, and both produced similar results at four of the five test locations (Figures 9–13). One permethrin (Dagnet FT<sup>®</sup>) was similar to fenvalerate in that no termite tunneling occurred in any soil type during the 36 month bioassays. Termites began tunneling into the treated (Dagnet FT<sup>®</sup>) soil during the 48 month bioassays, but only for 1 - 3 mm. After detecting the presence of the termiticide, the termites left the treated soil as indicated by high survival rates. The second permethrin, Torpedo<sup>®</sup>, produced results similar to Dagnet FT<sup>®</sup> at four of the five test locations. The only exception was at College Station where Torpedo<sup>®</sup> was effective at preventing termite tunneling through 36 months. However, termites were capable of tunneling completely through treated soil at 48 months indicating the termiticide had degraded to a point where it lost its effectiveness at providing an impenetrable barrier.

Bioassay results from untreated controls were consistent during both the 36 and 48 month tests (Figures 9–13). Termites were able to tunnel completely through all soil types during the test period and termite survival was good. Controls are important for indicating the health of the termites being subjected to termiticides so that true behavior can be assessed and proper termiticide evaluations can be made.

## DISCUSSION

The results of this research clearly indicate that modern termiticides applied to soils in Texas are unlikely to last as long as aldrin, chlordane or heptachlor. The chlorinated hydrocarbon



termiticides have long been recognized as providing long term protection of properties from termite invasion. When we questioned the retreatment rates with the older termiticides (chlorinated hydrocarbons), we were somewhat surprised to find that records from professional pest control companies, which we contacted, were incomplete. The general impression was that they had little difficulty in controlling termites prior to 1988. The retreatment rate with the organophosphate and pyrethroid termiticides appears to vary markedly depending on the application procedures used as well as the specific products and rates of application. Based on the results that we obtained, all the termiticides that we tested should have provided excellent control of termites through at least two years (Figures 1–8). This is based on the fact that all the termiticides residues were well above the minimum threshold levels needed to either kill or repel invading termite foragers (Su and Scheffrahn, 1990). There was however, little doubt that the termiticides were significantly degraded from the initial application levels within 6 months.

Because of the interest in our research program, we presented data from the field plots each year at our annual pest control operator workshop. The fall out from these reporting efforts was both surprising and unfortunate. Even though we continued to remind our audiences that the results were preliminary, the data was widely circulated through industry circles and in the ranks of the professional pest control operators. Several questions have been raised which need clarification. We recognize that the results of our testing procedures are different than those of the USDA Forest Service (Kard *et al.*, 1989; Kard and Mauldin, 1994; Stanley, 1994), but more closely approximate those represented by other published studies (Mix, 1995; Kard and McDaniel, 1993; Su *et al.*, 1993). Our testing procedures were basically different in that we took soil samples from the test plots which were analyzed for termiticide residues with a chromatograph as well as with bioassays utilizing live subterranean termites. Had we relied solely on the results of the pine stake bioassays as an indication of efficacy against invading termites, we would have concluded that all the termiticides were equal in effectiveness through time. Further, we would have concluded that none of the termiticides had failed to provide protection through the four years of the study. The reason for this conclusion would have been that the termites never fully invaded our test plot in any of the five locations.

We recognize that the utilization of “post hole tests” may not represent what happens to a termiticide applied in and around a home or place of business. What we believe is that the methods we used represents an attempt at a reductionist approach to managing variables. By thoroughly mixing weighed amounts of soil, and adding known amounts and concentrations of termiticide we probably represented the best possible situation as compared to applications made in the field with customary application equipment. We have done this type of field work (Gold *et al.*, 1993), and can report that the methods used in this research resulted in significantly more reliable applications of pesticide.

The results of the bioassay reinforce the importance of applying a uniform chemical barrier for termite prevention and control. We confirmed the work of Su and Scheffrahn (1990) and conclude that with the organophosphate termiticides, termites require contact with the treated soil in order to be killed, while the pyrethroids repelled the termites which subsequently survived inclusion in the bioassays. It is our understanding, based on the results of this work, that if there is sufficient termiticide present that treated soils will present an effective barrier to invading termites regardless of the mode of action of the chemicals. However, if there are gaps in the chemical barrier (Forschler, 1994), if the barrier layer is too thin (Su *et al.*, 1995), if the termiticide has degraded, or if the termiticide is not available to foraging termites, the barriers can be breached (Su *et al.*, 1993; Gold *et al.*, 1993), and termite invasion and infestation of structures will result.

It is our recommendation that persons interested in utilizing termiticides to protect wooden structures get the data and information that is most relevant to their local conditions including soil types, pH and organic content. We further recommend that professional pest control operators utilize the maximum label rates for termiticide applications, the labels be followed as carefully as possible, and that they be conservative in their contracts with clients regarding offers of termite control over extended periods of time. We also recognize the need for very thorough inspections of treated structures on a regular basis to detect as early as possible any missed areas in the chemical barrier, or the degradation of termiticide below the lethal threshold level.

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