Baiting Studies and Considerations with *Coptotermes formosanus* (Isoptera: Rhinotermitidae) in Hawaii

by

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ABSTRACT

This paper summarizes preliminary results of three field studies of the efficacy of a prototype commercial baiting system using the chitin inhibitor hexaflumuron against the Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae). Using mark-release-recapture methods, termite foraging populations at these three sites were estimated at 0.33 million, 0.94 million, and 5.35 million. Following application of hexaflumuron baits, no termite activity has been detected at these locations for 24, 10, and 20 months, respectively. At these sites, the amount of bait consumed had a logarithmic relationship to the size of the estimated populations, although in each case there was a great deal of variation among the individual population estimates used to calculate the weighted-mean population estimate. We argue that monitoring of termite activity at unbaited foraging sites is essential in order to document bait efficacy without the confounding factors of bait deterrence and/or localized termite mortality at the site of bait application. We conclude that suppression or removal of the termite population to a level where termite activity can no longer be detected in unbaited monitoring stations, in the structure to be protected, or elsewhere in the immediate vicinity of the structure is the only practical goal of bait applications.

INTRODUCTION

Baits are an attractive method of control for cryptic social insect pests, since they require application of only a small amount of insecticide and, ideally, contact with a relatively small proportion of the foraging population, who then proceed to distribute the toxicant to other colony members. In this paper, we summarize recent field studies in Hawaii to determine the efficacy against the Formosan subterranean

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termite, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae), of a baiting system using the chitin inhibitor hexaflumuron. Based upon results of these and other studies, we also discuss the criteria necessary to demonstrate bait efficacy and issues in applying these criteria to termite field studies.

PRELIMINARY SUMMARY OF SENTRICON™ FIELD STUDIES

The Sentricon™ *Colony Elimination System* is a baiting system for subterranean termite control manufactured and distributed by DowElanco (Indianapolis, IN) and introduced commercially in spring 1995. The Sentricon System uses a plastic cylinder, ca. 24cm in length by 4.5cm diameter, with side ports to permit termite entry (Su *et al.* 1995a). The plastic cylinder is placed in an augured hole in the soil, has a tamper-resistant cap, and contains two small pieces of wood as removable monitoring devices. Monitoring stations are placed in the ground around the building (at maximum 15-20 foot intervals), and elsewhere on the property where subterranean termites might be expected to occur.

When termites are found in a monitoring station, the wood in the station is replaced with a plastic Baitube™ device (a plastic cylinder with small holes in the sides) containing either wood flour or a laminated textured cellulose impregnated with the chitin inhibitor hexaflumuron (Recruit™). The studies described here utilized Baitubes containing approximately 35g of wood flour matrix impregnated with 0.1% (wt/wt) hexaflumuron.

From a scientific point of view, we believe that it is difficult, and perhaps even impossible, to directly demonstrate "colony elimination" in the field with a cryptic subterranean termite species. However, Lenz *et al.* (1996) provided evidence for elimination of colonies of more easily observed mound-building termites with hexaflumuron; and Su (1994) and Su & Scheffrahn (1996b) firmly proposed elimination as the most parsimonious explanation for the complete absence of detectable termite activity at their field sites in Florida following hexaflumuron applications.

In fall 1993, we began field studies with a prototype Sentricon System around three representative structures in Hawaii, each of which had a history of subterranean termite infestation and recurring problems: a four-unit condominium building on the island of Kauai (Kauai in Table 1), a single-family home on the island of Oahu (Manoa in Table 1), and a large commercial building on Oahu (Airport in Table 1). All of these buildings had concrete slab foundations, and had previously been treated around the exterior perimeter and through the

Table 1. Lincoln index estimates of *C. formosanus* colony foraging populations from the 1st, 2nd, and 3rd mark-release-recapture (MRR) cycles, and the weighted mean derived from all three cycles at five field sites in Hawaii. The Manoa, Airport, USDA, and MCBH sites are located on the island of Oahu. An "infinite" estimate indicates that no dye-marked termites were recovered, and was not included in calculation of the weighted mean.

	Population Estimate (Millions)			
Site	1st	2nd	3rd	Weighted Mean
Manoa	5.9	0.7	Infinite	0.9
Kauai	0.8	0.6	0.2	0.3
Airport	5.9	1.6	8.2	5.4
USDA	9.2	1.1	2.4	2.2
MCBH	9.8	5.1	10.8	9.8

slab at various locations inside with soil insecticides. Basaltic Termite Barrier (Ameron HC&D, Honolulu) gravel had also been installed in a trench around the condominium building. However, construction defects such as stucco extending into the ground, concrete and asphalt walkways abutting the buildings, and (in the case of the residential structure) rocky hillside soil conditions had contributed to continuing termite problems.

At each location, we placed Sentricon stations at least 30cm away from the building foundation, at intervals of 4-5m. We also placed additional stations near trees and fences. At the commercial building, we placed several stations on the opposite side of a parking lot, at least 20m from the building, where termites were active in scrap lumber. In total, we placed 25 stations around the condominium, 27 around the single-family house, and 45 around the commercial building. One month after installation of the stations, termites were found in 8-27% of the stations at each location.

As described by Grace *et al.* (1995), we estimated the size of the termite populations and mapped their foraging territories at each site using a triple mark-release-recapture method (Su & Scheffrahn 1988) in which captured termites were stained with 1% (wt/wt) Sudan Red 7B for 10d and then released back into the field collection trap (Grace *et al.* 1995). After three mark-release-recapture cycles, a weighted mean model (Begon 1979, Su 1994) was used to estimate the colony foraging population and associated standard error. After an estimate was obtained, we replaced the wooden monitoring devices in 4-5 active monitoring stations at each site with the Baitube device containing the hexaflumuron bait. After installing the Baitubes, the stations were inspected at 10-day intervals, and a Baitube replaced when about half

of the bait had been eaten.

At the condominium building there was an estimated foraging population of 0.33 million (SEM = 0.04 million) *C. formosanus* workers (Table 1). We used a total of 9 Baitubes (placed and replaced in 4 of the 25 Sentricon stations), with the termites actually consuming the equivalent of 3.25 tubes. In September 1994, twelve weeks after initiation of baiting, no termites were found in any of the monitoring stations at this site. All of the Baitubes were then replaced with wooden monitoring devices, and we continued to monitor the site monthly for one year and quarterly thereafter. To date, no evidence of termite activity has been found for 24 months.

The commercial building had a very large estimated foraging population of 5.35 million (SEM = 0.87 million), extending over a large area, which extended from the front of the building to the rear of the parking lot behind the building (ca. 20 m from the rear wall of the building). We placed and replaced a total of 17 Baitubes in 5 of the 45 Sentricon stations, and the termites consumed the equivalent of 9.4 Baitubes. Termites were no longer found 15 weeks after initiation of baiting. We have continued to monitor the site and no evidence of termite activity has now been found for 20 months.

The single-family home had an estimated termite worker population of 0.94 million (SEM = 0.13 million) (Table 1). We placed and replaced a total of 12 Baitubes in 4 of the 27 Sentricon stations at this property. The termites consumed the equivalent of 6.5 Baitubes, and no termite activity was noted after 6 weeks. As with our other sites, we continued regular monitoring. Eight months after cessation of baiting, termites were found in 4 of the monitoring stations. All 4 stations were adjacent to each other along one side of the property, and adjacent to an adjoining property which had also experienced severe termite problems in the past. Immediately prior to our discovery of termite activity in these stations, the owner of the adjoining property had begun remodeling work on his residence, including removal of wood and excavation around the structure. Thus, it is likely that the disturbance of the area had stimulated termites to forage away from the structure, and that the termites we detected represented a new invasion from the adjacent property. We placed Baitubes of the hexaflumuron bait in 2 of the 4 active monitoring stations in May 1995, and termites continued to be found in one to three of these stations through October 1995 and showed symptoms of hexaflumuron toxicity (Su & Scheffrahn 1993). No termite activity has been detected at any location on the property, however, since November 1995 (10 months).

At the three locations described here, a logarithmic regression of the

form y = 6.02 + 2.15 (ln x), r^2 = 0.97, provided the best description of the relationship of the amount of bait consumed to the estimated colony foraging population. Termite bait consumption is expressed in Fig. 1 as the equivalent number of Baitubes consumed, with each Baitube containing ca. 35 g of the Recruit bait (wood flour with 0.1 %

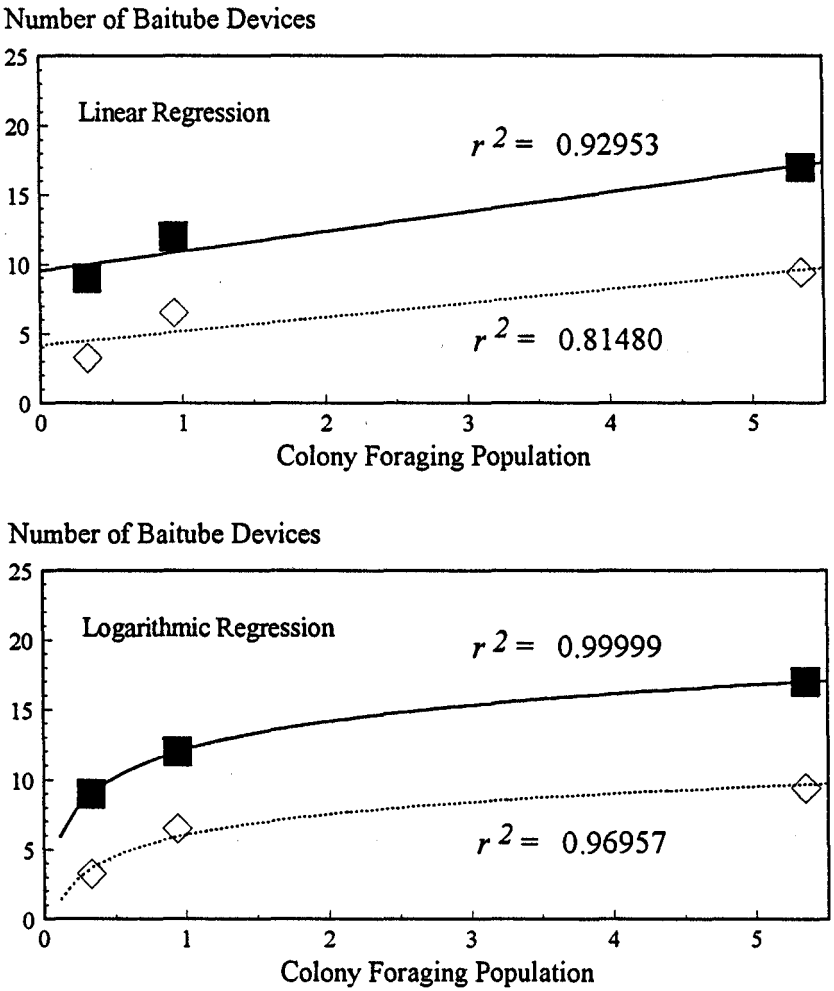

Fig. 1. Linear regression (top) and logarithmic regression (bottom) of actual hexaflumuron bait consumption by termites (dotted line) and the number of containers of bait ("Baitube devices") placed in the field (solid line) as a function of the estimated *C. formosanus* colony foraging population at three field sites in Hawaii. Each Baitube contained ca. 35 g of wood flour impregnated with 0.1% (wt/wt) hexaflumuron, and a Baitube was replaced when approximately half the bait was consumed. A logarithmic regression (bottom) provides the best fit to these data.

hexaflumuron). Since Baitubes with greater than about 50% consumption were routinely replaced during inspections of the stations, the number of Baitubes utilized at each site was approximately twice the actual consumption by the termites (Fig. 1). At these three locations, the amount of time needed to have an impact on the termite population was also clearly related to the size of the foraging population. However, we hesitate to place too much emphasis on relationships derived from three field experiments, since Su *et al.* (1995b) and Su & Scheffrahn (1996b) have pointed out, from their studies, the lack of a clear relationship between bait consumption and the onset of toxic symptoms with hexaflumuron; and Lenz *et al.* (1996) demonstrated that the age and physiological state of the termite colony, which affect molting, can have great impact on the appearance of symptoms from hexaflumuron exposure.

CONSIDERATIONS IN EVALUATING TERMITE BAIT EFFICACY

Termite researchers are certainly aware of the limitations of mark-release-recapture (MRR) methodology, and the likely violations of the underlying statistical assumptions when applied to population estimation of social insect colonies (Southwood 1978, Grace 1992). However, at present this is the best method available for censusing subterranean termite colonies and following the movement of foragers among foraging sites (Grace 1992, Jones 1988). Lincoln index population estimation based upon a single MRR event provides a rough estimate (Lai 1977, Esenther 1980), but the mean (Grace *et al.* 1989, Grace 1990) or weighted mean (Begon 1979, Su & Scheffrahn 1988, Su 1994) calculated from several MRR cycles is thought to provide a greater degree of confidence in the estimate. However, in practice one frequently observes extreme variation among the individual population estimates obtained in a triple MRR procedure, with the weighted mean amounting essentially to an average of the two most similar estimates of the three obtained (Table 1). Thus, although a better method is currently lacking, the word *estimate* needs to be strongly emphasized in MRR studies with subterranean termites.

In the field studies summarized here, the quantity of bait consumed and (roughly) the length of time required until colony decline proved to be associated with the population estimates obtained by MRR. However, since the termite population at each site was in fact reduced to a level below the limits of detection, population estimation was not really required to demonstrate efficacy. Connection of foraging sites (i.e., monitoring stations) via collection of dye-marked workers, though, provided valuable information that would have been of use in explain-

ing continued termite activity in some stations following hexaflumuron delivery in others. Basically, in an efficacy study we consider it advisable to know as much as possible about the termite population (including the possible presence of more than one colony) at a given location prior to initiating bait delivery, but we recognize that all of the information collected may not be required to explain the results.

We concur with Su & Scheffrahn (1996a) that methodical monitoring of termite foraging activity at sites removed from the immediate site of bait application is the most important requirement for establishing bait efficacy. In all of our field studies, we used MRR to determine connections among foraging sites, and reserved several of these active sites as unbaited "windows" into the colony's network of foraging galleries. The presence of several unbaited sites was considered essential, since termite foraging activity naturally fluctuates and foragers may abandon sites for reasons unrelated to any effects from bait application. For example, prior to bait application at the single-family residence (Manoa), the proportion of monitoring stations with termite activity continuing over two sequential inspections fluctuated between 57% and 100%.

Following bait application, (1) decline in evidence of termite feeding in unbaited foraging sites, (2) decline in termite numbers in the unbaited sites, and (3) overall decline in the number of active unbaited sites at each field location were considered the most reliable measures of bait efficacy. Certainly, a requirement for multiple unbaited feeding sites to monitor bait efficacy limits the number of viable study locations available for such research, and is more difficult for researchers to implement in regions where subterranean termite infestations may more typically consist of small colonies. However, although information obtained through less carefully structured bait applications and Experimental Use Permit (EUP) applications is also of value (particularly in refining application methods and equipment), we do not consider such essentially anecdotal information to be sufficient to demonstrate bait efficacy. Demonstration of efficacy should require demonstration of persistent effects on termite numbers and feeding (damage) at a visible and accessible location other than the immediate site of bait application. When categorical data, such as the scale of "low, high, excellent, complete control" used by Felix & Henderson (1995), are used to express bait efficacy results, we encourage researchers to clearly define the terminology.

The ultimate goal of baiting systems in subterranean termite control is structural protection by population reduction. Although "colony elimination" may be difficult or even impossible to demonstrate (except

by inference) with *C. formosanus*, one must consider what degree of population reduction is really necessary to prevent termite damage. A 90% reduction in a colony of 5 million termites is certainly a significant population reduction, but still leaves 500,000 termites threatening the structure. Is there any value in reducing termite numbers if other control methods, such as soil treatment, must still be used to prevent damage to the structure? Reasonably, the goal of baiting must be to eliminate or completely remove the termite population from the vicinity of the structure. Our studies demonstrate such a result from a few months of hexaflumuron application. Su *et al.* (1995b) and Su & Scheffrahn (1996b) demonstrated that termite colony populations can recover from the effects of a similar single period of application of other candidate bait toxicants (A-9248 and sulfluramid), and suggested that "learned avoidance" may be a problem with longer periods of application. On the other hand, although no data were provided, Thorne & Traniello (1994) described continued suppression of termite populations over several years by continuous baiting with hydramethylnon; and another report (Anonymous 1995) has described a situation in which no further evidence of termite activity was found in or around a structure after three years of baiting with hydramethylnon. Quantitative field studies are now needed to document the effects of such repeated or long-term bait exposures on termite foraging behavior and colony demographics.

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