Journal of Economic Entomology Advance Access published August 10, 2015

Household and Structural Insects

Elimination of the Mound-Building Termite, *Nasutitermes exitiosus* (Isoptera: Termitidae) in South-Eastern Australia Using Bistrifluron Bait

GARRY A. WEBB[1] AND CHARLES McCLINTOCK

Sumitomo Chemical Australia, PO Box 60, Epping, NSW 1710, Australia.

J. Econ. Entomol. 1–9 (2015); DOI: 10.1093/jee/tov232

ABSTRACT Bistrifluron, a benzoylphenylurea compound, was evaluated for efficacy against *Nasutitermes exitiosus* (Hill), a mound-building species in southern Australia. Bistrifluron bait (trade name Xterm) was delivered as containerized pellets inserted into plastic feeding stations implanted in the sides of mounds—60 g for bistrifluron bait-treated mounds and 120 g of blank bait for untreated mounds. Termites actively tunneled in the gaps between pellets and removed bait from the canisters. All five treated mounds were eventually eliminated, and all five untreated mounds remained active at the end of the trial. Four of the five treated mounds were considered dead and excavated after 26 wk, but there were earlier signs of mound distress—reduced repair of experimental casement damage and reduced activity in bait canisters by 22 wk and reduced internal mound temperature after 11 wk. One treated mound showed activity in the bait station right through until almost the end of the trial (47 wk), but excavation at 49 wk showed no further activity in the mound. The five untreated colonies removed on average 97% of blank bait offered, while the five treated colonies removed on average 39.1% of bait offered. There was a wide variation in temperature profiles of mounds (up to 15°C for both minimum and maximum internal temperatures), from the beginning of the trial and even before the effects of baiting were evident.

KEY WORDS bistrifluron, Xterm, *Nasutitermes exitiosus*, baiting, mound temperature

Nasutitermes exitiosus (Hill) is a common mound-building termitid species of southern Australia and is of some economic importance, causing damage to timber structures (McMahan and Watson 1975). *N. exitiosus* colonies may grow very large, with mounds exceeding 1 m in height and containing up to 1.8 million individuals (Evans et al. 1998).

Termite baiting using benzoylphenylurea compounds has been successful on rhinotermitid termites such as *Coptotermes* spp. but less effective against the higher termites (Termitidae) (Lenz et al. 1996; Lee et al. 2007, 2014; Neoh et al. 2011), and it's been suggested that this may result from a number of factors including food caching and delayed consumption, reduced trophallaxis and allogrooming in the colony relative to rhinotermitid termites, low bait pallatability, increased tolerance to the toxicant and incorporation of the bait matrix into the mound structure rather than actual consumption, and reduced frequency of molting in the worker caste (Lenz et al. 1996, Kubota 2011, Neoh et al. 2011, Gazal et al. 2014). Elimination of *Nasutitermes* colonies may also be delayed beyond that normally evident for *Coptotermes* largely due to the persistence of longer-lived final-instar workers and soldiers well beyond the stage where the colony loses brood and reproductive capacity (Lenz et al. 1996, Broadbent 2011).

In this study, we examined the effects of bistrifluron (a new benzoylphenylurea compound) formulated as 1% alpha-cellulose pellets (Xterm) when implanted directly into the mounds of *N. exitiosus*. The efficacy of bistrifluron bait has been demonstrated on various rhinotermitid termite species in the laboratory and in the field during the past 10 yr (Kubota et al. 2006, 2007, 2008; Evans 2010) and more recently on the termitid *Globitermes sulphureus* (Haviland) (Neoh et al. 2011). To our knowledge, there have been no previous published data on the effect of bistrifluron on *Nasutitermes* spp.

Materials and Methods

Field Evaluation. Ten active *N. exitiosus* mounds were identified on a cattle grazing property at Ladysmith near Wagga (NSW; 35° 12′31″ S, 147° 30′48″ E; altitude 210 m) on 5 December 2011. Mounds were relatively small, ranging in size from 30 to 60 cm in height and generally ∼50–60 cm in diameter at ground level. The 10 mounds were scattered over an area of ∼5 ha and separated by at least 50 m. This is consistent with previous observations that mound size decreases with distance from the coast (Watson and Abbey 1986).

Bait receptacles composed of 150 mm lengths of 100-mm polyvinyl chloride (PVC) pipe with two end

---

[1] Corresponding author, e-mail: gawebb@sumitomo-chem.com.au.

caps were installed in each mound on 5 December 2011. The inner end cap was drilled with multiple 10-mm holes to allow termite entry. Bait receptables were placed into the side of each mound after creating a suitable hole with a 100-mm corehole auger. The outer end cap was left exposed at the surface of the mound to allow for easy removal and inspection. Blank and loaded bait canisters of Xterm (1% bistrifluron, Sumitomo Chemical Singapore Pte Ltd.) differed in size (120 g for blank bait and 60 g for 1% bistrifluron bait) because of lack of availability of a consistent size at the time of the trial. Bait canisters were placed in each receptable 2 wk after installation of the bait receptacles (21 December 2011) to allow termites to repair the damage to the mound and become accustomed to the presence of the bait receptacles. At the time of the bait canister placement, all receptacles showed signs of internal mudding and casing repair around the receptacles, indicating that all mounds were healthy. For one treated mound, which persisted much longer than the other four, an additional 60-g canister was added at week 26.

Temperature probes were installed in each mound to monitor internal and external mound temperature. Thermodata button probes (DS1921H, Thermodata Pty Ltd, Brisbane, Australia) were secured to both ends of a 30-cm-long wooden timber dowel with PVC electrical tape and inserted into a 22-mm diameter PVC tubing of similar length. The ends of each PVC tube were capped at both ends to prevent termite entry or external disturbance. Holes (25 mm in diameter) were drilled into each mound into which the PVC tube and wooden dowel were inserted. At each subsequent inspection, the external endcap was removed and the wooden dowel extracted. Data from the Thermodata buttons were downloaded on a regular basis using a dedicated reader and software. DS1921H probes had a lower temperature limit of 14.5°C and maximum of 45°C and a limited storage capacity. Therefore, internal mound temperatures were recorded every 4 h from initial installation of the temperature probes through to final excavation on 21 June 2012 (treated mounds) or on 12 November 2012 (untreated mounds) to maintain continuous recording during the study period. On 21 June 2012, four of the five treated mounds were considered dead and excavated to remove bait receptacles and temperature probes. An additional 60-g canister was placed in the remaining baited colony (a total of 120 g of bait). Temperature probes and bait receptacles were removed from the five untreated mounds and the one remaining treated mound on 12 November 2012. All five untreated mounds were considered healthy at that time owing to the continued activity in the bait station and a clear defense response to the removal of the bait station. The five untreated mounds were not excavated, but the final treated mound was excavated to confirm inactivity.

Local weather records were obtained from the nearest weather station, 18 km away in Wagga township at a similar elevation.

At each inspection, beginning with the original installation, 25-mm holes were drilled in the side of the mound using a 25-mm masonary drill bit. The repair of these holes was used to assess the ability of colonies to repair damage to the mound over time. Drill holes were inspected at each subsequent visit. This varied in time span from ~2 wk at the beginning of the trial to 10 wk for the final inspection. Holes were considered repaired if they were completely closed over by new mud.

Determination of Bait Moisture Content. New 60-g canisters containing 1% bistrifluron pellets (five replicates) were removed from their plastic packaging and placed into an oven at 40°C for 72 h to remove any residual moisure and then reweighed to determine moisure content.

Bait canisters retrieved from mounds were placed into sealed plastic bags. Later, these canisters were opened and residual bait extracted and weighed. All termite mud was removed from pellets and fragments before weighing to determine weight of bait consumed or removed by termites. Contents of the canisters were sieved using a 2-mm geological sieve. An amount of bait (as fragments less than 2 mm in diameter) was discarded. However, it was estimated that the total weight of these fragments was no more than a few grams in total and not likely to significantly alter the final analysis of bait consumed or removed. Residual bait was oven-dried at 40°C for 72 h to remove any residual moisure and then reweighed to determine moisure content.

Statistical Analysis. Bait removed by termites was analyzed using a two-sample *t*-test on percentage values after arcsin transformation and confirmation of normality with Wilks–Shapiro test (Statistix version 10, Analytical Software, Tallahassee, FL). No statistical analysis was applied to either measure of mound activity. Temperature differences between treated and untreated mounds were analyzed in weekly segments using the mean minimum and maximum temperatures across the five mounds over 7 d (35 data points for each). A folded *F*-test was used to test for equality of variance and then a two-sample *t*-test was used to compare mean maximum temperatures of treated and untreated mounds and also mean minimum temperatures. The Satterthwaite *t*-test was used where variances were not considered equal.

Results

Mound Activity. Mound activity was assessed by monitoring the presence of live termites in the bait receptacles when opened for inspection, and by assessing the degree of repair of experimental holes drilled in the side of the mound. Complete hole repair in all untreated mounds occurred until the end of the trial and termite activity in bait receptacles was evident until the end of the trial (Fig. 1). In treated mounds, the degree of hole repair did not decline until after the 16th week of the trial and then relatively rapidly. No repair was evident after week 22. Termite activity in bait receptacles began to decline from week 22 onward. Four of the treated mounds were dissected at 26 wk and found to be dead. Some termite activity (presence

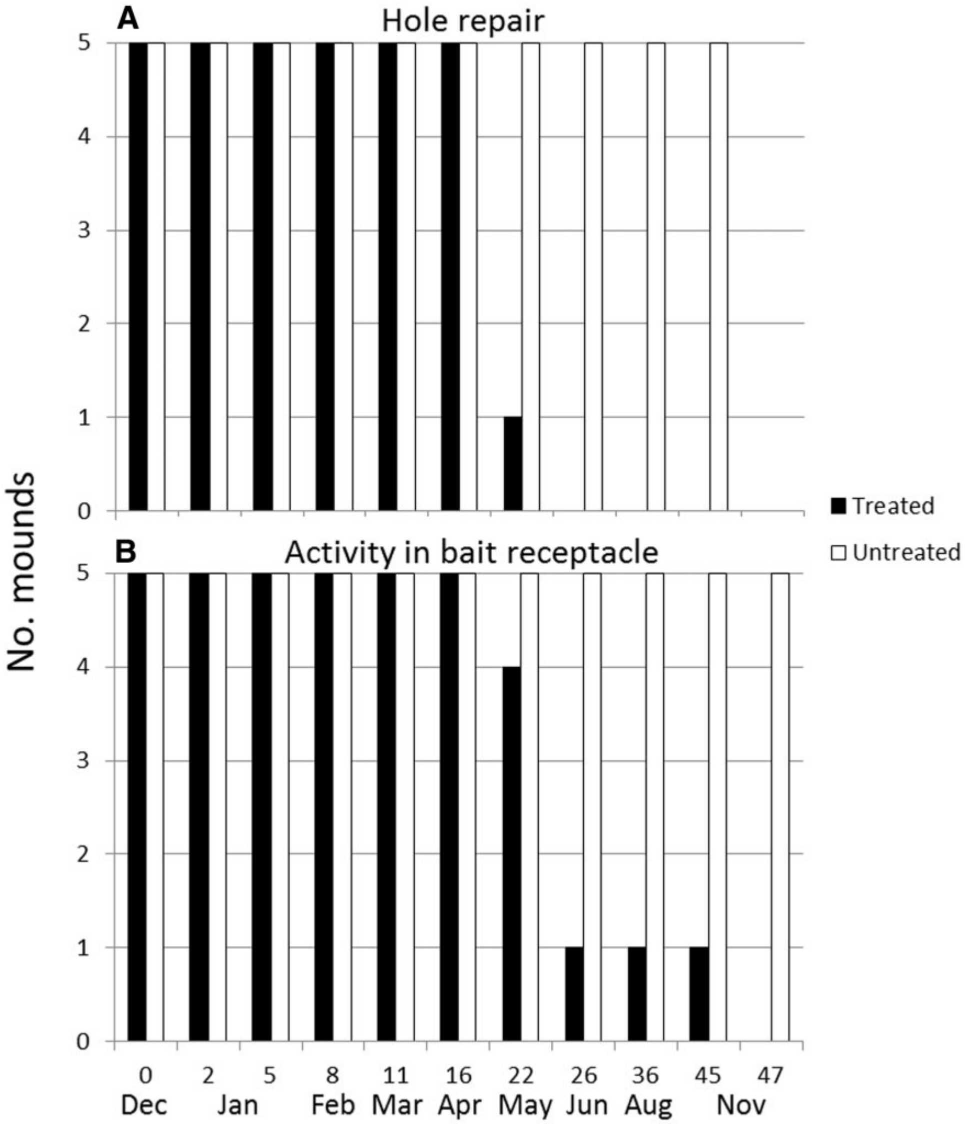

Fig. 1. Termite activity over 47 wk following baiting. (A) Number of mounds where the drilled hole was repaired by the time of the next assessment. Four of the five treated mounds were excavated at week 28, and all remaining mounds were excavated at week 47. (B) Number of mounds where termite activity was evident in the bait receptacle at that assessment.

of live termites) was still evident in the final mound at 45 wk, but by the final assessment and mound excavation at week 47, no activity was evident.

Bait Removal. The average weight of bait (minus canister) for fresh bait canisters before and after drying was 59.69 ± 0.17 SE and 58.64 ± 0.17 SE—an average moisture content of 1.8%. On this basis, bait recovered from dissected mounds was oven-dried under the same regime and weighed and the mean percentage removal from canisters adjusted for the starting moisture content. For mounds treated with blank bait, termites removed on average 97% of available bait (116.4 g per mound) over the period of the trial (49 wk; Table 1). For mounds treated with 1% bistrifluron bait, termites removed on average 39.1% of bait. These differences were statistically significant ($F = 12.51$; $df = 4$; $P < 0.05$) and largely the same when the second bait cartridge in treated replicate 5 was removed from the analysis. Of the four mounds dissected on 21 June 2012, termites removed on average 42.9% of the bait offered. The final treated mound was not dissected until the end of the trial, and of the total bait offered (120 g), termites removed 24.0% (39.1% from the first canister and just 10.0% from the second).

Mound Temperature. Daily maximum and minimum temperatures were considered to be the highest (usually 12 noon or 4 p.m.) and lowest (usually 4 a.m.) of the six temperature readings and, therefore, a proxy for the actual maximum and minimum daily temperatures. Mean internal temperature ranges for untreated and treated mounds were largely similar until week 11 (early March) after application, after which significant differences were evident between both maximum and minimum temperatures of untreated and treated mounds (Fig. 2). The internal core temperature range varied little, generally in the order of 1–2°C for untreated mounds and treated mounds up to ∼18 wk after treatment. In treated mounds, internal core temperature range was constricted to just 1°C from 18 wk after treatment, as daily temperature declined. The drop in mean core temperature of treated mounds at week 11 coincided with a prolonged and significant drop in ambient temperature in late February (Fig. 3).

Table 1. Bait consumption per mound by termites

	Replicate	Bait remaining	Total bait removed[a]	% Removal
Blank bait (120 -g canisters)	1	2.78	114.50	97.6
	2	0	117.28	100.0
	3	1.96	115.32	98.3
	4	12.01	105.27	89.8
	5	1.09	116.19	99.1
	Mean	3.65 ± 2.2	113.71 ± 2.16	97.0
1% bait (60 -g canisters)	1	0	58.64	100.0
	2	37.85	20.79	35.5
	3	44.24	14.40	24.6
	4	51.98	6.66	11.4
	Mean of 1–4	33.52	25.12	42.8
	5a	36.35	22.29	38.0
	5b	52.77	5.87	10.0
	Mean of 1–5	34.08 ± 8.96	24.56 ± 8.96	39.1

All weights shown are following oven drying for 72 h at 40°C. Canisters were removed from treated mounds (repetitions 1–4 only) at 26 wk. An additional 60 -g canister (5b) was added to treated replicate 5 at 26 wk. All remaining canisters were removed at 47 wk.

[a] Calculated based on oven-dried weight of new 60-g canisters (mean of 58.64 g).

With the exception of a few extreme peaks, the maximum internal temperature of untreated mounds tracked closely with the maximum daily ambient temperature through the study (Fig. 3), as did the treated mounds until at least week 11. As the temperature probes had a lower limit of 14.5°C, the minimum internal temperatures of most of the mounds (treated or untreated) reached down to or below this value during some part of the winter period (May–June). However, the maximum mound temperature was rarely below 14.5°C even during winter with the exception of the four treated mounds considered dead on 21 June 2012, and an anomalous untreated mound (Fig. 4). The treated mound, which was still active in June, maintained a maximum mound temperature well above 14.5°C until the end of the study, when it was dismantled and found to be inactive. Despite the unusually lower temperature range throughout the study for one of the untreated mounds, by all other measures, the colony remained active for the duration of the study.

The temperature profile of the external temperature probes generally matched that of the local weather records, although the daily maximum temperature at the mound surface often exceeded the local weather maxima during summer (Fig. 5). However, rarely did the daily minimum temperature drop below that of the local weather minima during the nonwinter period.

Discussion

Bistrifluron bait, when inserted directly in *N. exitiosus* mounds, resulted in complete elimination of all treated termite colonies sometime between 16 and

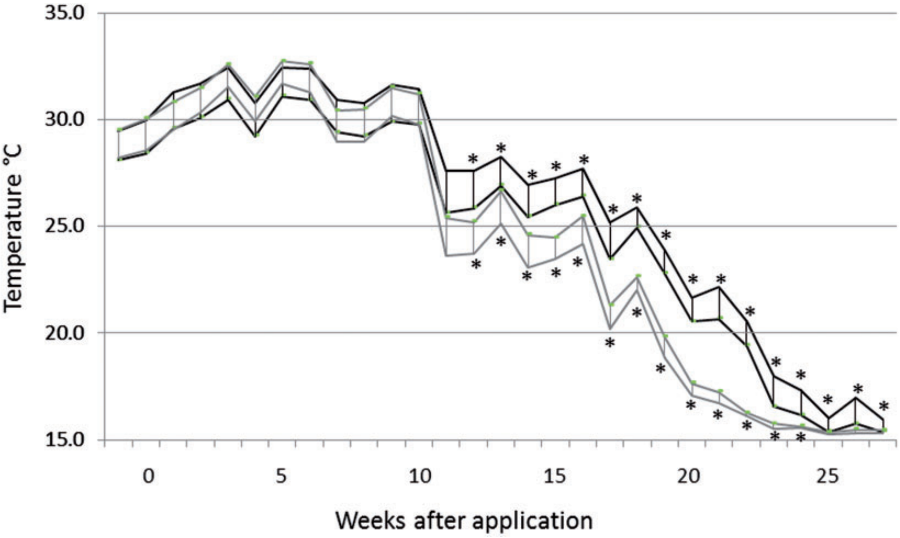

Fig. 2. Mean weekly maximum and minimum internal mound temperatures for untreated (black) and treated (gray) mounds. Horizontal scale shows weeks since application and not weeks since temperature recordings commenced. The upper band of asterisks represent those weeks where the maximum temperatures of untreated and treated mounds differed significantly ($P < 0.05$). The lower band of asterisks represent those weeks where the minimum temperatures of untreated and treated mounds differed significantly ($P < 0.05$).

47 wk after application, with four of the five mounds succumbing by week 26. The final colony succumbed sometime after 45 wk. However, colony decline was evident well before the final dismantling of treated mounds. Metrics based on repair of experimental damage and activity in bait receptacles indicate colony distress by 22 wk after application (for four of the five treated mounds) and mound temperature profiles indicate an even earlier sign of colony response (11 wk).

The response of higher termites (Termitidae) to baiting with benzoylphenylurea compounds is known to be slower than for rhinotermitid termites (Lenz et al. 1996, Ngee et al. 2004, Broadbent 2011, Neoh et al. 2011). Whereas rhinotermitid colony response and indeed collapse can be very rapid with indications of distress as early as three weeks after baiting (Evans 2010), in most cases, noticeable responses of termitid species to baiting are delayed. Elimination of *G. sulphureus* in Malaysia was achieved using bistrifluron bait in ∼16 wk, but signs of colony distress were evident at 8 wk after application (Neoh et al. 2011). Peters and Broadbent (2005) eliminated five colonies of *G. sulphureus* in Thailand using chlorfluazuron-based

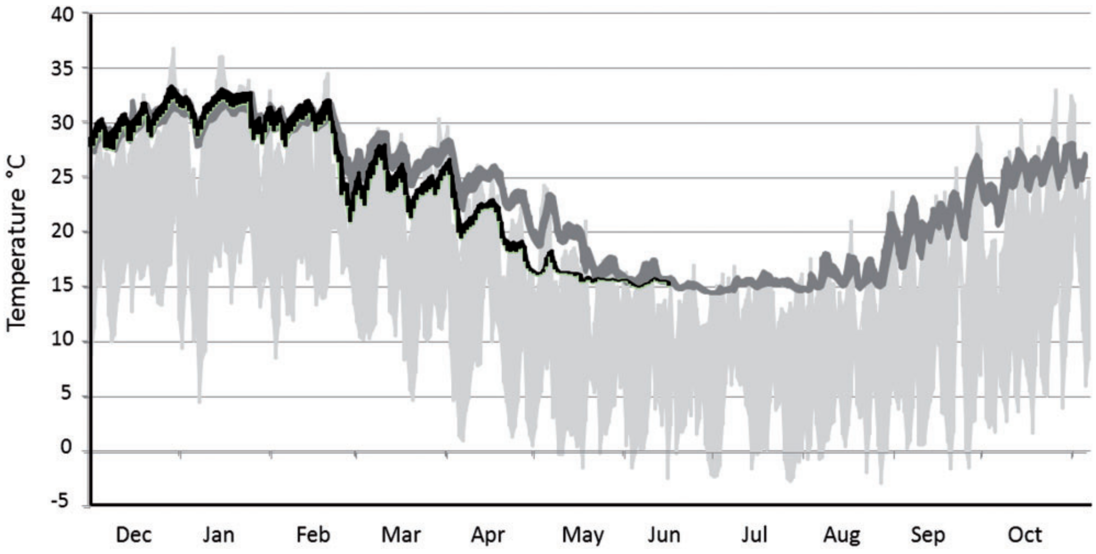

Fig. 3. Daily temperature range for local weather (light gray) and for mean temperature range for untreated (dark gray) and treated mounds (black) over the period of the trial from December 2011 to November 2012. Temperature data for treated mounds cease in June 2011 when four of the five mounds were considered dead. The remaining treated mound succumbed to baiting sometime between August and November 2012.

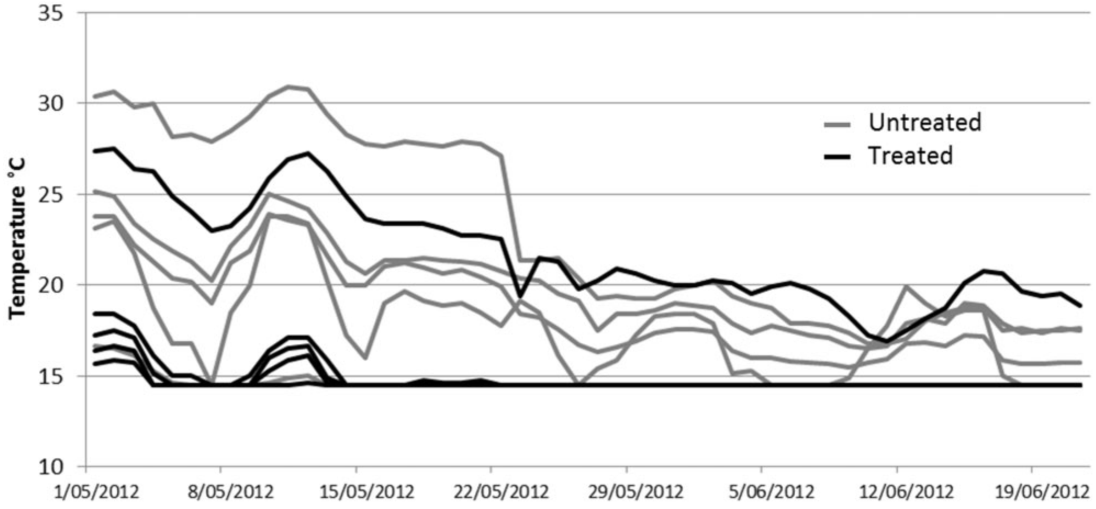

Fig. 4. Daily maximum temperature for the five untreated (gray) and five treated mounds (black) during the winter period (May–June 2012). Temperature probes had a minimum temperature of 14.5°C.

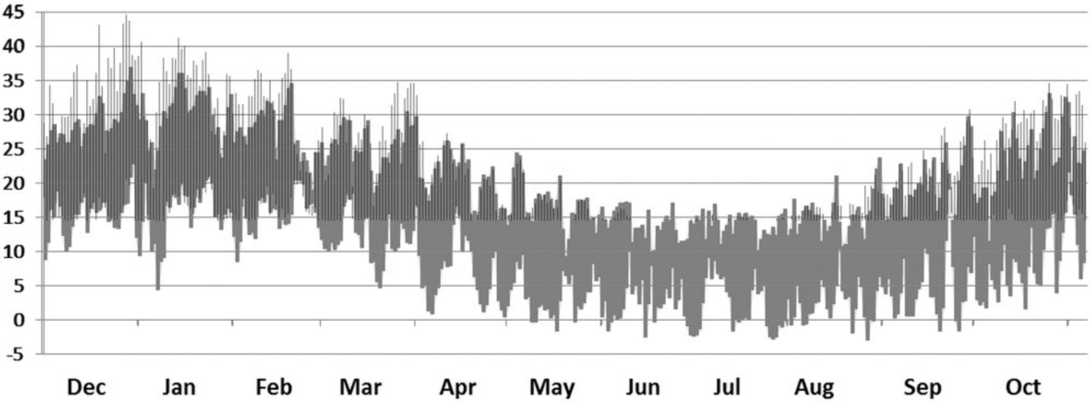

Fig. 5. Daily temperature range for local meteorological station (solid dark gray) and mean external temperature range for untreated mounds (light gray lines) from December 2011 to November 2012. Temperature probes had a minimum temperature of 14.5°C.

bait within 16 wk but did not detail any earlier signs of colony response. Dhang (2011) achieved elimination of two *Macrotermes gilvus* (Hagan) mounds using chlorfluazuron-based bait in 16 wk, and Peters and Broadbent (2005) eliminated three colonies within 16 wk, but Neoh et al. (2011) was not able to replicate these results. In fact, Lee et al. (2014) did not achieve complete elimination of any of the eight treated *M. gilvus* mounds using chlorfluazuron in their trial in Malaysia—they considered the four medium-sized mounds to be moribund at 16 wk but the four large mounds, at best weakening. The timeframe for elimination of *N. exitiosus* with bistrifluron baits was therefore largely consistent with other termitid species studied so far in southeast Asia using either bistrifluron or chlorfluazuron baits.

A number of factors have been suggested to account for the delayed action of benzoylphenylurea-based baits on termitid species. Cellulose digestion in rhinotermitids is achieved through the direct actions of their symbiotic intestinal protozoa, whereas termitids may have more complicated nutritional pathways (Eutick et al. 1978, Lee et al. 2014). This is particularly evident in the Macrotermitinae, involving fungal metabolism of cellulose materials, which may delay consumption of the toxin, and it has been suggested that toxicants may also be degraded in the fungal comb (Slaytor 1992, Neoh et al. 2011, Lee et al. 2014). However, for the wood-feeding Nasutitermitinae, lignocellulose is directly ingested, relying on symbiont bacteria in the hindgut for cellulose degradation (Brune 2014). Rhinotermitids may have higher levels of trophallaxis, which facilitates more rapid transfer of the active ingredient (Neoh et al. 2011), although trophallaxis is the key process for feeding dependent castes in all termites (Machida et al. 2001, Brune 2014). There may be a reduced frequency of, or absence of, molting in termitid workers (McMahan and Watson 1975, Neoh et al. 2011, Lee et al. 2012, Evans and Iqbal 2014). Bait may also be used for mound reinforcement rather than direct consumption (Peters and Broadbent 2005). Further, and more simply, bait may be removed but not consumed by termites for a variety of reasons including detection of the toxin or the presence of an alternate or higher value food source (Duncan 1997, Waller et al. 1999, Wallace and Judd 2010, Neoh et al. 2011). Gazal et al. (2012) demonstrated that weathered timber is preferred over intact timber by *Nasutitermes corniger* (Motshulsky), which might suggest that pure alpha-cellulose used in bait matrices may not, at least initially, provide the necessary chemical cues for attraction and consumption. Some species of termitids may also have a higher tolerance than rhinotermitids for the toxicant. For example, *N. exitiosus* appears more tolerant of higher doses of hexaflumuron and triflumuron than *Coptotermes acinaciformis* (Froggatt) (Lenz et al. 1996).

The amount of bait consumed (or removed from bait canisters) was consistent with previous studies for bistrifluron bait (Evans 2010, Neoh et al. 2011). For mound-building *C. acinaciformis* in northern Australia offered 400 g of bistrifluron bait, mean consumption was 23 g (range 17–33 g; Evans 2010), and for mound-building *G. sulphureus* in Malaysia offered 120 g of bait, mean consumption was 69 g (range 14–122 g; Neoh et al. 2011). In a recent study on mound-building *Coptotermes lacteus* (Froggatt) in southern Australia, mean bait removal was 105 g (range 7–239 g) when offered up to 240 g of bait and a mean of 147 g (range 50–305 g) when offered 480 g of bait, with all colonies eliminated (G.A.W., unpublished data). Colony elimination can be achieved with relatively small quantities of bistrifluron bait, yet large amounts of bait can be consumed. When offered to field colonies of *Coptotermes gestroi* (Wasmann) in Penang (Malaysia), colonies consumed up to 535 g of 0.5% bistrifluron bait and 834 g of 1% bistrifluron bait (Lee 2007), while in a recent study in Malaysia, *M. gilvus* in large mounds consumed up to a mean of 680 g of chlorfluazuron bait. In another recent study on *C. lacteus* in southern Australia, termites removed up to 480 g of bistrifluron bait, which was the total amount offered (G.A.W., unpublished data). It's not really clear why the amount of bait removed by colonies, whether higher or lower termite, varies so much, but it is likely the result of a wide variety of nonmutually exclusive factors including behavioral responses (e.g., rejection or partial rejection of bait, caching of bait or delayed consumption due to indirect food pathways, slow removal of bait when other high-value food resources are available, and preferential use of bait in construction) or physiological responses (e.g., enhanced tolerance and reduced, or absence of, molting). Evans (2010) and Neoh et al. (2011) suggest that the relatively small amount of bistrifluron 1% bait required to achieve colony elimination is likely the result of the enhanced feeding surface available in pellet form, resulting in greater access and direct contact than most other baits that are delivered as a solid slurry, and the higher bait concentration (1% compared with 0.5% and 0.1% for most other bait products).

Mean internal temperature ranges of treated and untreated mounds began to diverge ~11 wk after treatment. This also coincided with a steep fall in ambient temperature conditions over a week or so in late February. Whether this was causal in the final collapse of four of the five treated mounds is not possible to prove and may be just a coincidence. However, Watson and Abbey (1986) found that *N. exitiosus* colony death was signaled by a steep drop in internal core temperature. Termites were still active in the mound past the 11-wk time point—they were still present in all treated bait canisters at 16 wk and thereafter restricted to just one canister at 26 wk. Further, complete hole repair in all five mounds was still evident at 16 wk, declining rapidly to just one at 22 wk—the same colony where activity was still evident in the canister. Evans (2010) noted a loss of metabolic heat in bistrifluron-treated *C. acinaciformis* mounds as early as 3 wk after treatment and a diminished capacity to repair experimental damage to the mound wall at 4 wk after treatment. The delay from first indications of temperature variation to the decline in termite activity and mound repair capacity is not unexpected given that the worker and soldier castes can persist long after the colony ceases to be a viable reproductive unit (Lenz et al. 1996, Broadbent 2011).

Internal mound temperatures generally followed the pattern for the daily maxima, maintaining core temperature at ~30°C over the summer period (December 2011–February 2012). Core temperature over this period did respond to higher peaks and lower troughs in ambient and external mound temperature but did not adjust to these extremes. At the same time, external mound temperature as measured by the external probes, generally exceeded the peaks evident from the meteorological data during the spring to autumn period, and particularly in summer, but rarely fell below the ambient minimum. Colonies appeared to successfully moderate the internal temperature of the mound at least during the warmer period of the year. Malaka (1977) suggested that *Amitermes evuncifer* Silvestri mounds in Nigeria moderated high afternoon temperatures by retreating to lower strata in the mound and returning during the cooler periods when the termite metabolic heat maintained a higher temperature than outside. Such active temperature management combining metabolic heat and movement of termites in the mound (known as social homeostasis) has also been considered elsewhere (Holdaway and Gay 1948, Emerson 1956, Greaves 1964, Watson and Abbey 1986).

Temperature profiles of individual mounds were not consistent for either the untreated or treated group. For instance, one untreated mound maintained a very low (relative to the other four) internal temperature, even though the colony remained active. Over the period of the trial, one treated mound maintained relatively high internal temperature (relative to other treated mounds) right through to final excavation at 47 wk. This could be explained by differences in orientation and exposure to direct sunlight of the temperature probe (as Watson and Abbey 1986 noted), differing substrate conditions or just natural variation in core temperature between colonies. However, the mound was not remarkable in any particular way that would explain the difference in temperature profile. Such variation in the core temperature of untreated *N. exitiosus* mounds is known (Watson and Abbey 1986) with some mounds fluctuating with seasonal ambient temperature and others maintaining consistent high core temperature (>30°C) throughout the year. The latter is also consistent with tree nesting *C. acinaciformis* and *Coptotermes frenchi* Hill (Greaves 1964), which are insulated within the tree structure. Untreated mounds maintained a narrow range of daily variation across the period of the study (generally 1–2°C), which is consistent with Watson and Abbey (1986) (1–3°C). During summer, untreated mounds also maintained an internal core temperature of 28–33°C, which is also consistent with Watson and Abbey (1986) (32–34°C). During winter, the low mean core maximum temperature of ~14.5°C was similar to that for *N. exitiosus* around Canberra (200 km north of Wagga; 10–15°C; Watson and Abbey 1986). Both locations have similar elevation and winter weather conditions.

The low internal temperature ranges seen in this study for untreated mounds during the winter period indicates that colonies are incapable of maintaining a preferred temperature range when ambient temperatures are so low, and may survive cold winters by behavioral modification—retreating to lower strata in the mound, movement of the nursery to areas of the outer mantle receiving radiant heat or even outside the mound into surrounding soil (Holdaway and Gay 1948, Watson and Abbey 1986). Watson and Abbey (1986) noted a decline in mound size, moving from larger mounds in coastal areas with above ground nurseries to smaller nests further west and even subterranean nests in more arid regions, reflecting decreasing winter temperature moving away from the coast. Thermoregulatory capacity in the mound presumably declines as mound size decreases with nurseries descending to warmer lower strata as ambient temperature declines.

This study demonstrated the efficacy of 1% bistrifluron bait against *N. exitiosus* under typical conditions in southeastern Australia, achieving colony elimination with as little as 7 g and up to 59 g of bait. Treated mounds removed on average 39% of bait offered and untreated mounds, 97% of all blank bait offered. Early signs of colony distress in treated colonies were evident at 11 wk (mound temperature decline), and visible mound activity began to decline from 22 wk onward. Mound core temperatures tended to respond directly with ambient temperature through the year, but there were a few aberrant mounds that did not follow the expected pattern, with one treated mound maintaining higher than expected internal temperature through to final excavation and one untreated mound with core temperature consistently below 20°C.

References Cited

Broadbent, S. 2011. A stand-alone termite management technology in Australia, pp. 145–155. *In*. P. Dhang (ed.), Urban pest management: An environmental perspective. CABI, Oxfordshire, United Kingdom.

Brune, A. 2014. Symbiotic digestion of lignocellulose in termite guts. Nat. Rev. Microbiol. 12: 168–180.

Dhang, P. 2011. A preliminary study on elimination of colonies of the mound building termite *Macrotermes gilvus* (Hagen) using a chlorfluazuron termite bait in the Philippines. Insects 2: 486–490.

Duncan, F. D. 1997. Behavioural responses to poison baits by the termite *Hodotermes mossambicus* (Hagen). Int. J. Trop. Sci. 17: 221–225

Emerson, A. E. 1956. Regenerate behaviour and social homeostatis of termites. Ecology 37: 248–258.

Eutick, M. L., P. Veivers, R. W. O'Brien, and M. Slaytor. 1978. Dependence of the higher termite, *Nasutitermes exitiosus* and the lower termite, *Coptotermes lacteus* on their gut flora. J. Insect. Physiol. 24: 363–368.

Evans, T. A. 2010. Rapid elimination of field colonies of subterranean termites (Isoptera: Rhinotermitidae) using Bistrifluron solid bait pellets. J. Econ. Entomol. 103: 423–432.

Evans, T. A., and N. Iqbal. 2014. Termite baiting 20 years after commercial release. Pest Manage. Sci. 71: 897–906.

Evans, T. A., M. Lenz, and P. V. Gleeson. 1998. Testing assumptions of mark-recapture protocols for estimating population size of Australian mound-building, subterranean termites. Ecol. Entomol. 23: 139–159.

Gazal, V., O. Bailez, A. M. Viana-Bailez, E. L. Aguiar-Menezes, and E. B. Menezes. 2012. Decayed wood affecting the attraction of the pest arboretum termite *Nasutitermes corniger* (Isoptera: Termitidae) to resource foods. Sociobiology 59: 287–295.

Gazal, V., O. Bailez, A. M. Viana-Bailez, E. L. Aguiar-Menezes, and E. B. Menezes. 2014. Behavioural responses of the arboreal termite *Nasutitermes corniger* (Isoptera: Termitidae) to wood extracts. Wood Sci. Technol. 48: 581–590.

Greaves, T. 1964. Temperature studies of termite colonies in living trees. Aust. J. Zool. 12: 250–262.

Holdaway, F. G., and F. J. Gay. 1948. Temperature studies of the habitat of *Eutermes exitiosus* with special reference to the temperatures within the mound. Aust. J. Sci. Res. 1: 464–493.

Kubota, S. 2011. Colony elimination of subterranean termites by bait application using benzoylphenylurea compounds, with special reference to bistrifluron, *In*. M. Stoytcheva (ed.), Pesticides in the modern world - risks and benefits, InTech, Rijeka, Croatia.

Kubota, S., Y. Shono, T. Matsunaga, and K. Tsunoda. 2006. Laboratory evaluation of bistrifluron, a benzylphenylurea compound, as a bait toxicant against *Coptotermes formosanus* (Isoptera: Rhinotermitidae). J. Econ. Entomol. 99: 1363–1368.

Kubota, S., Y. Shono, T. Matsunaga, and K. Tsunoda. 2007. Termicidal efficacy of bistrifluron as a bait toxicant against the Japanese subterranean termites *Coptotermes formosanus* and *Reticulitermes speratus* (Isoptera: Rhinotermitidae). Sociobiology 50: 623–631.

Kubota, S., Y. Shono, N. Mito, and K. Tsunoda. 2008. Lethal dose and horizontal transfer of Bistrifluron, a benzoylphenylurea, in workers of the Formosan subterranean termite (Isoptera: Rhinotermitidae). J. Pestic. Sci. 33: 243–248.

Lee, C. Y. 2007. Evaluation of bistrifluron as an above-ground bait against the Asian subterranean termite, *Coptotermes gestroi* (Wasmann) in Malaysia, pp. 8–11. *In* K. Tsunoda (ed.), Proceedings of the Fourth Conference of the Pacific-Rim Termite Research Group. Kyoto University, Japan.

Lee, C. Y., C. Vongkaluang, and M. Lenz. 2007. Challenges to termite management of multi-genera faunas in southeast Asia and Australia. Sociobiology 50: 213–221.

Lee, C. C., K. B. Neoh, and C. Y. Lee. 2012. Caste composition and mound size of the subterranean termite *Macrotermes gilvus* (Isoptera: Termitidae: Macrotermitinae). Ann. Entomol. Soc. Am. 105: 427–433.

Lee, C. C., K. B. Neoh, and C. Y. Lee. 2014. Colony size affects the efficacy of bait containing chlorfluazuron against the fungus-growing termite *Macrotermes gilvus* (Blattodea: Termitidae). J. Econ. Entomol. 107: 2154–2162.

Lenz, M., P. V. Gleeson, L. R. Miller, and H. M. Abbey. 1996. How predictive are laboratory experiements for assessing the effects of chitin synthesis inhibitors (CSI) on field colonies of termites?–a comparison of laboratory and field data from Australian mound-building species of termites. IRG/WP 96-10143., International Research Group on Wood Preservation Meeting, 19–24 May 1996, Guadeloupe, France.

Machida, M., O. Kitade, T. Miura, and T. Matsumoto. 2001. Nitrogen recycling through proctodeal trophallaxis in the Japanese damp-wood termite *Hodotermes japonica* (Isoptera, Termopsidae). Insectes Soc. 48: 52–56.

Malaka, S. L. O. 1977. Temperature studies of the mounds and environment of *Amitermes evuncifer* Silvestri (Isoptera: Termitidae). Aust. J. Zool. 25: 711–719.

McMahan, E. A., and J. A. L. Watson. 1975. Non-reproductive castes and their development in *Nasutitermes exitiosus* (Hill) (Isoptera). Insect. Soc. 22: 183–198.

Neoh, K. B., N. A. Jaludin, and C. Y. Lee. 2011. Elimination of field colonies of a mound-building termite *Globitermes sulphureus* (Isoptera: Termitidae) by Bistrifluron Bait. J. Econ. Entomol. 104: 607–613.

Ngee, P. S., T. Yoshimura, and C. Y. Lee. 2004. Foraging populations and control strategies of subterranean termites in the urban environment, with special reference to baiting. Jpn. J. Environ. Entomol. Zool. 15: 197–215.

Peters, B. C., and S. Broadbent. 2005. Evaluating a termite interception and baiting system in Australia, Thailand and the Philippines, pp. 229–232. *In*. C. Y. Lee and W. H. Robinson (eds.), Proceedings of the Fifth International Conference on Urban Pests, Singapore. Perniagaan Ph'ng Press, Malaysia.

Slaytor, M. 1992. Cellulose digestion in termites and cockroaches: What role do symbionts play?. Comp. Biochem. Physiol. 103B: 775–784.

Wallace, B. A., and T. M. Judd. 2010. A test of seasonal responses to sugars in four populations of the termite *Reticulitermes flavipes*. J. Econ. Entomol. 103: 2126–2131.

Waller, D. A., S. E. Morlino, and N. Matkins. 1999. Factors affecting termite recruitment to baits in laboratory and field studies, pp. 597–600. *In.* W. H. Robinson, F. Rettich, and G. W. Rambo (eds.), Proceedings of the Third International Conference on Urban Pests, Prague, Graficke zavody Hronov., Czech Republic.

Watson, J. A. L., and H. M. Abbey. 1986. Seasonal cycles in *Nasutitermes exitiosus* (Hill) (Isoptera: Termitidae) II. Nest temperature. Sociobiology 11: 255–273.

Received 20 May 2015; accepted 14 July 2015.