Efficacy of Commercial Termite Baiting Systems for Management of Subterranean Termites (Isoptera: Rhinotermitidae) in Texas

by

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ABSTRACT

The success of commercial baiting strategies for remedial control of subterranean termites has historically had mixed results, owing to discrepancies in applicator error, pest pressure, and choice of toxicant. For this reason, an independent assessment of two specific active ingredients, and three dispensing mechanisms was evaluated to determine their overall efficacy for remedial control of subterranean termite activity in Texas. FirstLine® (FMC Corp.), Sentricon® with Recruit II® bait (Dow AgroSciences), and Terminate® (United Industries, Inc) systems were evaluated. The time required for foraging termites to locate and initiate feeding on Sentricon® and Terminate® bait stations was approximately one-half the time required to locate and begin feeding on FirstLine®, for both *Reticulitermes flavipes* and *Coptotermes formosanus*. The time required for *C. formosanus* to locate and initiate feeding on all termite baiting systems was approximately one-half the time required for *R. flavipes*. Significant differences in efficacy between the three baiting treatment systems for *R. flavipes* were not observed, with a mean efficacy of 84%. Sentricon® achieved efficacy (88%) results with supplemental liquid termiticide treatments. FirstLine® efficacy (80%) and Terminate® efficacy (84%) results required initial and subsequent spot-treatments with liquid termiticides for comparable results. Sentricon® yielded better results in the management of *C. formosanus*, if augmented with supplementary in-ground and above-ground bait stations. Optimum results were achieved when monitoring of bait stations occurred twice each month, rather than on a monthly monitoring regime.

Key words: termite baiting, *Reticulitermes*, *Coptotermes formosanus*, termites

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INTRODUCTION

While the concept of managing subterranean termites with baiting systems has been in practice over the past decade (Su 2002, 2003), it remains a paradigm shift from conventional soil applied barrier treatments for remedial pest control scenarios. Termiticide barriers are a "passive" treatment regime, following the initial application in the sense that further actions relating to the treatment are not generally needed if applied thoroughly and comprehensively. Conversely, termite baiting systems, with installation, monitoring, application of active ingredient, and continuous re-monitoring and re-application, as needed, constitute an "active" treatment regime. Bait stations are designed to facilitate the consumption of a bait-toxicant and its transfer to the rest of the colony; the goal is termite population reduction or elimination (Su & Scheffrahn 1996a, 1998).

The discovery and use of termite baiting systems to treat subterranean termites has created confusion and controversy in the industry (Potter 2004). There are many questions concerning the efficacy and time required before termites locate monitoring stations, feed on active ingredient (AI), distribute AI to other termites in the colony through the food exchange process of trophallaxis, achieve a level of control (i.e., termite population reduction or elimination), and ultimately protect structures. Many factors influence this time frame, including the species of subterranean termite, season of year, ambient temperature, colony size, moisture, palatability of bait matrix, number and distance between in-ground bait stations, and whether above-ground bait stations were utilized directly on active termite shelter tubes or in carton material in aerial nests.

One of the major advantages of the baiting system approach is the capability of reducing populations of subterranean termites, with the possibility of suppressing or eliminating termite colonies (Lax & Osbrink 2003). Some of the major disadvantages of the baiting system approach are the time and effort required in the "active" treatment regime; this approach has always been very labor-intensive, and must be continuously monitored and maintained in order to perpetuate an area that is "free" of termites (Potter 2004, Su & Scheffrahn 1998). The economics of this time and labor invested must be considered in this treatment choice, and has often determined whether a pest control company initiates or continues to utilize a termite baiting system in its arsenal of treatment strategies.

Three commercial termite baiting systems were available at the onset of this study, and were evaluated. The Sentricon® system (Getty *et al.* 2000, Haagsma & Bean 1998, Sheets *et al.* 2000, Su 1994, Su & Scheffrahn 1993, 1996b, Pawson & Gold 1996) utilized hexaflumuron at the time. The First Line® and the Terminate® systems both contain sulfluramid (Ballard 1997, Ballard & Lewis 2000, Lewis *et al.* 1998, Potter 1997).

Claims have been made that these three baiting systems have been effective in reducing termite populations and protecting structures from termite infestations. The Sentricon® system makes the claim of "colony elimination." This study was initiated in order to determine and quantify the efficacy of the three available termite bait systems under Texas field conditions.

Current subterranean termite management strategies have turned toward baiting system technologies (Traniello & Thorne 1994) utilizing chitin synthesis inhibitors (hexaflumuron and diflubenzuron) or slow-acting stomach poisons (sulfluramid) as active ingredients (Getty *et al.* 2000, Pawson & Gold 1996, Sheets *et al.* 2000, Su 1991, 1993). The objective of a termite baiting system is to protect a structure through the reduction of termite populations. This is accomplished through the distribution of a toxicant or growth inhibitor/regulator into a colony within a palatable food (cellulose) substrate (Grace *et al.* 1996; Thorne & Forschler 1998). The strategy relies on the foraging activity of the pseudergates (workers) to gather and introduce this material into the social fabric of a colony in its subterranean milieu where it would be shared through trophallaxis. The result would be to kill or inhibit the normal development and metamorphosis of colony members (Potter 1997, Su & Scheffrahn 1996a). The ultimate goal of this tactic is population reduction and the eventual collapse and death of the colony.

The previously discussed active ingredients used in baiting systems have been investigated through laboratory and field bioassays to determine their efficacy against subterranean termite populations (Forschler & Chiao 1998, Rojas & Morales-Ramos 2001, Su *et al.* 1995, 2004). Several termite baiting systems utilizing these ingredients are being marketed to pest control companies, or directly to the public as a means to achieve management of subterranean termites (Ballard & Lewis 2000). Comparisons of effectiveness of these different termite baiting systems under actual use situations are generally lacking. This is particularly true for the active ingredient, sulfluramid. It is currently marketed as the active ingredient in two different termite baiting systems. The objective of this evaluation was the investigation of effectiveness of available termite baiting systems as a pest management strategy in structures infested with either the Eastern subterranean termite *Reticulitermes flavipes* (Kollar) or the Formosan subterranean termite (FST), *Coptotermes formosanus* Shiraki.

While *Reticulitermes spp.* are relatively ubiquitous throughout North America, particularly *R. flavipes* (Austin *et al.* 2005), *C. formosanus* is an invasive species into the U.S., and its unintentional introduction and subsequent spread (Bennett *et al.* 1997, Howell *et al.* 2001, Su & Scheffrahn 1988) has created concern for many people with vulnerable structures and vegetation. This species of termite (FST) has spread rapidly in Texas, primarily through the human movement of infested cellulose materials, such as recycled railroad ties used in landscaping, pallets used in moving various articles, and timbers and lumber used in the construction industry. By 2007, Formosan subterranean termite infestations have now been confirmed in 28 Texas counties. The disparate locations of these infestations are indicative of human or commercial movement, rather than a progressive expansion that would be attributable to normal swarming of reproductives of the species. Of the 28 counties in Texas with confirmed infestations of Formosan termites, 14 have been added in the last six years. The large population size of the colonies, aggressive nature, and the ability to form aerial nests of "carton" material with no connection to the ground, has led to the well-deserved destructive reputation of the species. This damage is particularly severe in southern coastal regions, where they cause serious damage in a relatively short period of time (Cornelius & Osbrink 2001, Jones & Howell 2000). Because of its destructive capability, this target pest was also a suitable candidate pest to test the efficacy of termite baiting systems.

MATERIALS AND METHODS

Candidate structures with active infestations of *R. flavipes* and *C. formosanus* were selected for treatment. Field identification of termite species is very difficult (Szalanski *et al.* 2003), and so representative samples from the test sites were placed in vials with ethanol and identified at the Center for Urban & Structural Entomology. Cooperating pest management companies were hired to install and monitor the termite baiting systems in accordance with manufacturer's recommendations and with supervision by personnel from Texas A&M University. Each company and certified applicator had the required licenses, certifications, authorization, and training necessary to participate in all phases of this research project. All baiting systems and active ingredients were provided through commercial vendors or manufacturers. Three commercial termite baiting systems were used in the evaluation. The FirstLine® system, manufactured by FMC Corporation, contained the active ingredient: N-ethylperfluoro-octane-1-sulfonamide, or sulfluramid (0.01%). The Sentricon® system, manufactured by Dow AgroSciences, had: 1-[3,5-dichloro-4-(1,1,2,2-tetrafluoroethoxy)phenyl]-3-(2,6-difluorobenzoyl)urea (hexaflumuron) at 0.5%, a chitin synthesis inhibitor marketed as Recruit™ II bait. The Terminate® system, marketed by United Industries, Inc. also contains the active ingredient sulfluramid at 0.01%. Label instructions for both the FirstLine® and Terminate® systems required a spot-treatment (defined as any liquid termiticide treatment to soil less than 10 linear feet) at sites with an active termite infestation. The Sentricon® system discourages the use of spot-treatments, but they were allowed as needed.

There was a marked diversity in the size of the in-ground bait stations utilized in the termite baiting systems, although all were plastic cylinders which defined a cavity in the soil. The FirstLine® bait station outer housing dimensions were 20.5 cm long by 5.0 cm diameter, with a Smartdisc® cap footprint of 18.0 cm, and had a plurality of 3 mm holes drilled through the cylinder in order for termites to gain access or entry into the interior of the station, where the monitor or bait was placed. The Sentricon® bait station outer housing dimensions were 23.0 cm long by 5.5 cm diameter., with a cap footprint of 15.5 cm, and exhibited rows of 4 by 22 mm rectangular slits in the plastic cylinder for termite access. The Terminate® bait station outer housing was 11.0 cm long by 3.0 cm diameter without an extended top cap as part of the bait station construction, with rows of 2.5 mm holes drilled through the cylinder for termite access.

Termite baiting systems were installed around the perimeter of each of the infested structures, according to label instructions. This entailed drilling the appropriate size diameter hole in the soil with an auger for each style bait station at approximately three-meter intervals around the perimeter and placing the in-ground stations into the holes, flush with the top of the lawn or turf. Appropriate spot-treatments with a permethrin termiticide were made as required at structures chosen to utilize baiting systems with the active ingredient, sulfluramid. The FirstLine® system and the Sentricon® system utilized wooden monitors that were inspected on a monthly basis until termite activity was observed in the station. When termites were observed in the FirstLine® bait station, the entire station was removed and replaced with the treatment station that contained the AI, inserted into the existing hole. The top of the bait station was permanently sealed in order to maintain a tamper-resistant status.

When termites were observed in the two wooden monitor slats in the Sentricon® station, the top cap of the station was removed utilizing a station key. The two slats were then removed from the station, the termites were gently placed into the Recruit™ II bait cartridge by tapping, placed into the monitoring housing, and then the top cap was re-inserted and locked using the station key. The Terminate® system did not utilize a monitoring step prior to placement of bait toxicant; AI was present on a cardboard matrix in all bait tubes placed around a structure, and the top cap was permanently sealed in order to maintain a tamper-resistant status.

Fifteen structures infested with *R. flavipes.*, in each of five (5) urban areas in Texas, were randomly selected for treatment with each baiting system for a total of 75 structures. The treatments were performed in five Texas cities (Austin, Beaumont, Corpus Christi, Houston, and San Antonio), representing a diverse cross-section of soil type and climatic conditions in Texas. In a companion study, 30 structures infested with *C. formosanus* were selected, with 15 structures in each of the two major areas of infestation in Texas (Galveston/Texas City/La Porte area and Beaumont/Port Arthur/Orange area). Replications included five structures treated with each of the three baiting systems for each region.

Pest Management Professionals (PMPs) participating in this study were provided with the termite baiting systems. They were required to cooperate with the manufacturers of the baits, and to install and monitor the baiting systems as required by the label, and to attend training provided by manufacturers of the systems. This study was conducted for two years. An annual in depth inspection of each structure was performed to determine the effectiveness of the baiting systems in the management of subterranean termites. Supplemental monitoring stations were also established around the perimeter of each study site to confirm the presence or absence of foraging termites through time. These stations consisted of 4 x 4 x 15.5 cm pine stakes with a 20 mm hole drilled completely through the long axis of the wood. Regularly spaced 4 mm holes were drilled into each of the four sides of the wood to intersect with the center hole. The top hole was closed with a #3 rubber stopper, which was removed to monitor termite activity in the station.

Results from monitoring of termite activity, AI consumption, and structural inspections were used to determine "control" or management of subterranean termite populations. The efficacy of each termite baiting system was measured by the presence or absence of termites in bait stations, supplemental monitoring stations, or in structures. Alate swarming from structures was also considered. Because termite bait systems require foraging termites to locate monitors and feed on the AI, times varied for subterranean termites to locate the bait stations. Generally, a quicker discovery of monitors should equate to a more expeditious management effort, whereas a longer discovery interval may impede it. Consumption and biological processing of AI is required for control, and the number of days between installation of bait systems and the first observed termite activity was used to gauge the efficacy of these bait delivery systems. All three termite baiting systems use in-ground bait delivery, but Sentricon® system also employs above-ground bait systems when needed (3 of 25 structures).

Observations were recorded by PMPs. For logistical reasons, the initiation of this project on homes (75 treatments or homes) did not occur on exactly the same day; however, attempts were made to initiate as many homes as possible within the shortest time span possible. Bait stations were monitored at structures on a monthly basis, and AI was added when termite activity was observed, or recorded for stations already containing AI (Terminate®).

Behavioral differences between *R. flavipes* and *C. formosanus* termites were anticipated and differences were noted as variability can affect the success or failure of a control program (Cornelius& Osbrink 2001, Lax & Osbrink 2003). Differences between both species of termites were noted. Comparisons of days to first termite activity observed on monitors for each of the termite bait systems at all sites were performed using a nonparametric Kruskal-Wallis analysis of variance (ANOVA on Ranks)(Kruskal & Wallis 1952). An All Pairwise Multiple Comparison Procedure (Dunn's Method) differentiated the significantly different treatment (Dunn 1964). All data were analyzed applying SPSS software (SPSS 1997).

Results from termite baiting system activity, monitoring, bait-toxicant consumption, and structural inspections were utilized to determine efficacy or "control" of termites. The number of days between the installation of the baiting systems and the first signs of feeding ("hits") were recorded for each structure. Presence or absence of termites in baiting systems, supplemental monitoring stations, or in structures, and reproductive swarming were considered in the determination of efficacy against the termites for each test site. Observations were also made of any differences in the methods of application or monitoring utilized by pest control company personnel. The period of time for "monitoring" of bait stations prior to any "hits" on the bait stations by termites, and the number of days of active feeding on the active ingredient were recorded to ascertain the interaction of termites with the bait systems surrounding the infested structures. Atmospheric conditions were considered as indicators for termite activity in stations, and meteorological data for all six cities evaluated in this study was available from the National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center available on the web (NOAA 2007).

RESULTS

Reticulitermes flavipes

The time-lines for the three termite baiting systems used in the study reveal significant variation in observed termite activity. All three baiting systems exhibited "hits" in at least one study site within 35 days. All three baiting systems also exhibited study sites without any termite activity on baits for extended periods of time. The Terminate® system exhibited one or more sites without any termite activity for over 300 days, and the Sentricon® system and the FirstLine® system had one or more sites without any termite activity for over 500 days. There were 8 of the 25 sites treated with the FirstLine® system

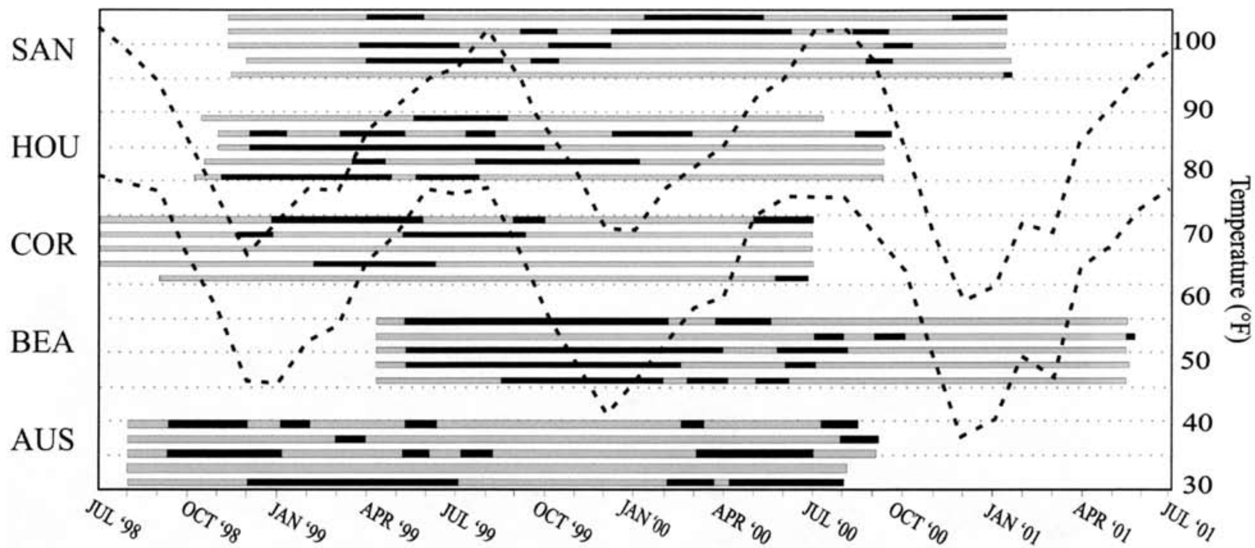

Fig. 1. *Reticulitermes flavipes* activity in Sentricon® monitors for locations in San Antonio (SAN), Houston (HOU), Corpus Christi (COR), Beaumont (BEA), and Austin (AUS). The offset horizontal bars reflect the different starting dates of each location throughout the duration of the study interval, whereas the black portions of horizontal bars reflect termite presence, either as non-baited or baited intervals. The upper (top) and lower (bottom) broken lines represent maximum and minimum temperature ranges for the duration of the study.

Table 1. Initial activity on bait stations for *R. flavipes* and *C. formosanus* across Texas[1].

City	Active (AI) Ingredient	Species of termite	Days until first activity ('hits') for each home (n=5)	'hits'	Mean ± SE	Cumulative Mean ± SE
Austin	FirstLine®	*R. flavipes*	75, 367, 500, 540	4/5	370.5 ± 105.2	272.2 ± 42.8
Beaumont		*R. flavipes*	35, 96, 131, 159	4/5	105.3 ± 26.7	
Corpus Christi		*R. flavipes*	258		1/5	258.0
Houston		*R. flavipes*	136, 157, 228, 413	4/5	233.5 ± 63.0	
San Antonio		*R. flavipes*	281, 293, 298, 661	4/5	383.3 ± 92.7	
Beaumont[2]		*C. formosanus*	61, 118, 131, 350, 376	5/5	207.2 ± 64.8	170.0 ± 42.7
LaPorte[2]		*C. formosanus*	90, 116, 125	3/5	110.3 ± 10.5	
Austin	Terminate®	*R. flavipes*	77, 145, 174, 181, 265	5/5	168.4 ± 30.4	185.5 ± 39.8
Beaumont		*R. flavipes*	30, 62, 62, 62, 125	5/5	68.2 ± 15.5	
Corpus Christi		*R. flavipes*	57, 57, 63, 68, 118	5/5	72.6 ± 11.5	
Houston		*R. flavipes*	60, 60, 60, 81, 116	5/5	75.4 ± 10.9	
San Antonio		*R. flavipes*	287, 601, 606, 609, 618	5/5	544.2 ± 64.4	
Beaumont[2]		*C. formosanus*	30, 49, 100, 129	4/5	77.0 ± 22.8	84.8 ± 10.8
LaPorte[2]		*C. formosanus*	61, 88, 92, 95, 119	5/5	91.0 ± 9.3	
Austin	Sentricon®	*R. flavipes*	42, 42, 120, 210	4/5	103.5 ± 39.9	154.4 ± 69.6
Beaumont		*R. flavipes*	29, 29, 30, 127, 441	5/5	131.2 ± 79.7	
Corpus Christi		*R. flavipes*	140, 173, 216, 622, 718	5/5	273.8 ± 68.5	
Houston		*R. flavipes*	28, 32, 32, 148, 216	5/5	91.2 ± 38.6	
San Antonio		*R. flavipes*	120, 134, 140, 295	4/5	172.3 ± 41.1	
Beaumont[2]		*C. formosanus*	34, 41, 43, 90, 379	5/5	117.4 ± 66.1	82.1 ± 33.8
LaPorte[2]		*C. formosanus*	26, 27, 34, 56, 91	5/5	46.8 ± 12.3	

[1]Results on sites with "hits" and AI placement; this does not include sites without termite activity.
[2]Formosan termite locations, cumulative means in last column for *C. formosanus* are for these two locations/treatments, respectively.

that never had termite activity on any of the monitors at those particular sites. Three of the 25 sites treated with the Sentricon® system never exhibited termite activity on any of the monitors. Only the Terminate® system exhibited 25 of the 25 sites treated with some termite activity on at least one bait station per site despite this bait station's small diameter and length. It is important to note that this particular bait station was the only one that used a cardboard matrix, rather than wood, for monitoring material.

Monitoring and feeding observed at bait stations varied widely. Some study sites had lengthy monitoring periods, described above, while another exhibited 14 alternating episodes of monitoring and feeding during the 2 yr study period. These observations of termite activity by *R. flavipes* are illustrated as

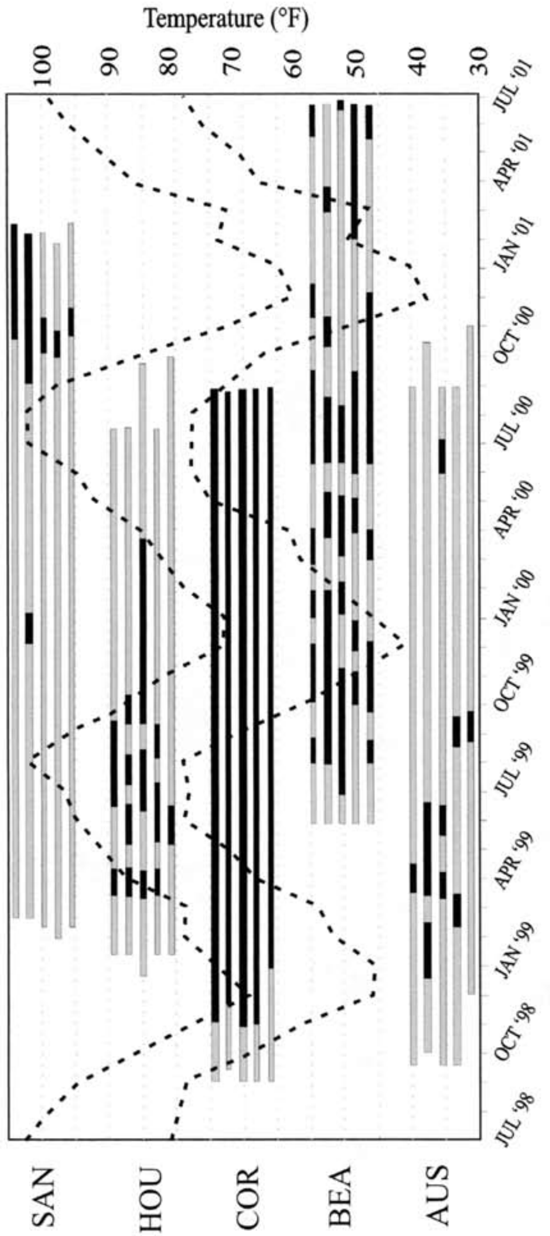

Fig. 2. *Reticulitermes flavipes.* activity in FirstLine® monitors for locations in San Antonio (SAN), Houston (HOU), Corpus Christi (COR), Beaumont (BEA), and Austin (AUS). The offset horizontal bars reflect the different starting dates of each location throughout the duration of the study interval, whereas the black portions of horizontal bars reflect termite presence, either as non-baited or baited intervals. The upper (top) and lower (bottom) broken lines represent maximum and minimum temperature ranges for the duration of the study.

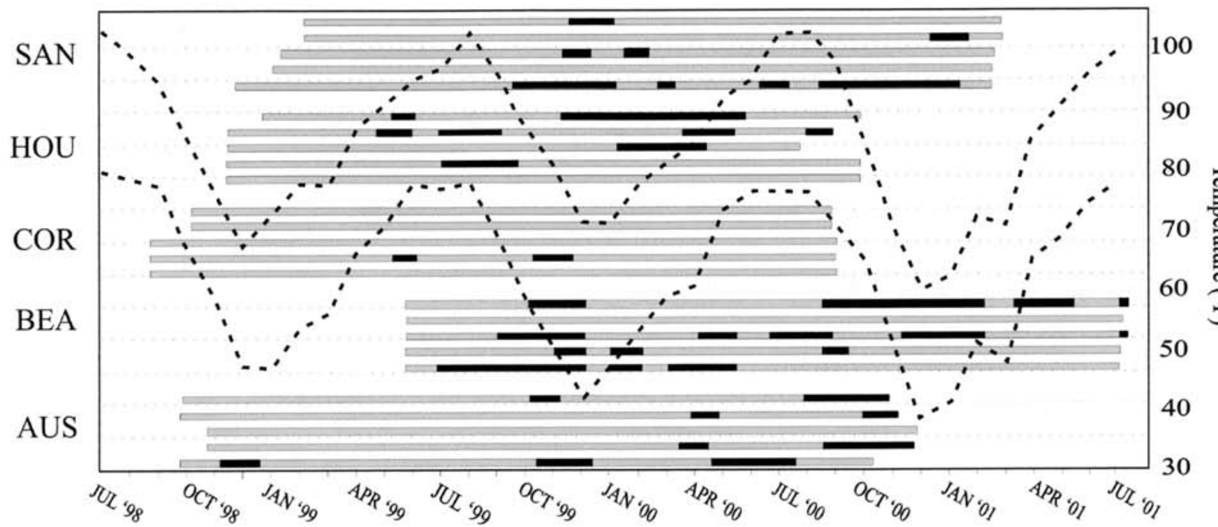

Fig. 3. *Reticulitermes flavipes* activity in Terminate® monitors for locations in San Antonio (SAN), Houston (HOU), Corpus Christi (COR), Beaumont (BEA), and Austin (AUS). The offset horizontal bars reflect the different starting dates of each location throughout the duration of the study interval, whereas the black portions of horizontal bars reflect termite presence, either as non-baited or baited intervals. The upper (top) and lower (bottom) broken lines represent maximum and minimum temperature ranges for the duration of the study.

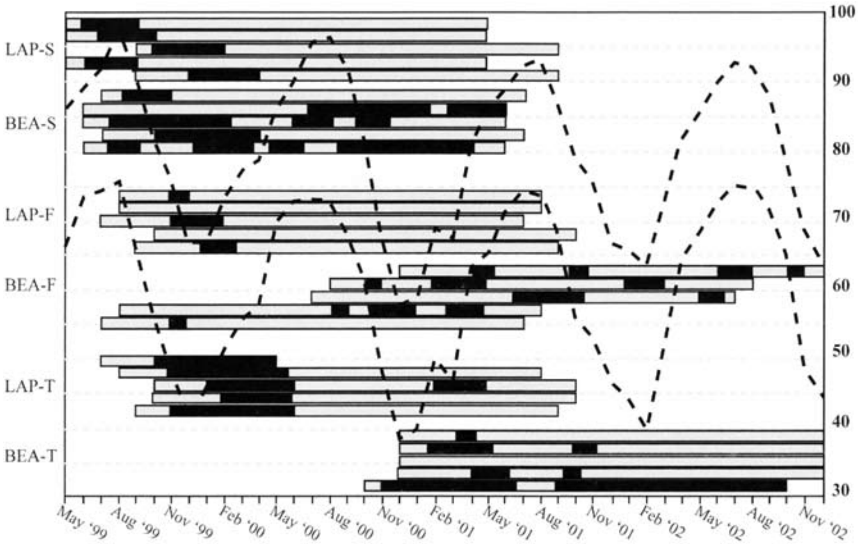

Fig. 4. *Coptotermes formosanus* activity in Sentricon® (LAP-S and BEA-S), FirstLine® (LAP-F and BEA-F), and Terminate® (LAP-T and BEA-T) monitors for locations in LaPorte (LAP) and Beaumont (BEA), Texas, respectively. The offset horizontal bars reflect the different starting dates of each location throughout the duration of the study interval, whereas the black portions of horizontal bars reflect termite presence, either as non-baited or baited intervals. The upper (top) and lower (bottom) broken lines represent maximum and minimum temperature ranges for the duration of the study.

time-lines for each of the termite baiting systems evaluated in Figs. 2, 3, and 4. When comparing these alternating episodes of monitoring and feeding; however, no significant differences were observed between the three termite baiting systems ($P = 0.576$). The low number of episodes of monitoring and feeding in Corpus Christi, when compared to the high number of episodes in Beaumont, was significantly different ($P = 0.028$). There were no other significant differences when comparing the other city sites.

The range of activity of *R. flavipes* on the FirstLine® system (Table 1) was between 35 and 661 days to first "hits" with a mean of 272.2 days. Each city had at least one study site without any "hits," and in Corpus Christi, four of the five structures revealed no activity throughout the duration of the study.

Activity by *R. flavipes* on the Sentricon® system (Table 1) ranged from 28 to 718 days to first "hits", with a mean of 153 days. Only three of the 25 study sites had no termite activity; one each in Austin, Corpus Christi, and San Antonio.

Activity by *R. flavipes* on the Terminate® system (Table 1) was between 30 and 618 days, with a mean of 185.5 days, with 100% of all sites exhibiting "hits" on bait stations.

The range of termite activity by *R. flavipes* on all three baiting systems was remarkably similar, from 35, 28, and 30 days, to 661, 622, and 618 days, for FirstLine®, Sentricon®, and Terminate®, respectively (Table 1). There were no significant differences ($P < 0.05$) in this characteristic between baiting systems. There were significant differences between mean values of the number of days to first "hits" when comparing the three baiting systems. The higher mean number of days to first "hits" in the FirstLine® system at 272.2 days, were significantly different from those of the other two systems, when comparing Sentricon® at 153.0 days ($P = 0.002$) and Terminate® at 185.5 days ($P = 0.014$) applying a one-way ANOVA with means separation (Tukey's HSD Test).

Many of the study sites required additional spot-treatments with termiticides, in addition to treatments required by label instructions for FirstLine® and Terminate® systems. This was in accordance with manufacturer's recommendations. In some instances, new evidence of termite infestations required multiple re-treatments with termiticides during the study. The breakdown of spot-treatments in this case were: 7, 2, and 22 cumulative spot-treatments for FirstLine®, Sentricon®, and Terminate®, respectively, among the five Texas cities in this study.

From 75 structures (25 per treatment), there were 8 and 3 structures without any AI consumption through the 24 months of the study for FirstLine® and Sentricon®, respectively. In homes where Terminate® was applied, all had feeding by termites. Overall, this equates to 68, 88, and 100% of treated structures with AI consumption. At the conclusion of the study interval, there were 5, 3, and 4 homes that continued to have persistent termite activity for FirstLine®, Sentricon®, and Terminate® systems, respectively. However, there was no statistical differences in efficacy (defined by the presence/absence of termites in structures that had a given bait technology regimen applied) for any of the three baiting systems in this study through 24 months post-inspection.

Observations of termite activity on monitors was an important factor in the consideration of a termite baiting system's efficacy. However, successful treatment depends on whether a structure was protected from infestation and damage. Five of the 25 structures treated with FirstLine® continued to have an infestation of termites at least for 24 months (Table 1). One was in Beaumont and four were in Houston. Three of the 25 structures treated with Sentricon® continued to have an infestation of termites at the end of the study; these were the same three structures without active ingredient consumption. Two were in Corpus Christi and one was in San Antonio. Four of the 25 structures treated with Terminate® continued to have an infestation of termites at the end of the study, despite the use of spot-treatments with permethrin. One was in Beaumont, two were in Houston, and one was in San Antonio.

The end result was that 80, 88, and 84% of treated structures did not have termite activity in homes at the study conclusion for FirstLine® with Permethrin spot-treatments, Sentricon® (without spot-treatments), and Terminate® with Permethrin spot-treatments, respectively. There was a cumulative mean value of 63 out of the 75 structures without termites at the end of the study, or 84.0%, among all treatments using the three termite baiting system regimes.

Coptotermes formosanus

The numbers of days for first feeding by FST on monitors in monitored systems, or AI bait tubes in non-monitored systems varied widely. Generally, FST feeding was more aggressive than *R. flavipes* under field conditions. A total of 30 detached residential structures were evaluated in two southeastern locations; including Beaumont and La Porte, Texas. Eighty, 100, and 90% of structures from both Beaumont and LaPorte recorded hits on FirstLine®, Sentricon®, and Terminate® systems, respectively. The mean time (± SE) and range in days until first "hits" recorded were 170.9 ± 42.7 (61-376), 82.1 ± 33.8 (26-379), and 84.8 ± 10.8 (30-379) days for FirstLine®, Sentricon®, and Terminate® systems, respectively. Baiting systems without activity were obviously not considered in this calculation; however, it should be noted that the cumulative mean for all baiting systems regardless of AI was 109.3 ± 19.1 days until active feeding by FST was observed.

All three baiting systems had termite activity in at least one bait station in at least one study site within 61 days. There were also examples for each of the three baiting systems where there was no termite activity in the bait stations for over 700 days. The Sentricon® system had at least two sites without any termite activity for over 700 days. Similarly, both FirstLine® and Terminate®

systems had one or more study site that exhibited over 700 days without any termite activity in the bait stations. Mean number of days until first feeding of FST on monitors, in monitored systems, or AI bait tubes in non-monitored systems, varied widely. There was no discernible pattern of control with either of the sulfluramid baits, likely attributed to the fact that spot-treatments were applied to all adjacent structures; successful termite management at those sites relied principally on spot-treatments with liquid termiticides. Rather than constituting a comparison between termite baiting systems, the test design allowed the opportunitiy of evaluating methodologies used by the two pest management specialists using the Sentricon® baiting system. These two dissimilar approaches resulted with efficacy results that were significantly different between the two test sites.

In La Porte, Texas, 100% control was achieved with the baiting system, without any termiticide spot-treatments, and continued to exhibit control for an extended period of time. An aggressively active management program involving the utilization of multiple supplementary in-ground bait stations, above-ground bait stations, and bi-weekly monitoring contrasts sharply with the traditional termite baiting program and corresponding reduced efficacy results in the Beaumont, Texas area. These observations of termite activity at test sites with FST infestations are illustrated (Fig. 4) as time-lines for each of the termite baiting systems. Termite activity on the bait stations was observed at eight of the 10 structures treated with the FirstLine® system, at all 10 structures treated with the Sentricon® system, and at nine of the 10 structures treated with the Terminate® system over the two-year time period of the evaluation.

Of the 30 detached residential structures evaluated in Beaumont and La Porte, Texas, 80, 100, and 90% of structures from both Beaumont and LaPorte recorded "hits" on FirstLine®, Sentricon®, and Terminate® systems. The mean time (± SE) and range in days until first "hits" recorded were 170.9 ± 42.7 (61-376), 82.1 ± 33.8 (26-379), and 84.8 ± 10.8 (30-379) days for FirstLine®, Sentricon®, and Terminate® systems. Again, baiting systems without activity were not considered in this calculation as no "hits" were recorded. The cumulative mean for all baiting systems regardless of AI was 109.3 ± 19.1 days until active feeding by FST was observed. The number of days to first "hits" by termites (excluding locations where activity was not observed), on any one of the bait stations installed around the perimeter of the structures, for all bait systems, ranged 26 to 379 days (Table 1). A t-test indicated no significant difference (P = 0.307, 0.325, and 0.555, respectively for FirstLine®, Sentricon®, and Terminate®) between groups to first "hits" from the two locations. Significant differences (Kruskal-Wallis test: H = 8.638, df = 2, P = 0.013) between FirstLine® and Sentricon® systems applying Dunn's Method, where observed for the number of days to first "hits" among the three baiting systems at all sites (Table 1).

The performance of the two sulfluramid-containing bait systems on FST populations was low, based in part on the limited amount of the active ingredient that was consumed. Examples of successful pest management and protection of structures apparently relied primarily on spot-treatments with liquid termiticides. Several structures required multiple spot-treatments during the two-year evaluation period. In addition, the relatively small Terminate® bait stations did not contain sufficient quantities of AI impregnated cardboard to adequately serve as a stand-alone treatment. The bait station was emptied of cardboard and corresponding active ingredient in a short period of time by foraging FSTs, and subsequently abandoned; termites then had to be re-recruited to the area after insertion of a substitute or replacement bait station. Also, PMPs found it very difficult to find these bait stations due to their relatively small observable "footprint", especially in turf areas.

The most significant observation made during this evaluation was the difference in treatment regime and corresponding results between the two different pest control companies utilizing the Sentricon® system. While both were authorized and trained to use this technology, the regime followed by PMPs in La Porte, Texas area differed markedly from that used by the corresponding specialists in the Beaumont, Texas area, who closely followed the label specifications. PMPs in the La Porte area applied what would have to be termed an "aggressive" regime, utilizing many supplementary in-ground bait stations. They also relied heavily on the placement of above-ground bait stations that were available with this system. They placed multiple above-ground units on active shelter tubes, whether on vertical surfaces of walls, slab foundations, or piers, or inside wall voids. After determining the presence of infestation by means of a non-destructive moisture meter, they gained access by means of keyhole saw or removal of wood trim to place the above-ground bait station. The treatment regime also involved frequent visits to the bait stations to insure active ingredient availability to feeding termites. The visits were never less than every two weeks, rather than the monthly visits suggested in the system protocol. In some cases, during periods with limited rainfall, the bait placements were watered to ensure attractiveness to the monitor and accompanying bait. The treatment regime by the Beaumont personnel, on the other hand, utilized few supplementary in-ground or above-ground bait stations. Inspections to monitor bait stations and add active ingredient tubes to stations with termite activity were limited to monthly visits.

The results of this difference of treatment regime are quite apparent in Figure 4. After early, consistent "hits" on monitors and heavy feeding of AI at all five sites in La Porte, Texas, FST were not detected again in either the structures or the bait stations for an extended period of time. No liquid termiticide treatments were performed, or required, in any of the five sites in La Porte, Texas. The mean values of termite activity for the five structures in Table 1 reflects the nature of this aggressive regime with a very abbreviated (46.8 days) period to first "hits" by foraging termites, followed by 107.8 days of active feeding on the active ingredient in the systems. It took only 154.6 days from installation of the baiting system to feeding cessation. The mean number of days that elapsed after feeding cessation without any new "hits" on bait stations, indicative of any subsequent termite activity in or around the test site structures, was 455.6 days for the five structures. In contrast, frequent, alternating periods of "hits" by FST, followed by periods of inactivity and no consumption of AI in the bait stations were exhibited at three of the five Sentricon® system sites in the Beaumont, Texas area (Fig. 4). Formosan termites would frequently consume all AI during the monthly inspection regime, and then foraging termites would abandon the station in their search for other cellulose food sources. Termites would then have to be re-recruited to a bait station, which took additional time in the baiting process. At the end of the two-year evaluation period, FSTs were still active in two of the five structures, and in surrounding bait stations in the Beaumont, Texas area. The number of days to first "hits" ranged from 26 to 379 days. This range was noticeably reduced for the Terminate® system at 30-129 days. Three of the study sites did not have termite activity for the duration of the study, two of the FirstLine® and one of the Terminate® baiting system sites.

There was no apparent correlation between temperature (maximum or minimum) or rainfall with the observed feeding behavior of either *R. flavipes* or FST in any of the baiting systems evaluated in this study. Linear Regression applying PROC REG (SAS Institute 2002) revealed no significant correlations between activity in monitors and max temperature for FirstLine® (R2=0.011) or Sentricon® (R2=0.019), and only a very weak correlation for Terminate® (R2=0.304) for *R. flavipes*. Similarly, there were no significant correlations between activity in monitors and maximum temperature for FirstLine®, a weak correlation for Sentricon®, and no correlation for Terminate® systems (R2=0.016, R2=0.321, and R2=0.007) for *C. formosanus*, respectively. Relationship of activity to minimum temperatures provided no significant correlations between activity in monitors and minimum temperatures for FirstLine®, Sentricon® or Terminate® systems for either *R. flavipes.* (R2=0.011, R2=0.012, R2=0.045, respectively) or *C. formosanus* (R2=0.022, R2=0.192, R2=0.007), respectively. Rainfall provided no significant correlation to activity in bait stations for either *R. flavipes* (R2=0.001 and R2=0.021, and R2=0.040) or *C. formosanus* (R2=0.041, R2=0.001, R2=0.013) for FirstLine®, Sentricon® or Terminate® systems, respectively.

DISCUSSION

All baiting strategies regardless of delivery device or AI have one inherent weakness; they are unlikely to be100% effective. The very definition of efficacy (sometimes called intrinsic activity) implies or describes the ability of the insecticide-receptor complex to produce a physiological response. With the chitin synthesis inhibitors this would imply the formation of a protein complex with chitin, inhibiting chitin biosynthesis of new chitin chains during eclosion and hence produces death in termites during the molting process (Valles & Koehler 2003). With stomach toxicants such as sulfluramid, the AI is converted by enzymes, making the AI toxic to the organism, disrupting energy (ATP) production through oxidative phosphorylation uncoupling (in the mitochondria) causing death (Valles & Koehler 2003). If termites do not encounter these AIs, they will not be killed.

For any baiting system there are limitations which preclude efficacy from being attained, including: 1) a monitoring requirement for either additional non-baited cellulose or AI, 2) colony elimination in virtually all application scenarios can not be distinguished from emigration/immigration events of neighboring populations; we discount colony identification by use of genetic microsatellite identification methods as this is logistically impractical in most circumstances, and 3) efficacy of any bait system assigns independent probabilities to the randomness attributed to termite foraging behavior into any monitoring device; if termites do not visit a monitoring device there is no possibility of efficacy even when 100% control may be observed. This might be attributed to the random probability of termites emigrating away from a structure or the equal probability of never locating the monitoring device. Unless sampling measures are taken to exclude the possibility of termiticide contamination of soil adjacent to monitors, there is no means of empirically establishing the reason for termites vacating a structure. A classic example of this was observed in Weissling & Thoms (1999), whereby 20 in-ground Sentricon® stations with 23 additional stations (43 total) were never "hit" even when a large population of FST was infesting the structure they were installed to protect. It was only after the inclusion of above-ground stations that control was achieved. They implied termiticide contamination as a possible reason (with its own independent probability) but did not state whether soil sampling to confirm this supposition was performed. As with this study, when supplemental above-ground stations were administered, control was achieved for FST in La Porte using the Sentricon® system. However, when only in-ground stations were used, as in Beaumont, only 60% control was observed, even with sustained feeding of baits by FST.

An unfortunate reality of monitoring long-term efficacy with baits owes its success to the capacity to which PMPs actually inspect stations and maintain the integrity of the baiting system. A recent litigation against one of the largest PMP companies in New York resulted with a $759,000 environmental and consumer violation for failure to adequately monitor stations in accordance with manufacturer's recommendations. Furthermore, it was determined that PMPs from this particular firm were fraudulently applying other termiticides and falsifying records to cover up their actions (Anonymous 2003). This is a reality that has been observed in numerous cases around the country, including Texas (JWA, personal observation).

In 2002, The Structural Pest Control Board of Texas amended section 599.3 (effective February 3, 2003) of the regulations governing pre-construction termite treatments, to add a provision allowing licensed pest control businesses to offer bait treatments as pre-construction termite treatments in lieu of liquid soil applied treatments (TXSPCB 2007). Since efficacy can only be evaluated with a bait system possessing an AI already in place prior to receiving "hits" from foraging termites (e.g., FirstLine® or Terminate), in most instances structures are not afforded any protection at all, only monitoring. This was one of the principle reasons the Texas Attorney General's office solicited this research from the Department of Entomology, Texas A&M University, hoping that an objective assessment of the use of baiting systems could be clarified.

When considering the entire baiting process, the law of parsimony (also known as Occam's razor) states that the best solution to any problem is the simplest, and should involve the fewest number of steps. For most PMPs, the use of liquid termiticides is a single step process and thus has a higher probability of achieving the desired outcome, compared to a multiple step process wherein each of the steps are dependent on the step prior. For PMPs, this is discontinuance of termite activity in the structure and no further remedial control steps required. The multiple steps required in baiting strategies, each have a specific probability P of being successfully completed. Applying this to FST, results in this study demonstrated a mean "hit" rate of 90% (27/30 homes = 0.90) for all bait systems (see Table 1) that we will designate P_A. When bait with AI is introduced into a monitor, with termites accepting and feeding on it, there is also an associated probability, designated P_B. Hypothetically, we will attribute that 90% (0.90) of the foraging termites will perform this action (at any given monitor). Following this, trophallaxis and allogrooming of other individuals occurs and the AI is distributed throughout all available colony members including the reproductives at 95% (0.95), designated P_C. In this simple example, there are three specific independent events, each with their associated probabilities P, designated as $P_A \times P_B \times P_C$, often written as $P(A,B,C) = P(A) \times P(B) \times P(C)$ or as the intersection of three events as $P(A,B,C) = P(A) \times P(B|A) \times P(C|A,B)$ where it is understood that A,B refers to the intersection of those events and $P(B|A)$ is the conditional probability of event B given that event A has occurred. Here, the agglomerative effect for all three independent probabilities would be as follows: 0.90 (hit frequency) x 0.90 (consumption of bait) x 0.95

(trophallaxis and distribution of bait throughout colony) = 0.77 (efficacy) or a cumulative probability of 77% success. However, this would tend to overestimate the associated probabilities of events B and C since each of these hypothetical steps should be dependent on the prior step, and when one event influences another, interdependence, rather than independence, is the result, particularly in a biologically complex system such a subterranean termite colony and it's interaction with a baiting system (Buchanan 2002). Therefore, a simple rearrangement of the independent formula that accounts for the associated interaction of dependent events can be written as P (A,B,C) = P (A) x P (A,B) x P (A,B,C) or where B cannot occur if A has not, and C cannot occur if B has not, i.e., P (B| not A) = 0 and P (C| not B) = 0. Under these restrictions, P (C| A,B) can be written as P (C| B) since B implies A. These restrictions also imply that P (B|A) > P (B) and P (C| A,B) > P (C), where P (B) and P (C) are the unconditional probabilities that events B and C will occur. Specifically, knowing the values for P (B| not A) and P (C| not B) does not clarify the values of P (B| A) and P (C| B). In the FST example from this study, applying the hypothetical probabilities of events B and C, this relates to a calculated probability of success of 56% (0.90 x 0.81 x 0.77 = 0.56). Therefore, the assigned probabilities for these events would be no less than 56% and equal to, but not more than 77% efficacy for this example. The estimated probability of success (77%) is within 10% of the actual calculated efficacy for all baiting systems for *R. flavipes* (84%) but would underestimate FST efficacy (90%) for this study. Regardless, it is extremely unlikely to ever achieve 100% efficacy given these probabilistic constraints.

Additionally, in order to assign a specific probability to the overall success of a baiting system, a hypothesis must be developed and framed in a question. For instance, are the efficacies of any two baiting systems the same (is $0_A = 0_B$)? In this example, we identify two hypotheses: the null hypothesis (H_0) and alternative hypothesis (H_1) as H_0: $0_A = 0_B$; H_1: $0_A \neq 0_B$ (for a 2-sided test), $0_A < 0_B$ or $0_A > 0_B$ (for a one-sided test). Based on the results of this example (for FST), we fail to reject the null hypothesis, as the efficacy for all baiting systems were not different. It is also important to note that simple manipulation of the bait stations themselves can affect the overall efficacy of the bait system (Evans & Gleeson 2006) and likely contributes to the variations in efficacy and control observed in this study. The concept of probability theory, and stochastic processes, in which a sequence of values is drawn from a corresponding sequence of jointly distributed variables, comes into play in such a treatment regime, with many opportunities for failure in the multi-step management strategy (Ott & Longnecker 2001). Protection against termites utilizing a baiting system occurs only if and when sufficient AI is consumed and shared among nestmates in a colony; this may take months, years, or may never occur in those instances where AI was never consumed (Cabrera *et al.* 2002).

Although environmental factors are believed to contribute to the overall success of baiting programs in general, there were no apparent relationships that could be garnered from the variable feeding activity among treatments and between locations in this study. It is believed that localized conditions at each specific treatment site contribute more to the presence of termites in monitors than the overall weather conditions. It may also be the accumulation of degree days which more likely triggers activity among termite groups such as *Reticulitiermes* species (Furman 2000), but there is no consensus on this behavior with *Coptotermes formosanus* (Raina *et al.* 2003). Essentially, the conditions around each home are so variable, they must be taken into account on an individual basis, rather than a generalized whole.

One of the disadvantages of any baiting technology is that it can take several weeks to several months to take effect, sometimes more than a year (Cabrera *et al.* 2002). Our results would appear to be consistent with this statement and a wealth of observations made by PMPs around the country. In many instances, baiting may be the only alternative given local conditions such as the potential for groundwater contamination by liquid termiticides (Austin *et al.* 2007). Similarly, modern liquid termiticides do not exact significant colony death, as would be anticipated from a slow acting bait system (Osbrink *et al.* 2005) and it is probably inappropriate to infer results of nonrepellent termiticide tests for their impact against subterranean termite populations (Su 2005). Although variable results were observed in the present evaluation, and labor costs often drive many PMPs to use cheaper liquid termiticides in lieu of long-term monitoring efforts that accompany most bait systems, they remain a viable control technology for subterranean termite management and may be essential when addressing control of FST. It is believed that the termite control industry's reliance on soil termiticide barriers is one factor that has allowed infestations of FST in the 1960s to expand to the entire southeastern United States by 2000 (Su 2003).

When evaluating populations of *R. flavipes,* the time-lines depicted in figures 1-3 illustrate the wide variance in the days to first "hits" for termite baiting systems. When considering all structures and all systems in the study, this ranged from 28 to 661 days. The time required for foraging *R. flavipes* to locate and initiate feeding on both Sentricon® and Terminate® system monitors and bait stations was approximately one-half the time required to locate and begin feeding on the FirstLine® termite baiting system. Wide variance was exhibited in the alternating episodes of monitoring and active ingredient consumption, up to 14 episodes when treating with the Terminate® baiting system. Although the randomness of termite foraging can partially explain this observation (Su 2005), termite foraging into monitoring units is also somewhat directed (Su & Puche 2003) and may actually be a function of the individual sizes of respective bait systems as has been observed from lab-based studies (Hedlund and Henderson (1999). The general palatability of different AIs, baiting system monitoring station design, and density of adjacent termite populations to these monitors may also contribute to this variability.

There were no significant differences in the treatments of structures with the three termite baiting system systems, with 80, 88, and 84 % of the structures without *R. flavipes* infestations, at the end of the study, for FirstLine®, Sentricon®, and Terminate® baiting systems, respectively. It is noteworthy that the baiting systems containing sulfluramid required spot-treatments with termiticides, in addition to the baiting regime, for all active termite infestations discovered. With this additional treatment, these baiting systems were equivocal. Several of these study sites also required subsequent spot- treatments with termiticide in order to maintain protection of the structures, with up to 22 spot-treatments made on structures baited with Terminate®. When applying the Sentricon® system, 12.0 % (or 3 out of 25) of the locations with no AI consumption, continued to have *R. flavipes* infestations at the end of this study. This is an important aspect to consider as many industry-based evaluations of bait systems often result with failures excluded from the calculation of final estimates of efficacy and control.

When evaluating the efficacy of baiting systems applied to populations of FST, there are examples of little termite activity on the bait stations for an extended period of time. This occurred despite the aggressive foraging and feeding reputation of FST. This has also been observed when attempting area-wide suppression of FST applying bait systems around urban forests in Texas (JWA, personal observation). The termite activity timelines exhibited in figure 4, for each of the respective baiting systems evaluated, demonstrate erratic patterns of feeding and monitoring. The monitoring stations at some structures remained inactive for an extended period of time, for years in some cases, despite the presence of active FST infestations, either in the structure, or in other cellulose sources on site. The exact reasons for this remain unknown, but disturbance may play a significant role in these urban housing areas.

The period of time between installation of the baiting systems and the first "hits," revealing termite feeding/activity, ranged widely. This time period ranged from 26 to 379 days (Table 1). As was observed with *R. flavipes*, the mean time required for foraging FST to locate and begin feeding on both the Sentricon® and Terminate® system monitors and bait stations was approximately one-half the time required to locate and begin feeding on the FirstLine® termite baiting system (Table 1). The mean time required for foraging FST to locate and begin feeding on any baiting system station was approximately one-half the time required for *R. flavipes* to do the same (Table 1). Three of the 30 structures (10%) never exhibited termite activity in any of the bait stations during the two-year time frame of the evaluation; two structures treated with FirstLine® in La Porte, Texas, and one structure treated with Terminate® in Beaumont, Texas. Hence, no AI was consumed at those structures, and no possibility of management was afforded by baiting technologies.

Both "baiting systems" utilizing sulfluramid corroborate the need for current instructions on the label and training materials provided by manufacturers that recommend a liquid termiticide spot-treatment at points of active infestation. Essentially, these baiting systems are "supplementary" to conventional barrier treatments. Termiticide spot-treatments were required for protection of structures treated with sulfluramid-based bait systems. Of the termite baiting systems evaluated, Sentricon® proved to be most effective in the management of structural infestations of FST, but only if used in a diligent, labor-intensive manner. If used as an "aggressive" pest management strategy with the necessary labor and materiel devoted to the process and with multiple supplementary in-ground and above-ground stations monitored in a frequent, two-week schedule, the system was successful in protecting the structures in a relatively short period of time. The period of time between installation of termite bait stations to feeding cessation for this system at the five La Porte, Texas sites had a mean value of 154.6 ± 16.3 days (Table 1), and after the termite management was achieved, the days elapsed since feeding cessation without any new hits had reached 455 days by the end of the study (Fig. 4). Clearly, the labor investment by PMPs is the determining factor in a successful termite baiting system regime. If sufficient time, energy, and "problem-solving" diligence is devoted to the "active" treatment process, control can be efficiently administered. It is important to note that this treatment regime was successful for one-half of the structures treated with the Sentricon® termite baiting system, which were the structures in La Porte, Texas. The treatment on those five structures diverges, or expands on, the standard regime listed in the label to the point that the eventual efficacy comparison was not between baiting systems, as planned, but between a standard and an aggressive pest management regime utilizing the Sentricon® termite baiting system. This is supported by Su *et al.* (2004), who clearly demonstrate that the more stations applied to controlling termite populations, the more quickly and completely elimination may be achieved. Furthermore, targeted bait applications which enhance zones of termite activity, rather than spatially, appear to enhance overall elimination goals (Jones 2003). Termite baiting requires more time and labor inputs by PMPs with no promise of increased efficacy when addressing infestations of *R. flavipes*, the most prominent urban termite pest species genus in North America (Austin *et al.* 2005). This is equally true for Formosan termite control. This is the most influential reality that has driven PMPs to move away from termite baiting systems as treatment tools, and to return to traditional termiticide barrier treatments for the protection of structures. Termite baiting remains a viable option in situations where there is societal or environmental restrictions to the use of conventional termiticide treatments, or when based on consumer request for this treatment strategy. Likewise, baiting is an essential component to any IPM approach to dealing with FST. Although manufacturers generally prefer to exclude all other AIs or treatment approaches, other than their own, this would be contradictory to any sensible IPM approach. Combination treatments which employ multiple control technologies will likely provide the most comprehensive means to controlling any termite problem. Thus, the use of baiting systems are not the absolute answer to control, rather they represent another important tool to employ against subterranean termite pest species such as *R. flavipes* and *C. formosanus*.

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