Evaluation of the Ability of *Reticulitermes flavipes* Kollar, a Subterranean Termite (Isoptera: Rhinotermitidae), to Differentiate Between Termiticide Treated and Untreated Soils in Laboratory Tests

by

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ABSTRACT

The minimum size of the untreated gap within the termiticide treated soil, and the minimum time required for the termites to reach the food source through these gaps were determined for each of five termiticide at the three concentrations. The effect of untreated gaps within the chemical barrier was determined for permethrin, cypermethrin, fenvalerate, chlorpyrifos, and imidacloprid at the termiticide concentrations of 1000 ppm, 500 ppm and 100 ppm. Field condition was simulated in the laboratory using experiment chambers made of Plexiglas® (30 x 15 x 15 cm) filled with layers of untreated, treated, and untreated soil. The broken barrier was created by inserting glass tubes containing untreated soil in the center of the chamber. Subterranean termites (*Reticulitermes flavipes* (Kollar) were introduced at the top layer of untreated soil. The system was observed for seven days or until the termites were seen at the food source which was at the bottom of the experiment chamber.

With pyrethroids (permethrin, cypermethrin and fenvalerate), termites reached the food source at all the three concentrations, though the size of the gap and time for tunneling was different for each pesticide. Ninety percent of the termites were alive on the seventh day of the tests. In the organophosphate termiticide (chlorpyrifos), termites were unable to make use of the untreated gaps within seven days, and no termites were found to be alive after seven days of testing. In the tests with chloronicotinyl (imidacloprid], termites were unable to locate the untreated gaps within seven days. However, only 10% of the termites were alive by the seventh day at a concentration of 100 ppm.

KEY WORDS: Subterranean termites, termiticides, untreated gaps

INTRODUCTION

Control of subterranean termites, Reticulitermes *flavipes* (Kollar)

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(Isoptera: Rhinotermitidae) has always been an important concern of the homeowners and the pest control industry. Subterranean termites are one of the most destructive insect pests of wooden structures throughout the world, especially in areas with warm, humid climates. These insects live in colonies, often with greater than one million individuals. They are socially organized into three castes - reproductive~soldiers, and workers (pseudergates). The workers forage above ground for decaying cellulose, which is then carried underground to feed the remainder of the colony. In nature, termites play an important role in the breakdown of dead trees and other cellulose products which accumulate in forests. Cellulose is broken down and returned to the soil as humus; however, a problem begins when termites invade our homes and other structures. They feed on wooden frames of structures and can weaken the wood to the point of collapse. Often the presence of termites is noticed only after the damage becomes very obvious.

For the past fifty years, termite control has relied mainly on termiticide treatments and the construction of a chemical barrier between structures and the invading termite colony. Pre- and post-treatments are done as prevention and remedial measures, respectively. These treatments are found to be very effective in preventing termite invasion, especially the attack of subterranean termites (*Reticulitermes flavipes*). The basic intention of establishing a chemical barrier around a building is to prevent the termites from having access to the structure. This can be achieved by the application of a uniform and continuous (unbroken) termiticide soil barrier which depends on the volume of the termiticide applied, the skill of the technician who applies the termiticide, the application equipment used, and the nature of the soil surrounding the structure. During the application, if untreated gaps are left **within** the treated soil, there is a possibility that the termites can tunnel through this untreated area and could reach the structure. If this happens, the treated zone will eventually fail and the efficacy of the termiticide could be questioned. Although different techniques and equipments have been developed against the ongoing termite infestation problem, a completely successful procedure has yet to be found. New approaches need to be developed which are less dependent on continuous coverage, if control of subterranean termites is to be accomplished. Until these technologies are developed, the use of soil treatments with termiticides will continue.

Studies were conducted by several researchers to determine the efficacy of different termiticides and how factors like soil type, moisture, temperature and the type of the termiticide affected the efficacy of the pesticides as well as the behavior of the termites (Chapman et al. 1982, Harris 1966. Thamashiro and Khur 1978. Kard and Mauldin 1994). To a certain extent, these studies helped to increase the success of the application of termiticides in controlling the termite invasion. Termiticides used in termite control have changed from the chlorinated hydrocarbons (aldrin, chlordane, heptachlor and dieldrin) to organophosphates (chlorpyrifos and isofenphos) and pyrethroids (permethrin, cypermethrin, fenvalerate and bifenthrin) (Gold et al. 1994, 1996). Both the organophosphate and pyrethroid termiticides were found to be effective, but with different modes of action. It had been proven that the organophosphates caused a direct kill of the termites, while the pyrethroids repelled these insects. The merits of these termiticides which acted as barriers to termite tunneling have been studied (Su & Scheffern 1990, Jones 1990, Smith and Rust 1990, 1991, 1992, Grace 1991, Gold et al. 1994, 1996, Forschler 1994 and Su. et *al.* 1995). but the question remained as to which approach to chemical control would be most effective. It had been shown that tunneling and penetration of termites in a termiticide treated area depended on various soil characteristics including type. particle size, moisture content, pH, and temperature. Termite activity could also be affected by the presence or absence of termiticide and the concentration of termiticide remaining in the soil. Su et al. (1993) and Gold et al. (1994 and 1996) reported that termiticide effectiveness was lost through time.

Mampe (1990) stated that gaps of untreated soil within a termiticide soil barrier could be one of the reasons for the failure of these treatments. He pointed out that the increased retreatment rates might be the result of insufficient application of the termiticide which at any one point could result in a broken barrier. He believes that termites will eventually find and penetrate breaks in termiticide barriers. In order to reduce these untreated gaps within the soil barrier treatment, the pest control industry has used different types of termiticide application techniques and a variety of equipment. Forschler (1994) demonstrated with bioassays that termites could locate and exploit gaps in treated soil within a termiticide soil barrier through random foraging behavior. He reported that there were no indications that the termites purposefully searched for untreated soil along the termiticide treated barrier. He stated that, excluding decomposition rates and application techniques, the termiticides he tested (permethrin, cypermethrin, fenvalerate, chlorpyrifos, isofenfos and chlordane) should provide adequate protection from termite invasion as long as applications provides a complete (unbroken) barrier.

The purpose of this study was: to evaluate the effects of untreated gaps (broken barrier) in the termiticide treated soil barrier; to determine the minimum size of the untreated gap that the termites could locate within the termiticide treated soil; to determine the minimum time required by the termites to reach the food source through the smallest untreated gap; and to understand the differences in termite tunneling at three concentrations (1000, 500, and 100 ppm) of the five termiticides (permethrin, cypermethrin, fenvalerate, chlorpyrifos, and imidacloprid).

MATERIALS AND METHODS

Experiments were conducted at the Center for Urban and Structural Entomology of the Department of Entomology, Texas A&M University, College Station, Texas.

Soil

A silt-loam soil (21% sand, 21% clay and 58% silt) acquired from the Park and Ground Maintenance Department of Physical Plant at Texas A&M University was used for all experiments. Soil characterization and analysis was done by the Soil Testing Laboratory in the Department of Soils and Crop Sciences, Texas A&M University, College Station. To get an uniform texture and to eliminate plant debris, the soil was dried and sieved through 0.5 cm meshed sieve. Three kg of treated soil and 1.5 kg of untreated soil was used to set up each experimental chamber (2 cm layer of untreated soil at the bottom, 8 cm layer of termiticide treated soil in the middle, and 2 cm layer of untreated soil on the top). The dry soil was mixed with de-ionized water at the ratio of 10 g of soil with 1 ml of water at room temperature (25 ± 2°C).

Termites

All experiments were conducted using subterranean termites (*Reticulitermes flavipes*) collected from field sites in College Station, Texas. Termites were collected from the field using wooden slabs buried in the soil in infested areas. In the laboratory, the termites were separated from the blocks and from the dirt and kept in plastic petri dishes at 26°C and 75% relative humidity. Moistened pine tongue depressors were provided as food. The termites were used for the experiment within ten days after they were collected from the field. Based on the results of the studies of population density, 100 termites were used for each experimental chamber.

Termiticides

The five termiticides tested in these studies were permethrin (sold as Prelude® by Zeneca with an active ingredient of 25.6%); cypermethrin (sold as Prevail® by FMC Corporation with an active ingredient of 24. 8%), fenvalerate (sold as Tribute® by AgroEvo with an active ingredient of 24.5%); chlorpyrifos (sold as Dursban TC® by DowElanco with an active ingredient of 42. 8%), and imidacloprid (sold as Premise™ by Bayer Corporation with an active ingredient of 5%). These termiticides were tested at concentrations of 1000 ppm, 500 ppm, and 100 ppm. Using the directions on label, all dilutions were prepared with water.

Experiment Set Up

Experimental chambers (15 x 15 x 30 cm) were constructed of clear Plexiglas@These chambers were assembled using RTV® silicon glue (Dow Coming Corp., Midland, MI) which were open on the top and bottom. The chambers were set up on top of 35 x 20 cm heavy duty glass plate. The heavy duty glass plate was supported on each end by 24 x 8 x 8 cm wooden blocks. This allowed inspection of the bottom of the chamber with a mirror. Untreated gaps were represented by glass tubes of 10 cm in length and 1 mm in thickness. The inside diameters (I.D.) were 7, 6, 5, 4, 3, and 2 cm respectively. Three replications with each size of glass tube were conducted at each concentration of the five termiticides.

Agar Preparation

A thin layer of agar was placed at the bottom end of the glass tubes. The agar separated the soil in the tube from the petri dish containing moistened tongue depressors, provided as a food source. This thin layer of agar was prepared by boiling Batco-Agar (Difco) and de-ionized water at a ratio of 3 g of agar with 100 ml of water at 250°C until the liquid became clear. This was then poured on to petri dishes to form thin layers. After cooling at the room temperature, the prepared agar was kept in the refrigerator. At the time the experiments were set up, thin layer of agar was cut from the petri dish by pressing the glass tube of desired size on the agar layer.

Untreated Soil (Control) Preparation

Soil was dried and sieved through a 0.5 cm meshed sieve to get a uniform texture. For each 100 g of soil, 10 ml of water was added. Using a hand shovel, the water was mixed well with the soil. This soil was used for untreated controls as well as to fill the glass tubes to represent the untreated gap.

Termiticide Treated Soil Preparation at Each Concentration

The dried and sieved soil was weighed and kept in a big plastic tray. The termiticide solution was poured on to this soil and mixed using a hand shovel.

Experiment Procedure

Glass tube was packed with untreated soil. The bottom of the tube was covered by a petri dish which would hold the pieces of moistened tongue depressors, the food source, along with a thin layer of agar in between the food source and the soil. This glass tube was placed at the center of the experimental chamber with the petri dish at the bottom (Fig.la.). The top of the tube was temporarily covered by a petri dish to avoid contamination by the termiticide treated soil. At the bottom of the chamber, a 2 cm layer of untreated soil was spread (Fig.lb.). On top of that, a layer of treated soil (8cm thickness) was spread (Fig.lc). Above this treated soil, a 2 cm layer of untreated soil was spread (Fig. 1d). This top layer of untreated soil covered the top end of the glass tube. Before placing the top layer of untreated soil, the petri dish covering the top end of the glass tube was gently removed. Twenty five termites (pseudergates) were placed in each corner of the chamber, to make a total of 100 termites in each chamber. The top of the chamber was then covered by clear plastic wrap to help retain moisture. The system was kept at 25°C for a maximum of 7 days with 11:13 L: D. Twice a day, a small mirror was used to exam the bottom part of the petri dish to look for termites which had found the gap and tunneled to the food. When termites were seen at the bottom of the petri dish, or after seven days, the soil was removed from the chamber using a stainless steel spoon. The nature of tunneling was measured by visual inspection. The soil in the tube was kept in the freezer for one week, then sliced to study the pattern of tunneling. The experimentwas repeated three times for each size of the glass tube until the smallest tube through which the termites were able to reach the food source was identified.

Untreated Control Set Up

An experiment chamber, filled with untreated soil, was prepared as a control. One control was conducted for each six treatments. Moistened tongue depressors were placed at the extreme bottom of the chamber with a gap of 4 mm in between. Above that, a thin layer of agar was spread, and then the chamber was filled with control soil up to 12 cm in height. At the top, 25 termites were introduced into each comer. The chamber was covered by clear plastic wrapping. The system was kept at 25°C for a maximum of seven days with 11:13 L:D. Each day, using a small mirror, the bottom part of the chamber dish was examined for the presence of termites.

Sample Preparation for Analysis by Gas Chromatography

After mixing the termiticide with the soil, approximately 5 g subsamples of the treated soil were weighed and placed in 25 ml plastic scintillation

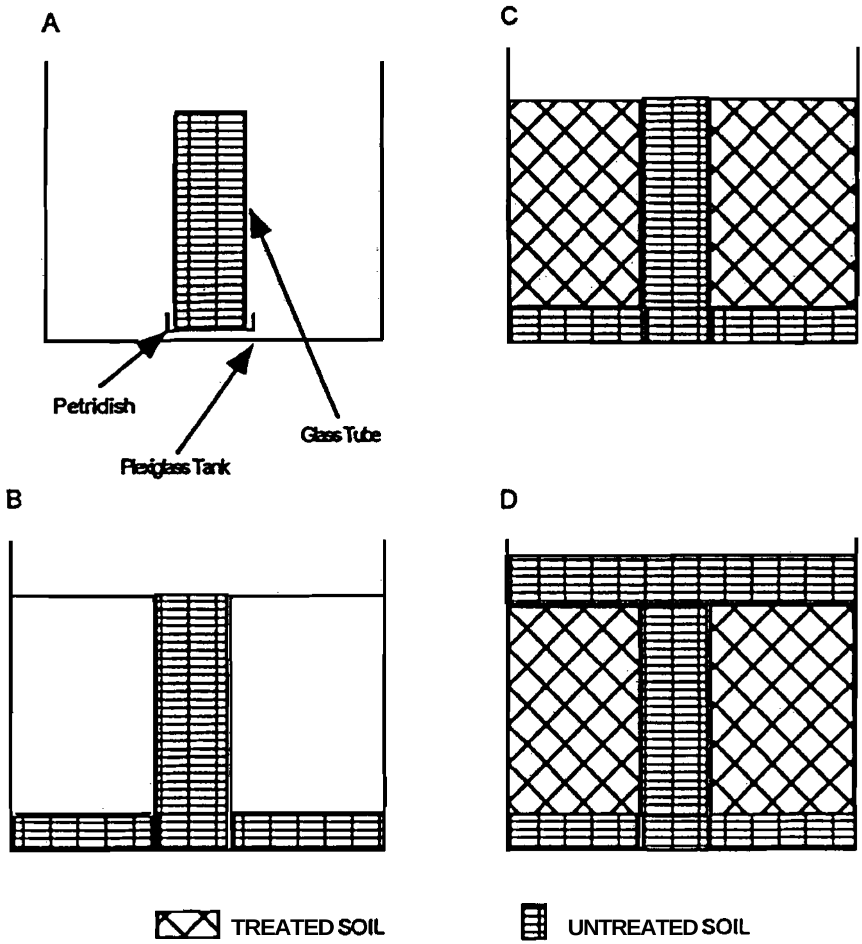

Fig. 1. Diagram showing how the test chambers were constructed and filled with termiticide treated and untreated soil.

vials. Fifteen ml of acetone was added and the vial was agitated for 30 min on a horizontal platform shaker. After 30 min, the samples were allowed to settle for 24 h. The extracts of all samples were diluted to a concentration within the linear sensitivity range of the chromatograph. Final solutions usually resulted in concentrations of 1 to 5 parts per million (ppm) by volume. The actual concentration of the active ingredient in the termiticide treated soil in each set of experiment was determined by finding the mean of the concentration of the five subsamples [Table 1).

Table 1. Mean concentration in parts per million (pprn) of active ingredient of permethrin, cypermethrin, fenvalerate, chlorpyrifos, and imidacloprid in the termiticide treated soils tested at the three concentration.

Termiticide	1000 ppm		500 ppm		100 ppm	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Permethrin	1124.06	± 232.72	559.63	± 171.51	89.36	± 45.86
Cypermethrin	1172.69	± 384.99	433.84	± 124.34	95.77	± 50.44
Fenvalerate	1093.28	± 302.79	629.44	± 129.70	157.43	± 72.76
Chlorpyrifos	1138.37	± 192.53	675.42	± 174.24	186.62	± 52.96
Imidacloprid	1209.52	± 192.53	490.85	± 144.08	141.48	± 38.10

Gas Chromatography

The samples were analyzed on a Perkin Elmer Autosystem GC IV gas chromatograph. The gas chromatograph was fitted with a 0.53 mm ID capillary column. The column was 15 meter XTI-5 column, 5% diphenyl-95% dimethyl polysiloxane, with 1.0 df. The column was manufactured by Restek. The carrier gas was He at 7 ml/min, the make up gas was P-5 (95:5) (Argon/Methane) flowing at 23 ml/min. The temperature of the injector was 250°C, the column was 225°C, and the electron capture detector was 375°C. Samples were run isothermally. These procedures were used to confirm the actual concentration of the termiticide in the treated soil. The sensitivity of the analysis was ± 0.1 pprn for all termiticides.

Data Analysis

Data from the studies were recorded as size of glass tubes (representation of untreated gaps) in cm, and time needed for tunneling in days. Termiticide concentrations were calculated using the Linear Regression Model from the data collection station on the gas chromatograph. The resulting data generated by the gas chromatograph was converted to parts per million (pprn)based on the dry weight of each soil sample. Standard curves ranging from 0.1 to 15 were generated from analytical standard for each pesticide used in the study.

RESULTS

Untreated Control

Termites were able to reach the food source at the bottom of the test chamber between 2 and 3 days in all tests. In the glass tubes of diameters ranging between 2 cm and 7 cm, termites reached the food source within one day.

Permethrin (1000ppm)

Termites were able to locate and tunnel through the untreated gap

Table 2. Diameter of the untreated gaps (cm) and the corresponding time (days) required by termites (*Reticulitermes flavipes*) to tunnel through the untreated gaps in soil treated with permethrin at the concentrations of 1000 ppm, 500 ppm, and 100 ppm

Diameter of untreated gap (cm)	Time required by termites to tunnel through the untreated gap (days) 1000 (ppm)	500 (ppm)	100 (ppm)
7	3	3	1
7	4	3	1
7	4	4	1
6	3	3	1
6	5	3	1
6	>7[a]	3	1
5	3	1	2
5	3	2	1
5	>7	2	2
4	6	1	1
4	6	1	2
4	>7	>7	2
3	>7	2	1
3	>7	3	>7
3	>7	>7	>7
2	>7	>7	>7
2	>7	>7	>7
2	>7	>7	>7

[a] No tunneling occurred by the seventh day when the test terminated.

of 7 cm in all the three replications, and in two replications of tests with 6 cm, 5 cm and 4 cm gaps, respectively (Table 2). The minimum size of the untreated gap that termites located and exploited was 4 cm, and they needed 6 days to reach the food source through this untreated gap. Upon dismantling the test arenas, tunnels were seen inside of the glass tube at the periphery. No tunneling occurred through either the 3 cm or 2 cm untreated gaps. Ninety percent of the termites were alive and active at seven days.

Permethrin *(500* ppm)

Termites located the untreated gaps of 7 cm, 6 cm, 5 cm in all the three replications. The untreated gaps of 4 cm and 3 cm were located in two out of three replications (Table 2). The minimum size of the untreated gap was 3 cm and the minimum time required by the termites to reach the food source was 3 days. No tunneling occurred through the 2 cm gap. Ninety percent of the termites reached the food source, and all of them were alive on the seventh day.

Permethrin (100 ppm)

Termites went through the untreated gaps of 7 cm, 6 cm, 5 cm and 4 cm in all the tests. The 3 cm gap was located only in one out of three replications (Table2).The minimum size of the untreated gap was 3 cm, and the minimum time of exploitation of this broken barrier was one day. All termites were active and found to be digging throughout the chamber including the termiticide-treated soil by day 7.

Cypermethrin (1000ppm)

Tunneling occurred only in two tests with 7 cm, and in only one out of three replications for tests with 6 cm, 5 cm, and 4 cm untreated gaps (Table3). The minimum size of untreated gaps was 4 cm, and minimum time required by the termites to reach the food source through this gap was 4 days. Ninety percent of the termites were alive and active on the seventh day and 50% of the termites reached the food source.

Cypermethrin (500 ppm)

Termites located untreated gaps of 6 cm in one test, 5 cm gap in two tests. and 4 cm gap in one test (Table 3). The minimum size of the

Table 3. Diameter of the untreated gaps (cm) and the corresponding time (days) required by termites (*Reticulitermes flavipes*) to tunnel through the untreated gaps in soil treated with cypermethrin at the concentrations of 1000 ppm, 500 ppm, and 100 ppm

Diameter of untreated gap (cm)	Time required by termites to tunnel through the untreated gap (days)		
	1000 (ppm)	500 (ppm)	100 (ppm)
7	4	>7[a]	>7
7	4	>7	>7
7	>7	>7	>7
6	>7	>7	>7
6	>7	>7	>7
6	2	7	>7
5	>7	>7	>7
5	>7	6	>7
5	6	6	>7
4	>7	>7	>7
4	>7	>7	7
4	4	4	7
3	>7	>7	>7
3	>7	>7	>7
3	>7	>7	>7
2	>7	>7	>7
2	>7	>7	>7
2	>7	>7	>7

[a] No tunneling occurred by the seventh day when the test terminated.

untreated gap was 4 cm, and minimum time required by the termites to reach the food source through this gap was four days. Ninety percent of the termites were alive and active on the seventh day, and 80% of the termites reached the food source.

Cypermethrin (100 ppm)

Tunneling occurred only in two tests with a 4 cm untreated gap (Table 3). The smallest size of untreated gap was 4 cm and the termites needed seven days to detect this gap. Ninety five percent of the termites were alive and active on the seventh day, and they were digging throughout the soil including the termiticide treated soil in all the tests.

Fenvalerate (1000 ppm)

Termites were able to locate and exploit the untreated gaps in all three replications of each test with 7 cm, 6 cm, 5 cm, 4 cm and 3 cm untreated gaps (Table 4). The minimum size of the untreated gap was 3 cm, and the minimum time required was two days. Ninety percent of the termites were alive on the seventh day.

Table 4. Diameter of the untreated gaps (cm) and the corresponding time (days) required by termites (*Reticulitermes flavipes*) to tunnel through the untreated gaps in soil treated with fenvalerate at the concentrations of 1000 ppm, 500 ppm, and 100 ppm

Diameter of untreated gap (cm)	Time required by termites to tunnel through the untreated gap (days)		
	1000 (ppm)	500 (ppm)	100 (ppm)
7	1	1	>7 [a]
7	2	2	>7
7	2	1	>7
6	1	1	>7
6	2	2	>7
6	2	2	>7
5	1	4	>7
5	2	4	>7
5	2	2	3
4	2	2	>7
4	2	2	7
4	1	1	7
3	2	5	7
3	3	5	6
3	3	>7	>7
2	>7	>7	>7
2	>7	>7	>7
2	>7	>7	>7

[a] No tunneling occurred by the seventh day when the test terminated.

Fenvalerate (500 ppm)

Termites were able to locate and exploit the untreated gaps in all three replications of each test with 7 cm, 6 cm, 5 cm, 4 cm and 3 cm untreated gaps except in one test with a 3 cm gap (Table 4). The minimum size of the untreated gap was 3 cm, and the minimum time required was five days. Ninety five percent of the termites were alive on the seventh day.

Fenvalerate (100 ppm)

Termites were able to locate and exploit the untreated gaps in only three test chambers (one with 5 cm untreated gap and in two with the 3 cm gap) out of 18 tests (Table 4). The minimum size of the untreated gap was 3 cm. Termites required a minimum of six days to reach the food source through this 3 cm gap. Ninety percent of the termites were alive on the seventh day, and they were found digging throughout the chambers including in the termiticide-treated soil.

Chlorpyrifos (1000 ppm)

No termites reached the food source and no tunneling was observed. All termites were found dead on the top layer of untreated soil in all the tests by day 5.

Chlorpyrifos (500 ppm)

All termites died by the seventh day, and no signs of tunneling were observed, nor did termites reach the food source.

Chlorpyrifos (100 ppm)

Signs of digging were found in the top layer of untreated soil in three out of 18 tests. No termites were seen at the food source, and all termites were dead by day 7.

Imidacloprid (1000 ppm)

No tunneling was observed and termites moved slower than normal and appeared to be disoriented. All termites had died by day 7.

Imidacloprid (500 ppm)

No tunneling was observed, and termites moved slower than normal, and appeared to be disoriented. Ninety percent of the termites died by day 7.

Imidacloprid (100 ppm)

Termites wandered around on the top layer of untreated soil. After two days, 25% of the termites disappeared from the top layer in five out of 18 tests. Signs of tunneling were observed in the top layer of untreated soil in these five tests; however, no termites reached the food source, and 90% of the termites were dead by day 7.

DISCUSSION AND CONCLUSIONS

These experiments support the conclusion of Forschler (1994) who demonstrated that, through random foraging behavior, termites located and exploited gaps of untreated soil within a soil barrier. Our observations of these tests showed that the foraging termites did not follow a definite pattern or sequence to locate the untreated gaps. In general, termites took longer to fmd the smaller gaps; however in some tests, termites failed to locate the larger gaps. For example, in the test with permethrin at 500 ppm concentration, termites located the 4 cm gap within one day. whereas they needed three or four days to locate the 7 cm gaps (Table 2). Likewise, in tests with cypermethein at 1000 ppm concentration, termites exploited the 4 cm gap within four days, but they required six days to locate 5 cm gaps. At 100 ppm concentration of cypermethrin, termites located the 4 cm gap, and this required seven days (Table 3).

In tests with pyrethroid termiticides, (Table 5) the response and the exploitation of the broken barriers by the foraging termites were different for each treatment. In the tests conducted with permethrin, the minimum size of the untreated gap and the time required to locate each gap decreased as the concentration decreased. Termites detected the larger gaps more rapidly than smaller gaps. Perhaps as the termites were repelled, they moved and tunneled more frequently and thus found the untreated gaps. As a result, termites were able to locate all the untreated gaps ranging between 3 cm and 7 cm.

In the cypermethrin tests, exploitation of the untreated gaps were rare, but occurred at all three concentrations tested. The number of untreated gaps detected by the termites apparently was not consistently influenced by the concentration: however, the termites were still alive at seven days.

In the tests conducted with fenvalerate, exploitation of the untreated gaps at the concentrations of 1000 ppm and 500 ppm demonstrated

Table 5. Comparison of the minimum size of diameter of untreated gaps (cm) and minimum time (days) required by termites (*Reticulitermes flavipes*) to locate untreated gaps in soil treated with permethrin, cypermethrin and fenvalerate at the three concentrations

Termiticide	1000 ppm		500 ppm		100 ppm	
	Gap size (cm)	Location Time (days)	Gap size (cm)	Location Time (days)	Gap size (cm)	Location Time (days)
Permethrin	4	6	3	2	3	1
Cypermethrin	4	4	4	4	4	7
Fenvalerate	3	2	3	5	3	6

strong repellency of the termiticide, and the termites were able to find the untreated gaps ranging between 3 cm and 7 cm.

At 100 ppm, the number of untreated gaps located by the termites was less than for either 1000 ppm or 500 ppm concentrations. It was observed that at 100 ppm, the termites dug numerous holes and apparently were neither killed nor repelled, and they failed to locate the untreated gaps.

The results of this work demonstrated that termiticides are either repellent or they kill the termites. The repellent termiticides included all of the pyrethroids. Chlorpyrifos and imidacloprid were highly toxic at the concentrations tested and termites died before they could find the gaps of untreated soil. The result was the same at 100 ppm concentration, however there was evidence that termites attempted to tunnel into the termiticide treated areas and were killed.

In the fenvalerate and cypermethrin tests using 100 ppm concentration, the termites tended not to use the untreated soil in the central tubes, whereas in the permethrin tests, the termites utilized the untreated soil in the central tubes regardless of the treatment rate. Fenvalerate and cypermethrin at 100 ppm may not have been repellent enough to cause the termites to seek the untreated areas and hence the termites spent time digging throughout the chamber which delayed the detection of the untreated gaps.

No termites utilized the 2 cm diameter gaps packed with untreated soil in any test. In the cypermethrin tests, the termites did not use the 3 cm diameter gaps, whereas in the permethrin and fenvalerate tests, the termites utilized untreated gaps of diameters from 3 to 7 cm. These tests determined that the diameter of the smallest gap that termites may locate, can vary between 3 and 4 cm.

These experiments were conducted in the laboratory where factors such as temperature, light, soil type, and humidity were controlled. In the laboratory, tests were conducted with 100 termites. Outdoors, the possibility of locating the untreated gaps would be even more positive where there are hundreds of thousands of termites in one colony. Additionally, the efficacy of the termiticide in nature would be affected by other factors such as temperature, humidity, rainfall and soil type. The presence of the glass tube itself could have acted as a barrier to a certain extent; however, in trials to test this concept the glass tube was not a factor in helping or deterring the termites.

As long as termite control is attempted through the construction of a chemical barrier or treated zone, the presence of untreated gaps within termiticide-treated soil can result in failure to protect structures. At higher concentrations, pyrethroids act as strong repellents, forcing the termites to move away from the treated soil. This movement may put them in contact with untreated gaps. At lower concentrations, termites tunnel through the termiticide - treated soils and thus gain access to the structure. In conclusion, it is suggested that pest control industry, as well as homeowners should provide for a complete chemical barrier or treatment zone regardless of the type or concentration of the termiticide used. It is further recommended that structures be trenched and treated with the maximum labeled rate of termiticides to provide for the most complete protection possible.

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