Field Trials With 0.5% Novaluron Insecticide Applied as a Bait to Control Subterranean Termites (*Reticulitermes* sp. and *Coptotermes formosanus* [Isoptera: Rhinotermitidae]) on Structures

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ABSTRACT A field study was initiated in 2009 with 0.5% novaluron the BASF Advance Termite Bait System, which was 100% effective in controlling *Reticulitermes* sp. Holmgren and *Coptotermes formosanus* Shiraki infestations on 11 structures in the Texas City, TX area. Stations with inspection cartridges (cellulose tablets) and monitoring bases (southern yellow pine) and independent monitoring devices were installed in an alternating pattern around each structure and were inspected every 30 d postinstallation. When subterranean termite activity was confirmed on the inspection cartridge or the monitoring base, the inspection cartridge was removed and replaced with a bait cartridge containing 0.5% novaluron insecticide on a proprietary matrix (124 g/cartridge) in a station. Once the novaluron-treated bait was inserted, inspections of that station were made on a 4-mo cycle until no termite activity was observed. The mean time to achieve control of the subterranean termites on the structures was 10.5 mo post initial installation of bait. Mean time to achieve control of the termites on the structures after the baits were installed was 5.4 mo. Control of the termites on the structures required consumption of a mean of 1.3 bait cartridges (166.2 g) of 0.5% novaluron bait matrix per structure. These results indicate that the baits with 0.5% novaluron were effective in controlling termites on the structures used in this study.

KEY WORDS subterranean termite, bait, termite control

There are at least 2,300 termite species found worldwide, with 183 of these species known to cause damage to structures (Su and and Scheffrahn 1998). Termites account for ∼$5 billion annually in terms of treatments and damage repairs to structures in the United States alone (National Pest Management Association [NPMA] 2005, Keefer et al. 2011), yet the majority of postconstruction management of termites has been approached in the same fashion for over half a century via application of liquid termiticides to the soil under and around infested structures (Gold et al. 1994, 1996; Rust and Su 2012).

While the use of slow-acting toxicants in baits to control termites dates back to Van Zwaluwenberg (1916), Wolcott (1924), Esenther and Gray (1968), and Su et al. (1998), most of the advances in the use of baiting for termite control have occurred in the past 30 yr (Beard 1974; Getty et al. 2000; Su 2002, 2003; Glenn et al. 2008). Currently, baiting systems are used successfully in both residential and commercial accounts for postconstruction control of subterranean termites (Grace and Su 2001) as well as atypical termite management scenarios such as railroad bridges (Austin et al. 2008). Essentially, termite baiting systems exploit the behavior of trophallaxis in which termites pass the active ingredient from individual to individual within the colony to effectively control termites (Suarez and Thorne 2000). Challenges to successful implementation of baits include large colonies, expansive foraging behavior (Su 1994), and cryptic lifestyles with subcolonies (Su and Scheffrahn 1986).

To ensure ongoing structural protection, continued monitoring and baiting of the site should be done on a consistent and regular basis, even after control of the original colony has been declared (Getty et al. 2000). Glenn et al. (2008) demonstrated that termite baiting could reduce termite populations to nondetectable levels, but that if baits were removed, termite populations rebounded within a few months. This concept follows one of the tenets of biology, in that a "vacant niche" does not go unoccupied through time (Grinnell 1924, Lekevicius 2009). This idea, simply stated, is that if the same conditions exist which favored termite survival before installation of the termite baiting systems and those conditions are not rectified, then that niche will, at some point, be reoccupied after the termite baits are removed. While the original termite colonies may have been controlled, termites from nearby, concealed, or incipient colonies may reinfest after bait removal. Unless properly educated, people may tend to misinterpret this subsequent termite activity as a failure of the

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baiting process even if an extended period elapses between control of the initial colony and reinfestation by the subsequent colony. Two methods have been developed to help answer this question, mark and recapture (Grace 1990) and most recently, applications of genetic markers such as microsatellites (Vargo 2003).

Suppressing termite populations with baits is considered an "active" management approach that is labor intensive, and the associated costs (e.g., time, labor, equipment, product) must be considered when implementing a baiting system for subterranean termite control (Glenn et al. 2008). Termite baiting technology has brought new insight to the termite pest management industry, which for decades has relied on fundamentally different control concepts when compared to the repellent chlorinated hydrocarbons and pyrethroids of decades past (Su 2003).

Because subterranean termites use recruitment behavior to find food sources, and using baits is a proven method in the suppression of termite populations, with up to 90–100% control in the field (Su 1994), bait matrices can be very effective for termite management. Novaluron (±)-1-[3-chloro-4-(1, 1, 2-trifluoromethoxyethoxy)phenyl]-3-(2,6-difluorobenzoyl) urea is a slow-acting chitin synthesis inhibitor formulated for use as a subterranean termite bait. The EPA considers novaluron ($C_{17}H_9ClF_8N_8O_4$) and other active ingredients found in termite baits, such as hexaflumuron, diflubenzuron, and lufenuron, "reduced risk" compounds due to favorable profiles with respect to environmental concerns and risk to nontarget organisms (Cutler and Dupree 2007, Fishel 2013) as compared with the chlorinated hydrocarbons and pyrethroids, which were commonly used for subterranean termite control in years past. The active ingredient novaluron has been shown to have attributes (e.g., transferability, acceptance) preferable for use in termite bait (Brown et al. 2012). Therefore, the purpose of this field study was to evaluate the effectiveness of 0.5% novaluron formulated within a proprietary edible bait matrix for the control of subterranean termite infestations on structures.

Fig. 1. Polyvinyl chloride (pvc) pipe (independent monitor [IM]) with southern yellow pine wood insert.

Materials and Methods

This study involved 11 structures located in the Texas City, TX area, each of which had an active exterior infestation of subterranean termites during pretrial inspections. The structures used in this study were concrete monolithic slab construction with a mean footprint of $\sim 152 \pm 4.6$ m^2. Structures were assessed for possible inclusion in this study using the following process: 1) inspection of exterior perimeter, 2) confirmation of presence of termite mud tubes on exterior perimeter, 3) inspection of termite activity within mud tube(s), 4) if live termites were found, specimens were stored in 95% ethanol as voucher specimens and deposited at the Center for Urban and Structural Entomology at Texas A&M University (College Station, TX).

Independent monitors made of polyvinyl chloride pipe (PVC) with five equally spaced grooves to facilitate termite activity, into which were inserted 3 mo aged southern yellow pine dowels (3.5 by 12 cm^2; Fig. 1), were used to monitor termite presence. Termite activity for this study was defined as live termites, or termite activity on the substrate in the monitors and stations. The independent monitors were installed within 1 m of the foundation and were inspected every month postinstallation for the duration of the study; they provided an independent method of determining termite activity or elimination in the vicinity of the structures. The independent monitors were not used to determine control of the subterranean termites on the structures. BASF Advance Termite Bait System stations were fitted with a monitoring base and an inspection cartridge (three cellulose tablets; Fig. 2). The independent monitors and the stations were installed in an alternating pattern with 2.25 m between the independent monitors and the stations so that there was 4.5 m between each neighboring independent monitor and each neighboring station. The stations with the monitoring base and

Fig. 2. Station with inspection cartridge with cellulose tablets and a monitoring base made of southern yellow pine.

inspection cartridge were installed with a gas-operated auger midway between the independent monitors around the exterior of each of the 11 structures. The monitoring base remained in the station for the duration of the study; however, they were changed out as needed with fresh replacements if the termites had removed >50% of the wood, or if it had been degraded by >50% by fungi or weathering (Shupe et al. 2008). When termite activity was first detected on the monitoring base or an inspection cartridge within any station, the inspection cartridge was removed from the station and replaced with a bait cartridge containing 124 g of cellulose matrix with 0.5% novaluron. Once a bait cartridge was placed within a station, the interval between inspections for that specific station was extended to 4 mo (to reduce the disturbance of the termites); however, all independent monitors and stations with an inspection cartridge remained on a monthly inspection cycle. If at any subsequent inspection, termites had consumed >50% of the novaluron bait matrix within a station, it was replaced with a new bait cartridge, and the 4-mo inspection cycle continued for that station. If during a regular 4-mo inspection of the stations with a bait cartridge, there were no live termites or termite activity on the bait or the monitoring base, the bait cartridge was removed and replaced with an inspection cartridge. The structure was visually inspected on the exterior to determine if there was an active termite infestation (same procedure as described in this section). If there were no visual signs of termites found on the structure, then that date of inspection was set as the time of the start for "termite control" (12-mo period) for that structure. If there were no subterranean termites found on that structure for 12 mo then control was achieved. Based on the inspection interval, the minimum time required to report the start of termite control at a structure was 4 mo (i.e., infestations eliminated in 1–3 mo would have been scored as 4 mo). Inspection of stations (with inspection cartridges) and independent monitors then continued every month for the duration of the study. After returning a station to a monitoring phase, if live termites or evidence of termite activity reappeared in a station, the inspection cartridge was removed and a new bait cartridge was installed, and the station inspection was done every 4 mo. Therefore, control was defined by no evidence of live termites on the structure for a period of 12 mo.

The following rating scale was used to grade the consumption or removal of bait from a bait cartridge; 1 = no activity detected, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100%. The effectiveness of 0.5% novaluron was evaluated visually based on consumption of bait, and live termites or evidence of any termite activity on the structure. All means and standard deviations were calculated using SPSS v19.

Results

The number of stations installed was 139, with a mean of 12.6 ± 2.0 per structure. Of these, 29 (18.9%) had activity by subterranean termites, with a mean of 2.6 ± 2.1 per structure (Table 1). A total of 36 bait cartridges were used in the study of which 27 (75.0%) had activity by subterranean termites. At each of these structures, there was evidence of subterranean termite activity on the bait cartridge containing 0.5% novaluron prior to achieving control. To achieve control of the termite infestations on the structures required the equivalent of 1.3 ± 1.5 bait cartridges (161.2 g of 0.5% novaluron bait) per structure. The mean amount of bait removed from bait cartridges was 48.2 ± 31.8 g per structure over a 4-mo evaluation schedule. The average time to first activity by subterranean termites on an inspection cartridge and monitoring base was 5.1 ± 2.9 mo postinstallation of the stations, and the mean time for control of the termite infestation on the structures from the initial activity on a bait cartridge was 5.4 ± 2.7 mo (Table 1). Start of control was observed at 8 of the 11 structures at the first postbaiting interval (4 mo). Therefore, the mean time from first installation of the bait cartridge to control of the subterranean termite infestations on the structures was 10.5 ± 4.6 mo (date of initial activity on inspection cartridge plus time in months from first activity on bait cartridge to control; Table 1). This is likely an overestimate of the actual time required to achieve control as the minimum time to document the effects of the 0.5% novaluron was 4 mo, based on the predetermined inspection intervals.

A total of 16 independent monitors, associated with six different structures, had subterranean termite activity during the study. Three structures (structures 2, 6, and 11) had independent monitors with termite activity after initial subterranean termite control had been achieved (Table 2). However, activity on the independent monitors was not an indication of a termite

Table 1. Summary of structures treated with 0.5% novaluron subterranean termite bait

Structure no.	Termite genera	Date of bait station install M/Y[a]	Date of initial activity on inspection cartridge	Time in mo from first activity on bait to control[b]	No. of bait cartridges used	Approx. amt (g) of bait consumed[c]	No. of bait cartridge equivalents consumed to achieve control	No. of bait stations with termite activity	Date of control M/Y of termites on structure	No. of mo with no activity on structure after control	Date of final inspection M/Y
1	R[d]	12/2009	06/2010	12	12	682.0	5.50	6	06/2011	30	12/2013
2[e]	C[f]	12/2009	02/2010	4	5	155.0	1.25	5	06/2010	20	12/2013
3	R	12/2009	10/2010	8	1	31.0	0.25	1	06/2011	30	12/2013
4	R	12/2009	05/2010	4	2	186.0	1.50	2	09/2010	27	12/2013
5	R	12/2009	05/2010	4	6	124.0	1.00	6	09/2010	27	12/2013
6	R	12/2009	10/2010	4	2	124.0	1.00	1	02/2011	34	12/2013
7	R	12/2009	02/2010	4	3	124.0	1.00	3	06/2010	30	12/2013
8[e]	C	01/2010	07/2011	4	1	62.0	0.50	1	11/2011	18	12/2013
9	R	02/2010	06/2010	4	1	31.0	0.25	1	10/2010	26	12/2013
10	R	02/2010	07/2010	8	1	31.0	0.25	1	03/2011	33	12/2013
11	R	02/2010	03/2010	4	2	186.0	1.50	2	07/2010	41	12/2013
Means ($N = 11$)			5.1 ± 2.9	5.4 ± 2.7	3.3 ± 3.3	157.8 ± 183.6	1.27 ± 1.48	2.6 ± 2.1		28.7 ± 6.4	

[a] M/Y, mo/yr.
[b] Minimum time to observe control is 4 mo based on inspection intervals of bait stations with termite activity.
[c] One bait cartridge is 124 g.
[d] *Reticulitermes* sp.
[e] Feeding on inspection cartridge within a bait station after the control date, but no termite activity was found on or in the structure.
[f] *Coptotermes* sp.

Table 2. Summary of subterranean termite activity on independent monitors (IM)[a] at structures treated with 0.5% novaluron termite bait

Structure no.	Date IM installed M/Y[b]	IM no. with activity Date(s) (M/Y)	Date of control for structure
1	12/2009	1 (4/2010, 6/2010), 11 (6/2010), 13 (6/2010), 14 (9/2010), 3(4/2011)	6/2011
2[c]	12/2009	11 (5/2010), (2/2011)[c], 12 (1/2011, 2/2011)[c], 9 (4/2013, 5/2013, 6/2013)[c], 10 (4/2013, 5/2013)[c]	6/2010
3	12/2009	0	6/2011
4	12/2009	9 (5/2010)	9/2010
5	12/2009	0	9/2010
6	12/2009	14 (3/2011, 4/2011) [c]	2/2011
7	12/2009	1 (2/2010, 3/2010, 4/2010, 5/2010) 2 (2/2010, 3/2010, 4/2010, 5/2010)	6/2010
8[c]	1/2010	0	11/2011
9	2/2010	0	10/2010
10	2/2010	0	3/2011
11	2/2010	13 (2/2011, 5/2011, 11/2011)[c], 2 (4/2011)[c]	7/2010

[a] IM—independent monitor consisted of southern yellow pine dowel in a polyvinyl chloride (PVC) housing.
[b] M/Y, mo/yr.
[c] Activity on IM after the date of control, but no termite activity was found on the structure.

infestation on the structures, as evidenced by the lack of observable termite activity during structural inspections once control had been achieved.

There were two structures which had active subterranean termites in stations following initial control of the termites infesting the structure (Table 3). Structure number 2 had a recurrence of subterranean termites in two stations in April 2013, and Structure number 8 had a recurrence in one station in May 2013, which occurred at 18 and 20 mo, respectively. Both of these recurrences involved *Coptotermes formosanus* Shiraki (Table 3), which were only found in the stations, not on the structures. In both recurrences, the inspection cartridges were removed and a bait cartridge with 0.5% novaluron was installed. Those three stations were then inspected at 4 mo postinstallation of the bait cartridge. The mean amount of bait consumed during this period was ∼75% (Table 3). There were no live termites in the bait stations or on the structures at that 4-mo inspection date, and there were no subterranean termite infestations on these two structures through the end of the study (Table 3).

Discussion

The goal of a termite baiting treatment is to protect a structure by reducing the termite population (Thorne and Forschler 2000, Glenn et al. 2008) through disbursement of a bait matrix with an effective active ingredient into the termite colony via trophallaxis (Grace et al. 1996, Thorne and Forschler 1998). Methodologies used to determine the efficacy of a liquid termiticide treatment are not relevant for evaluating the success or failure of termite baits as a treatment for subterranean termites (Thoms et al. 2009). In order to evaluate the success of a termite baiting system as successful stand-alone treatments, criteria were proposed by Su and Scheffrahn (1996) which included—1) reduction in termite foraging, 2) reduction in termite foraging territory, and, 3) reduction in termite population

Table 3. Summary of recurrence of subterranean termites on structures treated with 0.5% novaluron termite bait

Structure no.	Date of installation of bait stations	Date of control of initial termites on the structure	Months from control to recurrence of termites	Date of recurrence of termites in bait station(s) & date of installation of bait cartridge	Recurrence of termites and no. of bait stations with activity	No. of bait cartridges consumed	No. of months to control	Months of control after recurrence of termites (end of study)
1	12/2009	06/2011	*[a]	*	*	*	*	*
2	12/2009	06/2010	20	4/2013[b]	2	1.5	4	4
3	12/2009	06/2011	*	*	*	*	*	*
4	12/2009	09/2010	*	*	*	*	*	*
5	12/2009	09/2010	*	*	*	*	*	*
6	12/2009	02/2011	*	*	*	*	*	*
7	12/2009	06/2010	*	*	*	*	*	*
8	01/2010	11/2011	18	5/2013[b]	1	0.75	4	3
9	02/2010	10/2010	*	*	*	*	*	*
10	02/2010	03/2011	*	*	*	*	*	*
11	02/2010	07/2010	*	*	*	*	*	*

[a]* No recurrence of termites.
[b] *Coptotermes formosanus.*

size. Expanding on these concepts, Thorne and Forschler (2000) proposed additional criteria for termite baiting success including—1) there must have been termite activity on pretreatment monitors, 2) reduction in number of alates during posttreatment swarm seasons, 3) evidence of activity on the bait matrix, and, 4) no termite activity on monitors for sustained periods of time after control was achieved. We propose that the criteria for demonstrating successful control of subterranean termite infestations using a bait must include—1) an active termite infestation on a structure at the time of installation of the baiting system, 2) evidence that there was termite activity on the bait matrix, 3) that termite activity on the structure was eliminated for a period of at least 1 yr. In this study, all of the structures met our criteria stated above. Therefore, we concluded that the 0.5% novaluron successfully controlled the subterranean termite infestations on the structures.

One of the main questions when using baits for subterranean termite control is what is an acceptable time frame for control. There are many variables that play a role in how quickly a termite infestation can be controlled such as the active ingredient, time of year (season), termite species, ambient temperature, colony size, palatability of bait matrix, number of stations used, distance between stations, and usage of above-ground stations on active termite mud tubes (Glenn et al. 2008). The time from station installation to the first evidence of activity can vary markedly. In this study, which was done in the southern coastal region of Texas, the initial installations of the stations were completed in December through February, 2009–2010, during a period when the very first of the subterranean termite swarms normally begin to occur, but also at a time when temperatures fluctuate widely. It is also a time of year when people become aware of termite mud tubes in and on their homes, thus allowing us to select structures with an active subterranean termite infestation. The mean time from station installation until the first activity on an inspection cartridge was 5.1 ± 2.9 mo, with the shortest and longest times of 2 and 10 mo, respectively. The length of time from installation of stations to first activity on bait matrices with active ingredient varies markedly (Glenn and Gold 2003). As an example, it took between 35 to 661 d with FirstLine and 28–718 d with Sentricon to confirm termite activity on the bait (Glenn and Gold 2003). Glenn and Gold (2003) also reported that there were alternating periods of activity and nonactivity by subterranean termite populations associated with structures in the studies, and the fact that a lack of termite activity at baiting sites is not necessarily an indication that the colony has been controlled.

Another dilemma associated with the use of any chemical control measure used for subterranean termite population management is reoccurrence and reinfestation of a treated structure by termites. Thoms et al. (2009) noted that of the 24 buildings in their study, 13 were reinfested by new colonies after the initial termite colonies had been controlled as determined by DNA analyses. In terms of protecting the structure, it would not matter if the termites infesting homes were from the original colonies, or were from a different colony; the structure needs to be protected from further damage. In the present study, four structures had evidence of the return of subterranean termites in a station or an independent monitor after initial control was achieved, but there was no evidence of termites on the structures at these times or through the end of the study. Although there was termite activity in the vicinity of some of the structures (i.e., in monitors or stations), we did control the subterranean termite infestations on all 11 structures.

Within 2 mo of the initial installation, 30% of the structures had subterranean termite activity on an inspection cartridge or a monitoring base within a station. This is comparable to the work of Getty et al. (2007), who had activity of *Reticulitermes* sp. on 41% of structures at 2 mo postinstallation utilizing 0.5% hexaflumuron, and Grace et al. (1996) who reported 8–27% of stations with *C. formosanus* activity utilizing 0.1% hexaflumuron at 1 mo postinstallation on each of the three study structures (97 total stations) used in their study. In the current study, at 6 mo postinstallation there had been activity in stations at 70% of the structures. Of the 153 stations initially installed in the current study there was subterranean termite activity on 19% (29 stations) by the end of the study. This is comparable with Getty et al. (2007) who had activity on 12% of Sentricon II stations initially installed. At the three structures used in Grace et al. (1996) the mean number of bait tubes consumed to achieve control at each structure was 6.38 or 223 g. In the current study, the mean number of bait cartridges consumed per structure was 1.3 ± 1.5 or 158.1 ± 184.5 g to achieve initial control. In 2009, Thoms et al. reported the results of a study wherein 100% control of subterranean termites was achieved within 12 mo when using 0.5% noviflumuron which is similar (chitin synthesis inhibitor) to this study that achieved 100% control of the termite infestations on structures within 12 mo of initial termite activity in stations, using 0.5% novaluron.

There was never any subterranean termite activity on these structures after control of the initial infestations. As previously mentioned there was evidence of termite activity in independent monitors or stations containing inspection cartridges at four structures, respectively after initial control of the termites was confirmed, but there was no evidence of termites on the structures. Two of these recurrences were *C. formosanus* (100%) and two of these recurrences were *Reticulitermes* sp. (22%), suggesting that there could be a difference in the effects of novaluron on *C. formosanus* and *Reticulitermes* sp. There is evidence to support this from laboratory studies of different effects on *R. flavipes* and *C. formosanus* with hexaflumuron and diflubenzuron (Su and Scheffrahn 1993) and in a field study with hexaflumuron (Su 1994). In both cases in the present study showing recurrences of *C. formosanus* in stations, novaluron (0.5%) bait was reapplied, which controlled the termites. The two recurrences of *Reticulitermes* sp. was in independent monitors only, so novaluron was not reapplied. Getty et al. (2007) reported a similar situation where 14% of 120 bait stations were reinfested with subterranean termites after initial control was declared, in which case they removed the wooden monitoring devices from the stations and reinstalled bait. In order to reduce subterranean termite damage to infested structures, it is recommended that the active ingredient be preloaded in the stations at the time of installation. This study demonstrated that control of subterranean termite infestations on structures can be achieved using a novaluron bait.

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References Cited

Austin, J. W., G. Glenn, and R. E. Gold. 2008. Protecting urban infrastructure from Formosan termite (Isoptera: Rhinotermitidae) attack: A case study for United States railroads. Sociobiology 51: 231–247.

Beard, R. L. 1974. Termite biology and bait-block method of control, p. 748. Connecticut Agricultural Experiment Station, New Haven, CO.

Brown, K. S., E. L. Vargo, C. Riegel, R. E. Gold, E. D. Freytag, T. C. Keefer, and J. H. Cink. 2012. Laboratory and field evaluation of Trelona® compressed termite bait (0.5% novaluron). Proc. 2012 National Conference on Urban Entomology, 20–23 May, Atlanta, GA.

Cutler, G.C., and C. D. Scott-Dupree. 2007. Novaluron: Prospects and limitations in insect pest management. Pest Technol. 1: 38–46.

Esenther, G. R., and D. E. Gray. 1968. Subterranean termite studies in southern Ontario. Can. Entomol. 100: 827–834.

Fishel, F. M. 2013. The EPA conventional reduced risk pesticide program. University of Florida, IFAS Extension Publication PI224, FL.

Getty, M. G., M. I. Haverty, K. A. Copren, and V. R. Lewis. 2000. Response of *Reticulitermes* spp. (Isoptera: Rhinotermitidae) in northern California to baiting with hexaflumuron with Sentricon Termite Colony Elimination System. J. Econ. Entomol. 93: 1498–1507.

Getty, M. G., C. W. Solek, R. J. Sbragia, M. I. Haverty, and V. R. Lewis. 2007. Large-scale suppression of a subterranean termite community using the Sentricon Termite Colony Elimination System: A case study in Chatsworth, California, USA. Sociobiology 50: 1041–1050.

Glenn, G. J, J. W. Austin, and R. E. Gold. 2008. Efficacy of commercial termite baiting systems for management of subterranean termites (Isoptera: Rhinotermitidae) in Texas. Sociobiology 51: 333–362.

Glenn, G. J., and R. E. Gold. 2003. Evaluation of commercial termiticides and baiting systems for pest management of the Formosan subterranean termite, *Coptotermes formosanus* (Isoptera: Rhinotermitidae). Sociobiology 41: 193–196.

Gold, R. E., A. A. Collins, B. M. Pawson, and H. N. Howell. 1994. Termiticide technology-The isophenphos dilemma. J. Franklin Inst. 331: 189–198.

Gold, R. E., H. N. Howell Jr., B. M. Pawson, M. S. Wright, and J. C. Lutz. 1996. Evaluation of termiticide residues and bioavailability from five soil types and location in Texas, pp. 567–484. *In* K. B. Wiley (ed.). Proceedings of the 2nd International Conference on Insects Pests in the Environment, 7–10 July 1996, Edinburgh, Scotland.

Grace, K. 1990. Mark-recapture studies with *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). Sociobiology 16: 297–303.

Grace, J. K., and N. Y. Su. 2001. Evidence supporting the use of termite baiting systems for long-term structural protection (Isoptera). Sociobiology 37: 301–310.

Grace, J. K., C. H. M. Tome, T. G. Shelton, R. J. Oshiro, and J. R. Yates III. 1996. Baiting studies and considerations with *Coptotermes formosanus* (Isoptera: Rhinotermitidae) in Hawaii. Sociobiology 28: 511–520.

Grinnell, J. 1924. Geography and evolution. Ecology 5: 225–229.

Keefer, T. C., R. T. Puckett, and R. E. Gold. 2011. Effect of imidacloprid granules on subterranean termite populations (Isoptera: Rhinotermitidae). Sociobiology 57: 35–50.

Lekevicius, E. 2009. Vacant niches in nature, ecology, and evolutionary theory: A mini-review. Ekologija 55: 165–174.

(NPMA) National Pest Management Association. 2005. Cost to control subterranean termites in the United States, NPMA webpage (http://pestworld.org/database/Article.asp)

Rust, M. K., and N. Y. Su. 2012. Managing social insects of urban importance. Annu. Rev. Entomol. 57: 355–375.

Shupe, T., S. Lebow, and D. Ring. 2008. Causes and control of wood decay, degradation and stain. Louisiana Cooperative Extension Service, Pub.2703 (5M), Baton Rouge, LA.

SPSS 2010. SPSS, version 19.0. SPSS, Chicago, IL.

Suarez, M. E., and B. L. Thorne. 2000. Rate, amount, and distribution pattern of alimentary canal fluid transfer via trophallaxis in three species of termites (Isoptera: Rhinotermitidae, Termopsidae). J. Econ. Entomol. 93: 145–155.

Su, N. Y. 1994. Field evaluation of a hexaflumuron bait for population suppression of subterranean termites (Isoptera: Rhinotermitidae). J. Econ. Entomol. 87: 389–397.

Su, N.Y. 2002. Novel technologies for subterranean termite control. Sociobiology 40: 95–101.

Su, N.Y. 2003. Overview of the global distribution and control of the Formosan subterranean termite. Sociobiology 41: 7–16.

Su, N. Y., M. Tamashiro, J. R. Yates, and M. I. Haverty. 1982. Effect of behavior on the evaluation of insecicides for prevention of or remedial control of the Formosan subterranean termite. J. Econ. Entomol. 75: 188–193.

Su, N. Y., and R. H. Scheffrahn. 1993. Laboratory evaluation of two chitin synthesis inhibitors, hexaflumuron and diflubenzuron, as bait toxicants against Formosan and Eastern subterranean termites (Isoptera: Rhinotermitidae). J. Econ. Entomol. 86: 1453–1457.

Su, N. Y., and R. H. Scheffrahn. 1986. A method to access, trap and monitor field populations of the Formosan subterranean termite (Isoptera: Rhinotermitidae) in the urban environment. Sociobiology 12: 299–304.

Su, N. Y., and R. H. Scheffrahn. 1996. Evaluation criteria for bait-toxicant efficacy against field colonies of subterranean termites: A review, pp. 443–447. *In* K. B. Wiley (ed.). Proceedings of the 2nd International Conference on Insects Pests in the Environment, 7–10 July 1996, Edinburgh, Scotland.

Su, N. Y., and R. H. Scheffrahn. 1998. A review of subterranean termite control practices and prospects for integrated pest management programmes. Integr. Pest Manage. Rev. 3: 1–13.

Su, N. Y., J. D. Thomas, and R. H. Scheffrahn. 1998. Elimination of subterranean termite populations from the Statue of Liberty national monument using a bait matrix containing an insect growth regulator, hexaflumuron. J. Am. Inst. Conser. 37: 282–292.

Thoms, E. M., J. E. Eger, M. T. Messenger, E. Vargo, B. Cabrerea, C. Riegel, S. Murphree, J. Mauldin, and P. Scherer. 2009. Bugs, baits, and bureaucracy: Completing the first termite bait efficacy trials (Quarterly replenishment of noviflumuron) initiated after adoption of Florida rule, Chapter 5E-2.0311. Am. Entomol. 55: 29–39.

Thorne, B. L., and B. T. Forschler. 1998. NPCA Research Report on Subterranean Termites. National Pest Control Association, Dunn Loring, VA.

Thorne, B. L., and B. T. Forschler. 2000. Criteria for assessing efficacy of stand-alone termite bait treatments at structures. Sociobiology 36: 245–255.

Wolcott, G. N. 1924. The comparative resistance of woods to the attack of the termite *Cryptotermes brevis* walker. Porto Rico Insular Exp. Sta. Bull. 33: 3–15.

Van Zwaluwenberg, R. H. 1916. Report entomologist. Annual Report Porto Rico Agr. Exp. Sta. 1915: 42–45.

Vargo, E. L. 2003. Genetic structure of *Reticulitermes flavipes* and *R.* virginicus (Isoptera: Rhinotermitidae) colonies in an urban habitat and tracking of colonies following treatment with hexaflumuron bait. Environ. Entomol. 32: 1271–1282.

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