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Evaluation of Chemical Localized Treatment for
Drywood Termite Control

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The objectives of the project were to determine the insecticidal activity and potential efficacy of various prominent professional-use insecticidal products registered for spot or localized treatment of existing infestations of the western drywood termite, *Incisitermes minor* (Hagen). The products included in the study were Bora-Care®, Opitgard™ ZT, Premise® Foam, Termidor® SC, Tim-bor®, and XT-2000®. These were selected in consultation with Dr. Vernard Lewis at the University of California Berkeley to insure that the same products would be included in our laboratory studies and his field studies. The intent was that, done independently, our laboratory studies and Dr. Lewis' field studies would provide a more comprehensive assessment of the spot treatment products than would either study alone.

A similar series of studies were conducted with each registered insecticide. Our test protocol included continuous exposures to treated surfaces, limited exposures to treated surfaces, vapor toxicity tests, choice feeding studies, horizontal transfer studies, and determination of the effectiveness of spot treatments of termite-infested structural boards. The results of each test are summarized herein and a discussion of the potential activity of each of treatments as a localized treatment option is provided.

Methods and Materials

Insects.- Naturally occurring drywood termites for the study were collected as needed from infested lumber and wood. Presumably infested structural wood provided by cooperating PMPs was cut into approximately 3-in lengths, carefully dissected with a chisel, and the termites gently tapped from the wood and collected. The termites were kept in a sealed plastic food container (20.3 by 30.5 by 8.5 cm) provisioned with pieces of balsawood. Vials of water with cotton wicks were added weekly to provide moisture. The extracted termites were allowed to acclimate for at least 2 weeks before being used in the tests. This assured that only healthy termites were used after the extraction process. Only intermediate sized worker termites (3 to 5 mm long) were used in the studies. This reduced the likelihood of error based on differential responses of exceptionally young (i.e. small) termites or larger older termites about to become alates.

Insecticides.- The insecticides included in the study were Bora-Care® (disodium octaborate tetrahydrate [DOT] 40%, Nisus Corp., Rockford, TN), Optigard™ ZT foam (thiamethoxam 21.6%, Syngenta Crop Protection, Inc., Greensboro, NC), Premise® Foam (imidacloprid 0.05%, Bayer Environmental Science, Research Triangle Park, NC), Termidor® SC (fipronil 9.1%, BASF Corp., Research Triangle Park, NC), Tim-bor® (disodium octaborate tetrahydrate [DOT] 98%, U.S. Borax Inc., Valencia, CA), and XT-2000® (92% d-limenone, Speer Products, Inc., Memphis, TN). Bora-Care is a concentrate that we diluted as directed on the label in water 1:1 to make a 23% solution of disodium octaborate tetrahydrate (DOT). Tim-bor is a powder formulation (DOT), and we mixed it in water to make the desired 10 and 15% solutions. The XT-2000 was applied directly from the service container to the balsa surfaces. The Termidor was applied as a diluted aqueous preparation at 0.125% and 0.06%. All of the aqueous preparations were applied with a pipette to the wood surfaces. Premise foam was applied directly from the aerosol can. The Optigard® ZT (0.1% thiamethoxam) was prepared according to the label directions at a 15:1 ratio and was applied with the Optigard® ZT Foamer Kit injector (Fig. 1).

Commercial Tim-Bor and XT-2000 for the study were provided by Western Exterminator Co., Anaheim, CA; the Premise® foam from Bayer Environmental Science; the Optigard foam and Optigard® ZT Foamer Kit from Syngenta Crop Protection; and the Bora-Care® and Termidor® SC for the study were purchased from Target Specialty Products, Santa Fe Springs, CA.

Treated Surfaces.- We used balsawood for surface treatments because drywood termites readily eat it, it is a good model for the activity of toxicants on structural lumber, and it is readily available and easy to work with. We determined the activity of precise amounts of insecticide we applied to thin disks of balsawood. The thin disks prevent termites from tunneling into the wood where they are difficult to observe and count. The balsawood (0.125-in by 4-in; Midwest Products Co., Inc., Darien, IL) was cut into 9-cm diam. Disks were placed in the bottom of glass petri dishes (9 cm diam.) with the treated surface upwards. The products were tested at their maximum label strengths. Bora-Care was applied at a rate equivalent to 0.2 gal/ 100 ft^2. The 15% Tim-bor solution was applied once and allowed to dry overnight. The 10% solution of Tim-bor was applied twice, the first application being allowed to dry overnight at which time a second application was made. Each Tim-bor solution was applied at a rate equivalent to 0.05gal/100 ft^2. Termidor and XT-2000 were applied at a rate equivalent to 0.19 gal/100 ft^2.

Each of the insecticides was prepared according to label directions and applied at its maximum allowable rate. The rates and the resultant amount of active ingredient (AI) applied per unit area are listed in the following table:

Table 1. Rates and amounts of active ingredient applied to balsawood surfaces.

Treatment	Application rate	AI (mg/cm^2)	[g/ft^2]
XT-2000	0.5 ml/ 63.6 cm^2	5.4	5.10
Bora-Care	0.58 ml/ 63.6 cm^2	28.1	26.10
Tim-bor 15%	0.13 ml/ 63.6 cm^2	0.3	0.30
Tim-bor 10%	0.13 ml/ 63.6 cm^2	0.4	0.40
Tim-bor dust	0.96 g / 63.6 cm^2	15.1	14.00
Termidor 0.125%	0.5 ml/ 63.6 cm^2	0.009	0.008
Termidor 0.0625%	0.5 ml/ 63.6 cm^2	0.0049	0.004

Balsawood disks were completely covered with Premise or Optigard foam. To quantify the amount of foam applied in the treatments, the foams were injected into pre-weighed plastic Ziplock® storage bags (16.5 by 14.9 cm bag [730 ml], (S.C. Johnson & Son, Inc., Racine, WI) and weighed (Fig. 2). This allowed us to calculate the amount of active ingredient applied per unit volume. To treat disks of balsawood with the foam, the disks were placed in the bottom of glass Petri dishes (9 cm diam.), a glass cylinder (I.D. 3.25 cm-diam.) was placed on the balsawood to contain the foam, and approximately 2.5 cm of foam was applied into the cylinder (83 ml) (Fig. 3). When the foam broke, the disk was completely covered with excess liquid. The disks and liquid were allowed to dry overnight in the fume hood. Table 2 indicates the average amount of foam per ml, and its calculated theoretical amount of active ingredient applied to each disk.

Table 2. The amount of foam and active ingredient applied to each balsawood disk.

Treatment	Avg. ± SD weight (g/ml)	Vol. Foam (ml)	AI (mg/cm^2)
Optigard Foam	63.5 ± 1.87	82.95	2.5
Premise Foam	45.7 ± 3.46	82.95	23.2

Treated surfaces were aged at laboratory conditions 30-50% RH and 26 ± 2° C overnight before testing. Other treated surfaces were aged for 30 and 60 days.

Continuous Exposures.- To determine the insecticidal activity of treated surfaces, drywood termites were continuously confined to treated wood. Disks (2.2 cm diam.) of balsawood were cut with a hobby Exacto knife (Fisherbrand, Fisher Scientific, Pittsburgh, PA) from the larger treated disks. The treated surface was placed facing upwards in the bottom of a small glass Petri dish (2.2 cm diam.). Six drywood termites were placed on each of three such treated disks (n=18). The dishes and termites were placed in a chamber maintained at 26ºC and 75% RH in the dark. The number of dead termites was counted about five per week, the dead termites being removed at each count. Exposure tests were conducted when the surfaces were 1, 30, and 60 days old.

To determine if starvation was important in killing termites, especially on deposits that may prevent feeding, groups of termites were confined to 10 and 15 % Tim-bor treated surfaces 1-day-old, disks freshly dusted with Tim-bor dust, untreated balsawood, and plastic Petri dishes without food. The Tim-bor treatments were prepared as described above. The starvation control consisted of the inside bottom of plastic Petri dish (3.5 cm diam.) roughened with fine sandpaper to provided traction for the termites, but without food. Six drywood termites were placed on each surface. The dishes and termites were placed in a chamber maintained at 26ºC and 75% RH in the dark. The number of dead termites was counted regularly and the dead termites removed. Three replicates were tested for each treatment.

The data were used to determine the survivorship function ($S_{(t)}$) and survivorship percentiles (SPs) for each treatment with a Kaplan-Meier Survival function test (Statistix 2008). This test accounts for right-censored data or individuals not dead at the termination of the test. The survivorship function ($S_{(t)}$) is the probability that termites will be alive on day t. The survivorship percentiles (SP's) indicate the day at which a given number of termites will be alive. Both tests allow the different treatments to be statistically compared with one another.

Limited Exposures.- Termites were exposed for brief periods of time to treated surfaces, removed and held on untreated surfaces. This was done to determine the effect which may occur if termites were to encounter a treatment for only a short time after which they moved to an untreated area. Termites were exposed to disks of balsawood (2.2 cm diam.) treated as described in the continuous exposure studies. Six drywood termites were held on each of three treated surfaces for 4, 8, 12 or 24 hours at which time the termites were removed and placed on untreated balsawood. As in the continuous exposure and starvation trials, the termites were then maintained in a chamber at 26ºC and 75% RH in the dark. The number of dead termites was counted regularly and the dead removed. Three replicates were tested for each treatment (n = 18). The 24-hour exposures were conducted when the surface treatments were 1, 30 and 60 days old. The 4-, 8-, and 12-hour exposure tests were conducted on day-old deposits of Tim-bor dust, 0.06 and 0.125% Termidor, and Optigard foam.

The data were used to determine the survivorship function and survival percentiles for each treatment with a Kaplan-Meier Survival function test (Statistix 2008).

Vapor Toxicity.- It has been argued that vapor toxicity may have an effect against termites in enclosed spaces such as their galleries. We examined this possibility in a series of experiments whereby termites were held in chambers under treated surfaces and thereby exposed to potential vapors emanating from the treatments. Pieces of untreated filter paper were placed in the bottom of a glass Petri dish (9 cm diam.). A glass cylinder (6.5 cm ID by 7.5 cm tall) was placed on the untreated filter paper. Groups of drywood termites were placed on the untreated filter paper disk. The treated disk of balsawood was placed on top the cylinder with the treated surface facing downwards in the cylinder. The treated wood disk was covered with a Petri dish. The number of termites knocked down (KD) was counted for the next 24 hours.

Disks of balsawood were treated as described above in the continuous exposure study. The disks were allowed to dry for 1 hour and then lightly patted with a paper towel to remove excessive liquid that might drip onto the filter paper. Additional disks were treated and aged for testing when 24 and 48 hrs old. Two replicates (n = 12) were tested for each treatment and aged. Those 1-hr-old deposits providing significant vapor toxicity were tested again for their vapor effect after they had aged 24 and 48 hrs.

Choice Feeding. - A choice test study was conducted to determine if drywood termites would contact, avoid, or tunnel through surfaces treated with the spot treatment products. Avoidance was measured by the mortality produced by a treated balsawood disk sandwiched between two pieces of untreated balsawood. Termites readily tunnel throughout the disks and few of them die within a month if all three disks are untreated. However, survivorship is reduced if the center disk is treated with an insecticidally active or repellent substance.

For these tests, a 5-cm-diam disk of balsawood cut from a larger treated disk was placed between two similar sized untreated disks and placed in the bottom of a 5-cm-diam glass Petri dish. A small amount of modeling clay was used to fill any space between the top edge of the wood and the dish. This prevented termites released onto the top disk from merely walking between the wood and the glass. For each treatment, 3 replicates of 6 termites were released onto the top (untreated) disk, a cover was placed on the dish, and the termites were allowed to feed and tunnel through the disks for 30 days. The setups were maintained in the dark at 26º C and 75% RH. The number of dead termites was counted regularly and the dead termites removed.

The data were used to determine the survivorship function and survival percentiles for each treatment with a Kaplan-Meier Survival function test (Statistix 2008).

Horizontal Transfer.- Unexposed termites were mixed with termites that had been exposed to treated deposits to determine if relevant amounts of the spot treatment insecticides could be transferred among termites. Three groups of >100 termites were held on disks of Whatman No.1 filter paper (9 cm diam.) that had been dyed with 1 ml of an aqueous 0.008% Nile blue dye solution. The termites were also provided dyed water to drink from a cotton wick in a small vial of aqueous 0.008% Nile blue solution. The termites were held on the dyed filter paper for about 7 days in a chamber maintained at 75% RH and 26º C in the dark or until they turned a light blue color from eating the paper and drinking the water. These blue termites served as the potential recipients (unexposed) termites in the transfer study.

Undyed (white) potential donor termites picked up their dose from treated disks before being mixed with the blue recipients. Disks of balsawood were treated with Tim-bor dust, Optigard, and 0.06 and 0.125% Termidor as described above. The deposits were allowed to dry in a fume hood for 24 hours. Disks (4.8 cm diam.) of treated balsawood were placed in the bottom of Petri dishes with the treated surface facing upwards. Aliquots of 6 white, undyed termites (donors) were held on the treated deposits for 5, 15, 30, and 60 minutes. These exposed potential donors were then placed on disks of untreated balsawood in Petri dishes. For each exposure, 6 blue termites (recipients) were added to each dish. Three replicates were conducted for each exposure period and treatment. The dishes and termites were covered and maintained in the dark in a chamber kept at 75% RH and 26º C. The number of dead white and blue termites was counted and removed each day. We assumed that increased mortality of the blue recipient termites beyond their untreated check level was attributable to horizontal transfer of active ingredient from the white donors.

Infested Boards Studies.- Structural boards with visible evidence of drywood termite feeding and damage were obtained from cooperating PMPs and residents. The boards had been removed from homes infested with drywood termites. Most of the boards were 5 by 13 cm (2 by 4-in.) or 5 by 15 cm (2 by 6-in.), 1.8 to 2.4 m (6 to 8 feet) long. The boards were cut into about 1.2 to 1.5 m (4 to 5-foot) sections. The level of termite activity in each section was determined with a portable acoustic detection device (Termite Tracker, Dunegan Engineering, Midland, TX). This device has a peak sensitivity at 40 Khz and detects nearby termite feeding and movement by means of a metal probe which must be inserted into the wood. A 11/64-in. hole ¾ in. deep was drilled along the centerline of the boards every 18 in. to accommodate the probe. These holes were designated as left and right monitoring sites (Fig. 4). We took activity readings at each monitoring hole for 2 minutes, one typically taken in the morning and one in the afternoon. The two counts were averaged for the day for each monitoring hole. A piece of tape was placed over each hole between readings. A solid piece of clean lumber without termites was checked periodically to compensate for any background noise. Only boards with average counts consistently > 10 per 2 minutes were used in the study. Other researchers have used > 4 counts/min with this device as basis for including wood in their studies (Lewis and Power 2004, Scheffrahn *et al.* 1997), so we are confident in using >5 counts/min.

Boards were ranked according to the average number of activity counts. The boards were randomly assigned to treatments so that each series had boards with high, medium and low activity counts. Each treatment was assigned three boards. Standard treatment method for spot treatment for drywood termites is the injection of chemical via surface injection holes presumably intersecting a termite gallery in the wood. To mimic a reasonable treatment as might be made by a PMP, a diamond pattern was drilled into each board with approximately 18 in. between the injection holes along the same line (see Fig.4). Although the injection holes could be drilled closer together, this pattern seemed to us to be about the maximum number that a professional would use. There was a sudden release of resistance as the drill entered the wood and intersected a termite gallery. If a termite gallery was not located, another hole was drilled. After 3 unsuccessful attempts, we moved on to the next hole. Exactly 5 ml of 0.06% Termidor, 10% Tim-bor, or XT-2000 was injected in each hole. The Optigard foam was applied to each hole for 10 seconds. Premise foam and Bora-Care were not tested.

We incorporated an innocuous red dye into each treatment to help us detect how well each treatment penetrated the termite galleries at the end of the study. We hoped to find a pattern of penetration when we opened the boards at the end of the study that might maximize the spread through galleries. About 5 ml of red food dye (Red 40, Chef's Review, Amerifoods Trading Co., Los Angeles, CA) was added to about 100 ml of Termidor, Tim-bor, and Optigard. About 1-2 g of Sudan red dye (Sudan IV, Aldrich Chemical Co., Milwaukee, WI) was added to 100 ml XT-2000. The XT-2000 is an oil formulation and an oil soluble dye was required.

Acoustical activity counts were taken before and at 1, 7, 14, 21, and 28 days after the treatment. Efficacy was partially determined by comparing the reduction of the average number of counts after treatment with the number before.

Efficacy was also partly determined from the number of dead termites ultimately found a month after treatment. This allowed a full month for the treatments to produce their desired effect. At 30 days, the boards were cut into 3-in sections and each section was carefully divided into smaller pieces with a hammer and chisel. The termites were gently tapped from each section. The number of live and dead workers, soldiers, and alates was recorded. We assumed that the most efficacious treatments would provide the highest level of kill and the lowest level of survival. A comparison was made between the number of live termites we found at 30 days and the average acoustical counts with a Kendal τ analysis (Statistix 2008). The percent mortality data were transformed by arcsine $p^{1/2}$ and analyzed with an ANOVA. The treatments were compared with a Tukey's HSD.

RESULTS

Continuous Exposures

Continuous exposures on fresh deposits of Termidor and Optigard provided significantly faster kill than did the other treatments (Table 3). The 10% and 15% Tim-bor and Bora-Care deposits provided median mortality (50%) at day 1, 4 and 7, respectively. Each of these treatments failed to produce sufficient mortality by the end of the exposure test to provide a 10% survivorship percentile. Tim-bor dust provided 100% kill within 7 days and 50 and 10% survival percentiles of 5 and 6 days, respectively. The median survivorship (50%) for Premise foam and XT-2000 was 11 and 12 days, respectively. The Premise foam failed to kill 100% of the termites within 26 days. In the untreated control, 22.2% of the termites died by day 26.

The 30-day-old deposits of Termidor and Optigard provided significantly faster kill than did the other treatments (Table 4). The 10% survival percentiles of the Termidor and Optigard deposits were 1 to 1.6 days, respectfully. Tim-bor dust and 15% Tim-bor deposits provided 50% mortality at 7 and 4 days, respectively. The XT-2000, Premise foam, Tim-bor 10%, and the untreated controls had similar mortality at day 26, the median survival time being 26, 19, 26, and 19 days, respectfully.

The 60-day-old deposits of Termidor and Optigard provided 100% within 7 days (Table 5). The Tim-bor dust and 10% Tim-bor liquid deposits provided 100% kill of termites within 14 days and the median survival (50%) at day 5. The median survival of Bora-Care, 15% Tim-bor, Premise foam and untreated deposits was 18, 19, 19, and 19 days, respectfully; none of them provided 100% kill at day 26. The mortality on deposits of XT-2000 was considerably lower than the untreated control. Mortality on untreated controls varies greatly and small groups of dry wood termites typically don't survive well over long periods of time.

The continuous exposure of drywood termites to 1-day-old borate treated surfaces was compared with untreated controls and a group of termites that were not provided food (Table 6). Exposure to Tim-bor dust provided significantly faster mortality than did any of the other treatments with 100% mortality within 21 days. The 10 and 15% Tim-bor treatments provided significantly lower survivorship ($S_{(25)} = 0.22$) than did the untreated control and the starved termites ($S_{(25)} = 0.78$ and 0.72, respectfully). The starved termites and the untreated controls provided very similar survivorship at day 25. In another test, unfed termites survived for nearly 5 months.

Limited Exposures

Exposures limited to 24 hours on 1-day-old deposits of 10 and 15% Tim-bor, Tim-bor dust, Optigard, and Termidor provided significantly greater mortality than did exposures on Bora-Care, XT-2000, and Premise foam (Table 7). The 24-hour exposures on the Optigard and Termidor deposits provided 100% kill within 7 days. The mortality of termites at day 27 exposed to Bora-Care, XT-2000, and Premise foam was not significantly different from the untreated control. None of them produced 10% survivorship percentiles within 26 days.

Exposures limited to 24 hours on 30-day-old deposits of Optigard foam and Termidor provided 100 % within 7 days (Table 8). Tim-bor dust, Bora-Care, and XT-2000 provided > 80% kill of termites at day 27. The median survivorship for Tim-bor dust, Bora-Care, and XT-2000 was 6, 11, and 4 days, respectfully. The 10 and 15% Tim-bor, Premise foam, and untreated deposits did not produce sufficient kill to result in a median survival percentile at day 27.

Limited exposures of 24 hours to 60-day-old deposits on Otigard foam, and 0.06 and 0.12% Termidor produced 100% kill within 14 days (Table 9). The 10% survivorship percentiles Optigard foam, and 0.06 and 0.12% Termidor were 1, 6, and 4 days, respectfully.

Tim-bor dust provided 100% kill within 25 days. The 10 and 15% Tim-bor, Bora-care and XT-2000 produced 50% survivorship percentiles at 15, 22, 29, and 18 days, respectfully. None of them produce 10% survivorship percentiles at day 25. Premise foam and the untreated controls provided similar results at day 25.

Shorter exposures of 4, 8, and 12 hours were conducted on deposits that provided significant mortality on deposited aged 60 days. Exposures as brief as 4 hours on Optigard treated surfaces provided 100% within 7 days (Table 10). The two Termidor treatments also provided 100% mortality in all cases except for a 4-hour exposure to 0.06% Termidor at day 14. The 10% survivorship percentiles for Termidor deposits ranged from 1 to 11 days on the different exposures. A 12-hour exposure to Tim-bor dust provided 100% at day 7, but shorter exposures failed to kill 100% of the termites at day 14.

Vapor Toxicity

Only the XT-2000 had sufficient volatility to produce 100% kill of termites when termites were exposed to the airspace below the deposits (Table 11). The Termidor deposits provided 60% mortality of drywood termites. None of the other treatments had sufficient enough volatility to kill drywood termites. The XT-2000 deposits did not have any vapor toxicity between 24 and 48 hours. However, the termites were sluggish and did not feed on the filter paper. When those termites were placed on a piece of untreated filter paper, the termites completely recovered and began feeding. Termidor deposits aged for 1 day continued to kill about 60% of the termites exposed for 24 hours.

Choice Feeding

Termites fed and tunneled into disks treated with Optigard or Termidor and aged 1 day, providing 100% kill within 28 days (Table 12). The Premise foam and Tim-bor dust deposits provided 100% kill within 42 days. The two liquid Tim-bor treated surfaces and Bora-Care provided similar survivorship functions to the untreated controls with the $S_{(38\text{-}39)}$ ranging between 0.16 to 0.27. The XT-2000 provided greater survivorship than did the Bora-Care and liquid Tim-bor treatments, but the survivorship function of the XT-2000 overlapped with the untreated control.

When treated deposit were tested at day 30, termites tunneled into the Optigard and Termidor treatments providing 100% within 14 days (Table 13). The 10% Tim-bor and Tim-bor dust deposits provided significantly lower survivorship at day 20 than did 15% Tim-bor, Bora-Care, XT-2000, Premise foam and the untreated control. However, the 10% Tim-bor and Tim-bor dust failed to provide 100% kill by day 26.

At day 60, only the Optigard and Termidor treatments provided 50% survivorship percentiles within the 25-day test period (Table 14). Both Termidor deposits provided 100% kill with 25 days.

Horizontal Transfer

Even brief exposures of as short as 5 minutes were sufficient for donors to acquire a lethal dose of Tim-bor dust, Optigard, or Termidor (Table 15). Five-minute exposures produced 94.4 and 88.9 % mortality of donors within 3 weeks after the exposure to 0.06% and 0.125% Termidor, respectively. Sufficient amounts of Tim-bor dust and Optigard were transferred to kill 100% of the recipients at all exposure periods. Exposures of 15, 30, and 60 minutes of the donors to Termidor deposits produced 100% kill of the recipients. Five-minute exposures produced 94.4% kill of recipients at week 3.

None of the dead termites were consumed by other termites.

Infested Board

There was a consistent drop in activity counts 1 day after treatments (Fig. 5). At 1 week, the average activity counts for Termidor, Opitgard, and XT-2000, dropped by 89, 97, and 84%, respectfully, compared with the 1 day pre-treatment counts. The percent reduction in activity counts for the Tim-bor treatments was 35.6%. The activity counts of the Termidor and Opitgard treatments remained low through the 30 days. The activity counts of the XT-2000 increased to 42.2 counts per 2 minutes at week 4. The average activity counts of the Tim-bor treated boards decreased to 40.4 counts per 2 min at week 4. Activity counts varied in both series of untreated boards and they averaged about 90 counts per 2 min at week 4. The 0.06% Termidor provided 92% kill of workers and 100% kill of soldiers at day 30 (Table 16) and provided significantly greater kill than did XT-2000, Timbor, and the controls. The Optigard provided 73% kill of workers and 85% kill of soldiers. The XT-2000 killed 51% of the workers and was not significantly different from the Optigard and Timbor treatments. The Timbor treatment killed 20 % of the workers, but was not significantly different from the controls.

There was a significant negative correlation between the number of activity counts and the percent kill of worker termites ($r_s = -0.9429$, $P = 0.0167$). As the number of the counts decreased, the percent kill of drywood termites increased.

Discussion

The continuous and brief exposure data clearly showed that the deposits of Tim-bor dust, Termidor, and Optigard provided the fastest kill of drywood termites on deposits aged up to 60 days. The active ingredients in deposits of liquid Tim-bor, Bora-Care, XT-2000, and Premise foam were not as readily available to termites and provided kill only after extremely long continuous exposures. Drywood termites can survive for months without food. Consequently, deposits that prevent feeding and are not readily available to termites do not provide rapid kill. The long delayed toxicity of liquid borate deposits against drywood termites is consistent with recent findings by Habes *et al.* (2006) that the toxicity of boric acid mortality is time-dependent and effects increase with dose and the duration of the treatment. Their studies suggest that boric acid affects the mid-gut structure killing the cockroaches. Our findings also corroborate Scheffrahn *et al.* (1997) findings that Tim-bor dust deposits were more active against two drywood termite species in Florida than were liquid deposits of Tim-Bor. Drywood termites did not feed on XT-2000, Tim-bor and Bora-Care treated surfaces. Exposures on Premise deposits inhibited feeding, but the mortality was not significantly different than drywood termites on untreated disks of balsawood.

When drywood termites were exposed to fresh deposits of Tim-bor liquid and dust for 24 hours, the time required to achieve the median survival time ranged between 5 and 12 days (Table 7). The liquid deposits of disodium octaborate tetrahydrate (DOT) were not as active on aged deposits suggesting that it may have penetrated into the wood surfaces making it less available to termites. As in the continuous exposure studies, the DOT provided very slow and delayed toxicity after exposure.

The active ingredient in XT-2000, d-limonene, had sufficient vapor pressure (2,666 Pascals at 25º C, www.arb.ca.gov) to produce 100% kill of drywood termites 1 hour after treating the wood. By day 2 the deposits no longer produced mortality of drywood termites, but the termites did not feed on the filter paper during the exposure. The Termidor deposits surprisingly produced about 60% mortality of the drywood termites. This test was repeated several times with similar results. The vapor pressure of fipronil is only 3.7 x 10^{-4} mPascals and the Henry's constant is 6.6 x 10^{-6} m^3·atm/mol and not particularly volatile (Gunasekara *et al.* 2007). A plausible explanation is codistillation of the fipronil from the surface of the treated wood as it dried. Acree *et al.* (1963) reported the codistillation of DDT from water. DDT's vapor pressure is 2.5 x 10^{-2} mPacals and it is also not very volatile (www.the-piedpiper.co.uk/thl3(1).htm). However, Termidor deposits aged for 24 hours also produced 60% kill of drywood termites suggesting that other mechanisms of transfer may also be involved. Fipronil is extremely toxic to subterranean termites (0.2 ng/termite; Saran and Rust 2007), and it may be possible for sufficient toxicant to volatize from the treated surfaces.

In choice feeding studies, termites avoided the disks treated with borates and XT-2000. Only the Optigard and Termidor deposits provided 100% kill within 30 days. The data suggests that once wood has been treated with borates and XT-2000, the termites will avoid feeding on those deposits and acquiring lethal doses. This is consistent with Scheffrahn *et al.* (2001) findings that DOT solutions were not dislodgeable and had low toxicity to the West Indian drywood termite, *Cryptotermes brevis* (Walker).

On a 1:1 basis, drywood termites exposed to Tim-bor dust, Optigard (thiamethoxam) and Termidor (fipronil) deposits acquired sufficient amounts of each toxicant to kill >90% of untreated termites that came in contact with them. Brief exposures to Optigard deposits provided the fastest kill of donors and recipients. Termidor and Tim-bor dust provided somewhat slower kill of the donors and recipients. It is likely that these three treatments provide horizontal transfer of insecticide and will kill termites beyond the area treated. We did not quantify whether this transfer may be tertiary, quaternary, or more. Although it was somewhat surprising that there was much effective horizontal transfer of Tim-bor, its transfer among termites may be accounted for by the dust formulation. Its dry dust particles are probably more readily available and dispersed than are the dried borate liquid deposits. Liquid borate deposits become crystalline and adhere tightly to the surface to which they are applied. Dust deposits do not. The lack of transfer of liquid DOT is consistent with Ferster *et al.* (2001) that reported no effective transfer of 10% liquid DOT and sporadic results with DOT dust. In their study, they applied the DOT at a rate equivalent to about 34 mg/ cm^2 about twice as much DOT as we did. Possibly *I. synderi* is less susceptible to DOT dust deposits than is *I. minor*. It is also possible that higher RH conditions in southern Florida may also explain the difference. They stated, "…our results demonstrate that active ingredient, formulation, deposit condition, and time of exposure affect the transfer of the toxicant from contaminated to uncontaminated *I. synderi* nestmates."

When boards were injected with 10- 30 ml of 0.025, 0.05, and 0.1% thiamethoxam (active ingredient in Optigard), there was > 98% kill of termite workers (Lewis and Powers 2004). The AE readings dropped dramatically with 24 hours declined by 96% in the thiamethoxam treated boards compared with a slight increase in the untreated controls. When drywood termite infested boards were drilled with a diamond pattern and drill holes spaced every 12.7m cm (5 inches), the XT-2000, Tim-bor, Termidor and Optigard produced 81, 99, 100, and 81% kill of termites, respectively (Lewis and Rust 2009). Premise foam only provided 41% kill at 90 days.

In our studies, the distance between drill holes was 18 inches. This distance was chosen because Lewis and Rust (2009) reported that injections points every 5 inches were highly effective. We also found that Termidor and Optigard performed very well. We did not inject Tim-bor dust because we did not have suitable equipment to inject dusts into galleries. We believe that the increased performance of Termidor and Optigard compared with XT-2000 and Tim-bor can be explained by increased bioavailability and potential for horizontal transfer. The Termidor and Optigard don't require as thorough a treatment as the XT-2000 and Tim-bor. This can be especially important in situations where termite galleries are inaccessible and infested lumber may not be thoroughly drilled and injected.

Scheffrahn *et al.* (1997) stated, "Results suggest that chemical toxicity, formulation, and application method, as well as drywood termite behavior and gallery system architecture, influenced the performance of local chemical treatments." This is particular true in our laboratory study. The XT-2000, Premise foam, Bora-Care, and Tim-bor primarily killed drywood termites by contact. Even though the residual deposits were not readily bioavailable to workers, the deposits did prevent feeding.

The Tim-bor dust, Termidor liquid, and Optigard foam appear to be highly effective localized treatments that could be incorporated into an Integrated Pest Management program against drywood termites. Inspection and detection of active drywood termite infestations remain an essential component of an IPM program.

Executive Summary

1. Deposits of Tim-bor dust, Termidor liquid, and Optigard foam were lethal to drywood termites on both continuous and brief exposures. The active ingredients were readily available from the treated surfaces.

2. Deposits of Tim-bor dust, Termidor liquid, and Optigard foam were not repellent and lethal doses of active ingredient were readily transferred from treated termites (donors) to untreated termites (recipients).

3. Fresh deposits and XT-2000 liquid were extremely toxic to drywood termites. However, the deposits rapidly lost their contact activity with 24-48 hours.

4. Vapors of both XT-2000 and Termidor were toxic to drywood termites. Deposits of XT-2000 lost their vapor toxicity within 24 hours.

5. Prolonged exposures of drywood termites on deposits of Timbor liquid, Bora-Care, and Premise Foam were necessary to provide kill. Non-lethal deposits deterred termite feeding.

6. Non-lethal deposits of XT-2000 deterred feeding.

7. Tim-bor dust, Termidor liquid, and Optigard foam consistently provided the best results in the laboratory tests.

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Fig. 1. The Optigard® ZT Foamer Kit used to apply the Optigard foam to the balsawood surfaces.

Fig. 2. Loading foam into a 730-ml plastic bag.

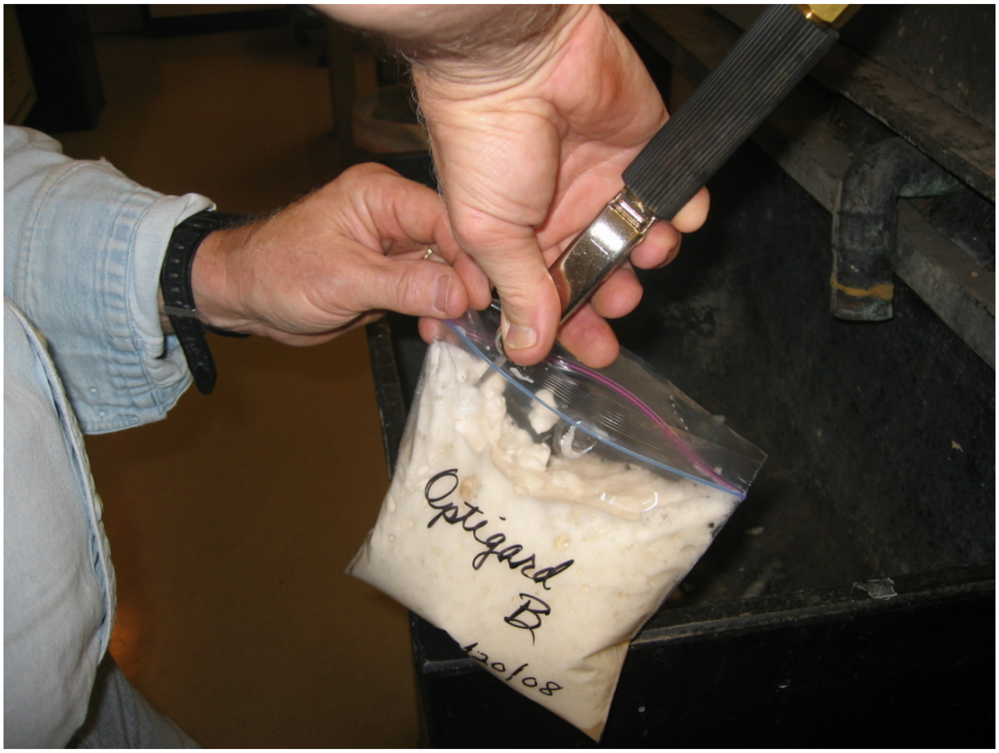

Fig. 3. Applying the foam by way of the Optigard ZT Foamer Kit into the glass cylinder resting on a balsawood disk. The cylinder is removed when the foam breaks, leaving a pool of liquid covering the disk.

Fig. 4. Diagram of monitoring sites (circles) and injection points (diamonds) on a typical termite infested board.

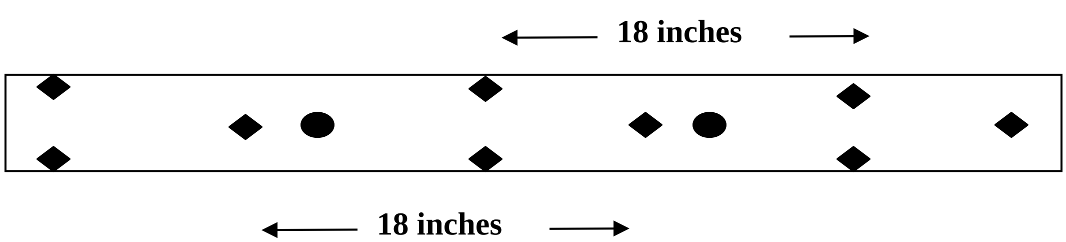

Fig. 5. The average number of activity counts recorded from drywood termite infested boards.

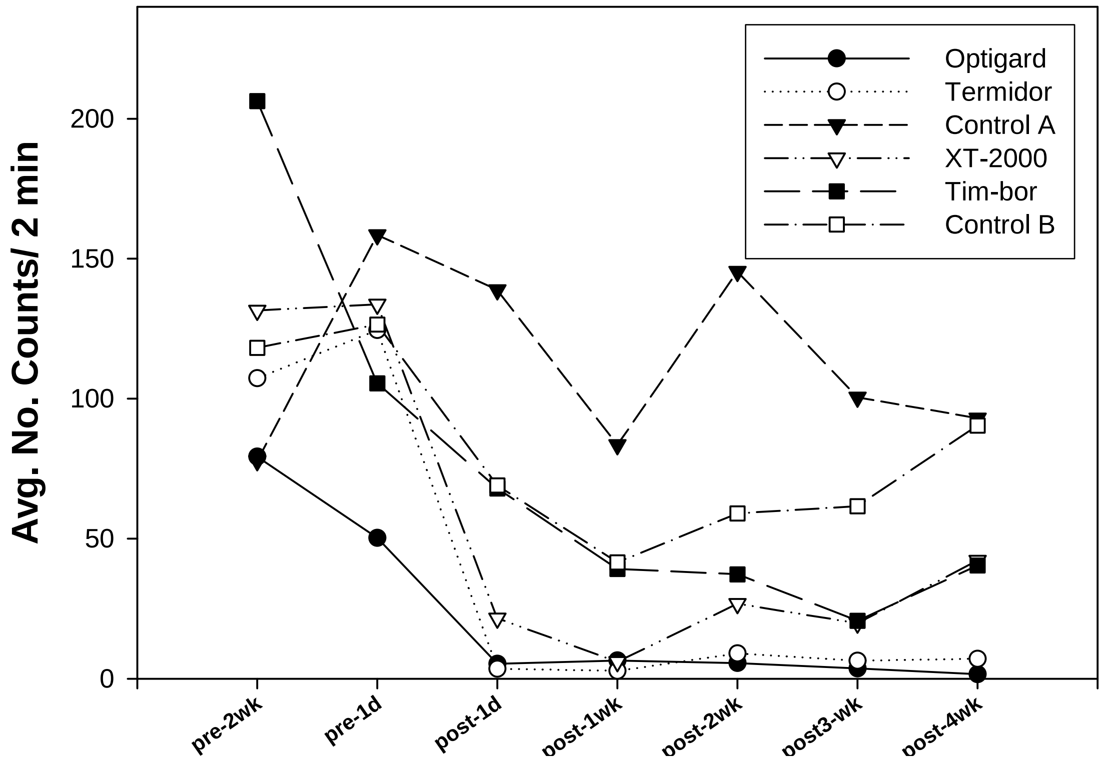

Table 3. The mortality of workers of the western drywood termite, *Incisitermes minor*, exposed continuously to 1-day-old deposits.

	% Dead at day				Survivorship Percentile (days)[a]	
Treatment	1	7	14	26	50	10
Tim-bor, 15%	33.3	50.0	61.1	83.3	4	M
Tim-bor, 10%	33.3	50.0	61.1	100	7	M
Tim-bor dust	0.0	100			5	6
Bora-Care	11.1	50.0	88.9	88.9	7	M
XT-2000	5.6	33.3	100		12	14
Termidor, 0.12%	100				1	1
Termidor, 0.06%	61.1	94.4	100		1	4.2
Premise foam	5.6	38.9	66.7	88.9	11	M
Optigard foam	100				1	1
Untreated	5.6	16.7	16.7	22.2	M	M

[a] Survivorship percentiles indicate the time (days) at which 50% or 10% of the termites survived (Kaplan-Meier test). M indicates an insufficient number of dead termites by day 26 to determine the survival percentile at the end of the study.

Table 4. The mortality of worker western drywood termites exposed continuously to 30-day-old deposits.

	% Dead at day				Survivorship Percentile (days)[a]	
Treatment	1	7	14	26	50	10
Tim-bor, 15%	27.8	100			4	4.4
Tim-bor, 10%	0.0	0.0	16.7	55.6	26	M
Tim-bor dust	0.0	83.3	100		7	8.2
Bora-Care	0.0	5.6	50.0	88.9	14	23.2
XT-2000	0.0	0.0	22.2	50.0	26	M
Termidor, 0.12%	100				1	1
Termidor, 0.06%	88.9	100			1	1.6
Premise foam	0.0	5.6	5.6	77.8	19	M
Optigard foam	100				1	1
Untreated	0.0	16.7	44.4	61.1	19	M

[a] Survivorship percentiles indicate the time (days) at which 50% or 10% of the termites survived (Kaplan-Meier test). M indicates an insufficient number of uncensored observations (dead termites) to determine the survival percentile at the end of the study.

Table 5. The mortality of western drywood termites exposed continuously to 60-day-old deposits.

	% Dead at day				Survivorship Percentile (days)	
Treatment	1	7	14	26	50	10
Tim-bor, 15%	22.2	38.9	38.9	72.2	19	M
Tim-bor, 10%	22.2	72.2	100		5	12
Tim-bor dust	0. 0	83.3	100		5	8.6
Bora-Care	0.0	5.6	5.6	94.4	18	25.2
XT-2000	0.0	0.0	0.0	11.1	M	M
Termidor, 0.12%	100				1	1
Termidor, 0.06%	94.4	100			1	1
Premise foam	0.0	5.6	5.6	77.8	19	M
Optigard foam	100				1	1
Untreated	0.0	16.7	44.4	61.1	19	M

[a] Survivorship percentiles indicate the time (days) at which 50% or 10% of the termites survived (Kaplan-Meier test). M indicates an insufficient number of uncensored observations (dead termites) to determine the survival percentile at the end of the study.

Table 6. Mortality of worker western drywood termites starved or confined continuously to 1-day-old deposits of Tim-bor.

	% Dead at day					Survivorship function S(t)	
Treatment	1	7	14	21	28	$S_{(7)}$	$S_{(25)}$[a]
Tim-bor, 15%	0	0	5.6	50.0	88.9		0.22 (0.117-0.381)
Tim-bor, 10%	0	0	33.3	34	94.4		0.22 (0.099-0.427)
Tim-bor Dust	0	83.3	94.4	100		0.16 (0.073-0.088)	
Starved (Plastic)	0	0	11.1	22.2	44.4		0.72 (0.450-0.871)
Balsa check	0	0	5.6	22.2	27.8	0.83 (0.750-0.990)	0.78 (0.556-0.098)

[a] Survivorship function (day) with 95% CI indicates the probability that termites will be alive on that day (Kaplan-Meier test).

Table 7. Subsequent mortality of worker western drywood termites after a 24–hour exposure to 1-day-old deposits.

	% Dead at day				Survivorship Percentile (days)[a]	
Treatment[b]	1	7	14	27	50	10
Tim-bor, 15%	0	61.1	88.9	88.9	5	M
Tim-bor, 10%	0	27.8	72.2	94.4	12	23
Tim-bor dust	0	83.3	94.4	94.4	7	8
Bora-Care	0	0	11.1	44.4	14	M
XT-2000	0	11.1	22.2	44.4	M	M
Optigard foam	100				1	1
Termidor 0.12%	83.3	100			1	2.6
Termidor, 0.06%	94.4	100			1	1
Premise foam	0	0	5.6	33.3	M	M
Untreated wood	0	5.6	16.7	44.4	M	M

[a] Survivorship percentiles indicate the time (days) at which 50% or 10% of the termites survived (Kaplan-Meier test). M indicates an insufficient number of uncensored observations (dead termites) to determine the survival percentile at the end of the study.

[b] Deposits treated 6 May, 2008 and aged 24 hours before testing.

Table 8. Subsequent mortality of worker western drywood termites after a 24-hour exposure to 30-day-old deposits.

	% Dead at day				Survivorship Percentile (days)	
Treatment[b]	1	7	14	27	50	10
Tim-bor, 15%	5.6	16.7	22.2	44.4	M	M
Tim-bor, 10%	0	22.2	38.9	44.4	M	M
Tim-bor dust	0	55.5	94.4	100	6.0	11.8
Bora-Care	5.6	33.3	61.1	88.9	11	M
XT-2000	16.7	77.8	77.8	83.3	4	M
Optigard foam	100				1	1
Termidor, 0.12%	83.3	100			1	1.6
Termidor, 0.06%	88.9	100			1	4
Premise foam	0	5.6	11.1	50.0	M	M
Untreated	0	0.0	5.6	16.7	M	M

[a] Survivorship percentiles indicate the time (days) at which 50% or 10% of the termites survived (Kaplan-Meier test). M indicates an insufficient number of uncensored observations (dead termites) to determine the survival percentile at the end of the study.
[b] Deposits treated 6 May, 2008 and aged 30 days.

Table 9. Subsequent mortality of worker western drywood termites after a 24-hour exposure to 60-day-old deposits.

	% Dead at day				Survivorship Percentile (days)	
Treatment	1	7	14	25	50	10
Tim-bor, 15%	0	11.1	27.8	50.0	22	M
Tim-bor, 10%	0	27.8	44.4	66.7	15	M
Tim-bor dust	0	22.2	88.9	100	10	14.6
Bora-Care	0	0	0	38.9	29	M
XT-2000	5.6	22.2	33.3	50.0	18	M
Optigard foam	100				1	1
Termidor, 0.12%	72.2	100			1	4
Termidor, 0.06%	66.7	94.4	100		1	6
Premise foam	0	11.1	16.7	27.8	M	M
Untreated	0	0	5.6	11.1	M	M

[a] Survivorship percentiles indicate the time (days) at which 50% or 10% of the termites survived (Kaplan-Meier test). M indicates an insufficient number of uncensored observations (dead termites) to determine the survival percentile at the end of the study.
[b] Deposits treated 6 May, 2008 and aged 60 days.

Table 10. Mortality of worker western drywood termites after limited exposures to 1-day-old deposits.

		% Dead at day			Survivorship Percentiles (days)[a]	
Treatment	Exp. Time (hours)	1	7	14	50%	10%
Tim-bor dust	4	11.1	55.6	94.4	4	11
	8	0.0	50.0	94.4	7	13.4
	12	5.6	100		3	3
Termidor, 0.12 %	4	94.4	100		1	1
	8	94.4	94.4	100	1	1
	12	33.3	100		3	4
Termidor, 0.06 %	4	72.2	83.3	94.4	1	11
	8	83.3	100		1	4
	12	50.0	100		3	3
Optigard foam	4	100			1	1
	8	94.4	100		0.3	0.3
	12	84.0	100		0.5	3
Untreated	4	5.6	16.7	16.7	M	M
	8	0.0	0.0	5.6	M	M
	12	11.1	27.8	disc.	M	M

[a] Survivorship percentiles indicate the time (days) at which 50% or 10% of the termites survived (Kaplan-Meier test). M indicates an insufficient number of uncensored observations (dead termites) to determine the survival percentile at the end of the study.

Table 11. The vapor toxicity against worker drywood termites produced by localized treatment products when applied to the surface of balsawood.

	% mortality at hour [a]					
Treatment	0.25	1	1.75	3.16	19.5	24
Bora-Care	0	0	0	0	0	0
Optigard foam	0	0	0	0	0	0
Premise foam	0	0	0	0	0	0
Termidor	0	0	0	0	60	60
Tim-bor	0	0	0	0	20	20
XT-2000	0	30	30	50	100	
Untreated	0	0	0	0	0	10

[a] Two replicates of 5 termites (n = 10) were exposed in a confined airspace beneath each treated surface.

Table 12. Mortality of worker western drywood termites in choice feeding studies on 1-day-old deposits on balsawood.

	% Dead at day[a]					Survivorship function[b]
Treatment	1	14	28	42	56	S(t) 95% CI
Timbor, 15%	5.6	27.8	50.0	83.3	100	0.22 (0.099-0.427)
Timbor, 10%	16.7	16.7	61.1	94.4	100	0.17 (0.067-0.358)
Timbor dust	0	38.9	83.3	100		0.0
Bora-Care	0	27.8	44.4	83.3	NA	0.16 (0.073 – 0.336)
XT-2000	0	11.1	27.8	50.0	55.6	0.56 (0.346-0.747)
Optigard Foam	16.7	94.4	100			0.0
Termidor, 0.12%	44.4	88.9	100			0.0
Termidor, 0.06%	5.6	100				0.0
Premise Foam	5.6	44.4	72.2	100		0.0
Untreated	0	22.2	50.0	72.2	83.3	0.27 (0.134-0.489)

[a] NA= data not available. Dishes had been discontinued.
[b] Survivorship function (day) with 95% CI indicates the probability that termites will be alive on day 38-39 (Kaplan-Meier test).

Table 13. Mortality at day 20 of worker western drywood termites in choice feeding studies on 30-day-old deposits on balsawood.

	% Dead at day				Survivorship function[a]
Treatment	1	4	14	26	S(t) 95% CI
Timbor, 15%	0.0	11.1	11.1	61.1	0.56 (0.378-0.720)
Timbor, 10%	0.0	16.7	50.0	94.4	0.11(0.052-0.222)
Timbor dust	0.0	11.1	55.6	88.9	0.28 (0.142-0.473)
Bora-Care	0.0	5.6	11.1	61.1	0.61 (0.403-0.786)
XT-2000	0.0	0.0	5.6	55.6	0.78 (0.556-0.907)
Optigard foam	55.6	83.3	100		
Termidor, 0.12%	77.8	94.4	100		
Termidor, 0.06%	88.9	100			
Premise foam	0.0	5.6	5.6	50.0	0.61 (0.422-0.772)
Untreated	0.0	0.0	27.8	50.0	0.67 (0.446-0.832)

[a] Survivorship function (day) with 95% CI indicates the probability that termites will be alive on that day 20 (Kaplan-Meier test).

Table 14. Mortality of worker western drywood termites in choice feeding studies on 60-day-old deposits of treated balsawood.

	% Dead at day				Survivorship Percentiles (days)	
Treatment	1	7	14	25	50	10
Tim-bor, 15%		0.0	5.5	38.9	38.9	M
Tim-bor, 10%	0.0	5.5	27.8	50.0	M	M
Tim-bor dust	0.0	0.0	50.0	50.0	M	M
Bora-Care	0.0	5.6	22.2	50.0	M	M
XT-2000	0.0	5.5	5.5	16.7	M	M
Optigard foam	5.5	50.0	66.7	77.8	8.0	M
Termidor, 0.12%	0.0	61.1	77.8	100	6.0	18.6
Termidor, 0.06%	5.5	72.2	83.3	100	4.0	15.8
Premise foam	5.5	11.1	11.1	11.1	M	M
Untreated	0.0	5.5	11.1	11.1	M	M

[a] Survivorship percentiles indicate the time (days) at which 50% or 10% of the termites survived (Kaplan-Meier test). M indicates an insufficient number of uncensored observations (dead termites) to determine the survival percentile at the end of the study.

Table 15. The horizontal transfer of spot treatment product insecticides between donor and recipient drywood termites.

		% Mortality[a]					
		week 1		week 2		week 3	
Treatment	Exposure (min)	D	R	D	R	D	R
Tim-bor dust	60	66.7	100	88.9		88.9	
	30	27.8	88.9	66.7	94.4	72.2	100
	15	66.7	77.8	88.9	94.4	100	100
	5	50.0	55.6	66.7	100	100	
Optigard foam	60	100	100				
	30	72.2	100	100			
	15	100	100				
	5	100	100				
Termidor, 0.12%	60	100	100				
	30	72.2	66.7	83.3	94.4	100	100
	15	94.4	100	94.4		94.4	
	5	72.2	77.8	72.2	94.4	88.9	94.4
Termidor, 0.06%	60	27.8	88.9	88.9	94.4	88.9	94.4
	30	55.6	94.4	77.8	94.4	83.3	94.4
	15	100	100				
	5	77.8	88.9	94.4	88.9	94.4	94.4
Untreated	60	0	5.6	0	5.6	0	5.6
	30	5.6	5.6	5.6	5.6	5.6	5.6
	15	22.2	5.6	22.2	5.6	27.8	27.8
	5	0	5.6	0	5.6	0	16.7

[a] For each exposure, 3 replicates of 6 exposed undyed drywood termites (donors) mixed with 6 blue dyed untreated drywood termites (recipients).

Table 16. The mortality of drywood termites in naturally infested boards treated with local treatment product injected according to label direction every 18 inches in a diamond pattern.

Treatment	No. Drill holes	Amt. injected (ml)	% Mortality [total no.][c]		
			workers	soldiers	alates
Termidor liquid[a]	9	45	91.9 a [393]	100 [25]	67.6 [34]
Optigard foam[a]	7	35	73.2 ab [779]	85.5 [62]	74.0 [100]
Control A[a]	7	35	0.2 d [910]	7.4 [27]	0.0 [64]
XT-2000 liquid[b]	9	45	51.4 bc [366]	80.4 [46]	-
Tim-bor liquid[b]	10	50	20.3 cd [700]	16.7 [18]	5.6 [71]
Control B[b]	8	40	2.9 d [541]	0 [17]	0 [7]

[a] Wood treated 4 May 2009. .
[b] Wood treated 22 May 2009.
[c] Percentages followed by the same letter are not significantly different at $P < 0.05$ (Tukey's HSD). .