SUMMARY

Heterotermes aureus (Snyder) is the primary subterranean termite pest in the Sonoran Desert region of the U.S. and adjacent portions of Mexico. The Sentricon* *Termite Colony Elimination System* eliminated an infestation of *H. aureus* at the San Xavier del Bac Mission within 6 months of termite bait introduction. A similar study completed at a Tucson residence showed colony elimination within 16 months. Other studies involving monitoring devices indicated that termites prefer monitoring devices made of MD499 over southern yellow pine.

CONTROL OF STRUCTURAL INFESTATIONS OF HETEROTERMES AUREUS IN ARIZONA WITH THE SENTRICON SYSTEM

By T.H. Atkinson,[1] M.S. Smith,[2] and R.E. Williams[3]

INTRODUCTION

Heterotermes aureus (Snyder) is the principal subterranean termite and structural pest in the Sonoran Desert region of the United States and adjacent portions of Mexico (20) (Figure 1). It is the only species of this circumtropical genus that is naturally found within the United States, although there are economically important species in the Caribbean, Latin America, Africa, the Middle East, and Australia (26,27). Recently a Neotropical species of this genus has been introduced and become established in southern Florida (25).

Heterotermes is closely related taxonomically to *Reticulitermes*, and to a certain extent, *Heterotermes* species are ecological replacements for those of *Reticulitermes* in tropical and especially warm arid regions. Haverty and Nutting (15) demonstrated this for *H. aureus* and *R. tibialis* Banks within Arizona, showing that *H. aureus* is found at lower elevations with lower rainfall and higher average temperatures while *R. tibialis* is characteristic of higher elevations with higher rainfall and lower average temperatures. *H. aureus* is predominant in areas of natural vegetation, and it is also quite abundant in heavily urbanized areas within its range (5).

In many regards, the overall ecology of *Heterotermes aureus* is similar to that of other Rhinotermitidae in the U.S. Estimates of foraging populations (17) and foraging territories (18) are comparable to those reported for species of *Reticulitermes* in other areas of North America (11,12,14,32). On the other hand, *H. aureus* is well adapted to a desert region with low rainfall and high temperatures. Foraging activity continues at air temperatures up to 33°C (4,16), and workers of *H.*

FIGURE 1. Heterotermes aureus *is the only* Heterotermes *species native to the U.S. It is distributed throughout the Sonoran Desert region of the U.S. and adjacent portions of Mexico.*

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[1] Senior Research Biologist, Dow AgroSciences LLC, Coppell, Texas.

[2] Technology Transfer Leader, Dow AgroSciences LLC, Indianapolis, Indiana.

[3] Senior Scientist, Dow AgroSciences LLC, Moorpark, California.

aureus lose water through the cuticle more slowly than species of *Reticulitermes* (3).

Protecting structures from *Heterotermes aureus* infestations is usually attempted by applying liquid termiticides to soil. These termiticides act as a barrier to the termites tunneling from their subterranean nests into a building. However, the introduction of the Sentricon* *Termite Colony Elimination System* in 1995 made baiting for subterranean termites commercially viable (Figure 2). Baiting for termites to a location containing insecticide offers the advantage of eliminating specific termite colonies with a minimum amount of active ingredient. The commercial launch of the Sentricon System came after many years of extensive developmental research (2,6,10,13,22,28,29,31,34) and the EPA registration of hexaflumuron, the active ingredient in Recruit* II termite bait (24). Hexaflumuron is a chitin synthesis inhibitor that kills termites by inhibiting their molting process (24).

The Sentricon System involves placing monitoring stations in soil areas around the perimeter of a building. A pest control professional then monitors the stations for subterranean termites and places Recruit II termite bait in the station when active termite feeding is detected. In 1997, Dow AgroSciences enhanced the Sentricon System with the commercial launch of an above-ground baiting component to the system: the Recruit* AG station. This station is specially designed for above-ground locations, and it uses a cellulosic bait containing 0.5% hexaflumuron.

This article discusses a study that began as a cooperative research project concerning application of the Sentricon System to colonies of the Sonoran Desert subterranean termite, *Heterotermes aureus*. Two infested structures were chosen for this project, and prototype monitoring stations were installed around both structures in 1993 as part of a basic research project. In 1995, the project was revised to a commercial demonstration of the efficacy of the Sentricon System in Arizona. There were three objectives:

- Determine if colonies of *Heterotermes aureus* can be eliminated with hexaflumuron in the Sentricon System.
- Determine if the addition of corrugated cardboard, grooving of monitoring devices, or addition of water to stations affect the likelihood of termite activity within monitoring stations.
- Determine if foragers of *H. aureus* pre-

FIGURE 2. *Components of the Sentricon System.*

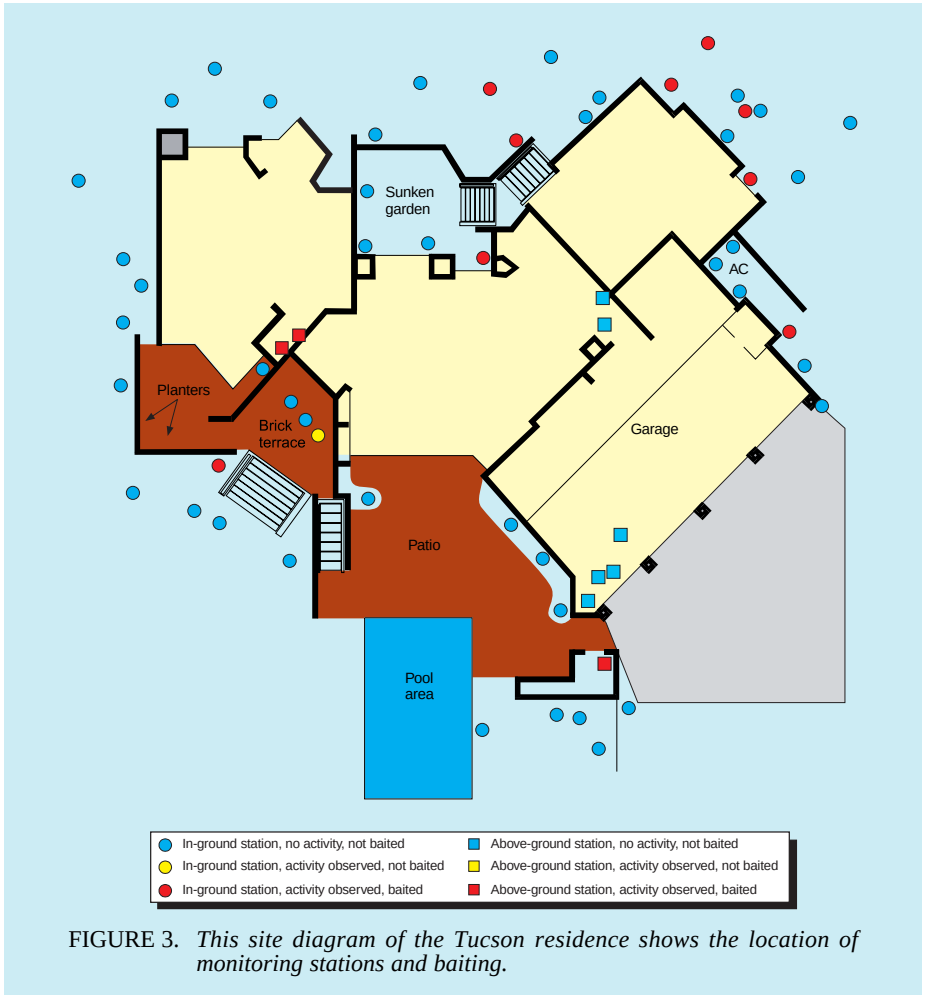

FIGURE 3. *This site diagram of the Tucson residence shows the location of monitoring stations and baiting.*

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fer monitoring devices made of MD499[1] over southern yellow pine.

MATERIALS AND METHODS

Structural Protection Sites

Ventana Canyon Residence

This relatively new residence (5,000 ft^2) was built in the foothill area to the north of Tucson on a sloping lot in 1987. Minimal changes were made to the existing vegetation away from the actual construction site. The house has a complicated floor plan and multiple foundation levels (Figure 3). Since 1991 there have been ongoing termite problems despite numerous treatments with conventional termiticides in the past. The fact that detectable termite infestation began when the structure was only 4 years old strongly suggests that the house was built "on top of" one or more pre-existing, well-established colonies.

Pre-commercial prototypes of Sentricon monitoring stations were installed in May 1993. Limited studies on agonistic encounters (methods described in ref. 19) between groups of termites collected in different areas in and around the house suggested the presence of two or more distinct colonies. In early 1995 the decision was made to convert this installation from a research site to a commercial demonstration site. Additional in-ground Sentricon monitoring stations were installed around the periphery of the structure, and components of existing stations were upgraded to the then current commercial standards.

In late 1995 Recruit II termite bait became available and was installed in in-ground stations with termite activity. At the same time the initial prototype of Recruit AG above-ground stations became available on an experimental basis and were installed inside the structure at sites of termite activity. In the fall of 1996 monitoring devices in all in-ground stations were changed from southern yellow pine to MD499. The locations of all stations as of early 1995 are shown in Figure 3. Baited stations are indicated only from 1995 onwards.

[1] MD499 is a Dow AgroSciences reference number for a species of wood that has been documented to be preferred by termites.

FIGURE 4. *Several sections of the historical San Xavier del Bac Mission were found to be infested with* Heterotermes aureus. *The termite colony was eliminated at the site 6 months after termite bait introduction.*

San Xavier del Bac Mission

The adobe mission complex is located south of Tucson, Arizona, and was originally built beginning in 1783 (Figure 4). Different parts of the current structure were added later. Adobe construction is virtually impossible to treat with conventional termiticide strategies because of the difficulty of establishing continuous barriers. This is primarily because the adobes (bricks) are made from the surrounding soil and mortared with more of the same. To increase the strength of the adobes, straw is added during mixing. The resulting wall has built-in flaws, some of which are edible plant parts that the termites may easily exploit. Typically, older structures such as the mission complex do not have a

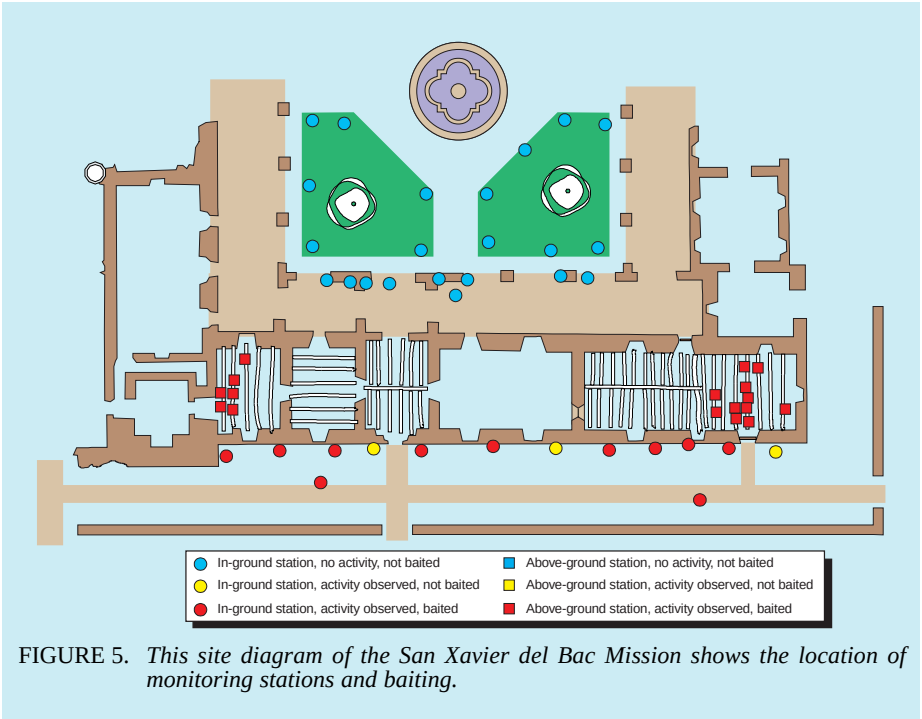

FIGURE 5. *This site diagram of the San Xavier del Bac Mission shows the location of monitoring stations and baiting.*

continuous foundation, but rather are built directly on the existing soil. Inside floors are usually pavers or bricks dry-set on sand.

An area along the right front, including the priests' chapel, artisan work rooms, and museum, was infested with the Sonoran Desert subterranean termite, *Heterotermes aureus* (Figure 5). Termite feeding and activity were visible in door and window frames and in beams in the ceilings of several rooms in this area. The main sanctuary (to the left) and the gift shop (around corner to right) have never shown any signs of infestation.

Pre-commercial prototypes of Sentricon monitoring stations were installed in early 1994 around the infested area and internal courtyard. Limited studies on agonistic encounters (methods described in ref. 19) between groups of termites collected in different areas in and around the structure did not indicate multiple colonies.

In early 1995 the decision was made to convert this installation from a research site to a commercial demonstration site. At that time additional in-ground Sentricon monitoring stations were installed around the periphery of the structure, and components of existing stations were upgraded to the then current commercial standards. Because of the disturbance caused by the large numbers of tourists visiting the mission, the original in-ground stations had been covered with round pavers, which also had the effect of maintaining higher moisture within the stations.

In late 1995 Recruit II termite bait became available and was installed in in-ground stations with termite activity. At the same time the initial prototype Recruit AG above-ground stations became available on an experimental basis and were installed inside the structure at sites of termite activity. In early 1997 monitoring devices in all in-ground stations were changed from southern yellow pine to MD499. The locations of all stations as of early 1995 are shown in Figure 5. Baited stations are indicated only from 1995 onwards.

Monitoring Device Tests

1995 Tucson Test

The study was set up at the long-term Santa Rita Range experimental site near Tucson with a previously established rectangular grid (20-ft centers) of toilet paper rolls for monitoring termite activity. On May 16, 1995, five Sentricon monitoring stations were installed in a circle around 12 grid points (existing stations) with activity of *Heterotermes aureus*. New stations were approximately 18 inches from their nearest neighbors and from the hub. Stations were left empty, without monitoring devices, until August 2, 1995, when several different monitoring device alternatives were installed.

Standard Sentricon in-ground stations were used for all alternatives. The five alternatives included:

- Two standard southern yellow pine (SYP) monitoring devices
- Two SYP monitoring devices with three longitudinal grooves on both wide surfaces (to a depth of about 1 mm)
- Two SYP devices and 1 qt water added to the station at the time of installation
- Cardboard cylinders made by tightly wrapping a monitoring device lifter (current type) with a 7-inch-wide strip of single-sided corrugated cardboard and taped with clear plastic tape
- One SYP device wrapped once longitudinally with a narrow "ribbon" of single-sided corrugated cardboard

The cardboard-wrapped SYP devices were installed with an earlier version of the station lifters, which had two arms on the outside of the monitoring devices rather than a single central arm that fits between the monitoring devices (current design). All other treatments used center lifting devices (current type). Prior to field installation, all monitoring devices were oven-dried for 48 h at 50°C. Cardboard-wrapped monitoring devices were weighed as a single unit, without separately accounting for the weight of the wood and cardboard. Cardboard cylinders were weighed with the monitoring device lifter included.

Stations were checked for activity on September 26, 1995. After checking in the field, monitoring devices were returned to the lab, oven-dried, and reweighed (except for cardboard cylinders). At the time that stations were checked, damage (feeding) to monitoring devices was rated using a subjective scale (hit rating) of 0 (no damage) to 5 (considerable damage). The number of live termites was also rated using a subjective scale (termite rating) of 0 (no termites) to 4 (numerous termites).

Binary measurements (either a station was hit or it was not hit) were analyzed using binary logistic regression. Weight loss of monitoring devices was analyzed using classical ANOVA methods appropriate for continuous variables. Discrete measurements (hit ratings, termite ratings) were analyzed using classical linear models, which assume continuous, homogenous responses. Bartlett's and Levene's homogeneity of variance tests were run to ensure satisfaction of this assumption, but the discrete, non-normal nature of the responses was ignored. As a result, p-values resulting from the ANOVA are more of an approximation than if the responses had actually been normally distributed continuous values. All statistical analyses were performed with MINITAB software, release 12, 1997.

MD499 vs. Southern Yellow Pine

The study was set up at a long-term study site with a previously established rectangular grid (20-ft centers) of Sentricon stations in Scottsdale, Arizona. Stations were inspected on January 20, 1997, for current termite activity. Appreciable feeding activity and live termites were noted at four stations. Six new stations were installed in a circle around each active station. New stations were approximately 18 inches from their nearest neighbors and from the hub. Three stations had MD499 monitoring devices; three stations had southern yellow pine monitoring devices. Devices were randomly assigned. Stations were checked for activity on February 22 and again on March 18. Before installation, the monitoring devices were oven-dried at 50°C and weighed. After March 18, they were removed from the stations, oven-dried again, and reweighed.

Binary measurements were analyzed using binary logistic regression. Weight loss of monitoring devices was analyzed

TABLE 1. History of the Sentricon System at the Ventana Canyon residence.

Activity	1995				1996								1997		
	2/15	3/23	7/12	9/28	2/13	3/27	5/13	6/12	7/29	8/29	9/20	10/8	1/22	3/19	4/9
In-ground stations															
Total number of stations	24	50	50	50	51	52	52	52	52	52	52	52	52	52	52
Number of active stations	1	—	—	5	2	2	1	2	2	5	2	2	1	0	0
Number of baited stations	—	—	—	—	5	3	2	1	2	1	4	2	3	2	—
New Baitube* devices	—	—	—	5	1	1	1	1	1	4	1	1	—	—	—
Hexaflumuron consumed (g)	—	—	—	—	0.41	1.24	0.08	—	—	—	—	1.40	0.25	—	—
Above-ground stations															
Total number of stations	—	—	—	4	5	5	5	5	5	—	—	—	—	—	—
New stations added	—	—	—	—	2	—	2	—	—	—	—	—	—	—	—
Hexaflumuron consumed (g)	—	—	—	—	1.00	—	—	1.78	0.58	—	—	—	—	—	—
Total															
Hexaflumuron consumed (g)	—	—	—	—	1.41	1.24	0.08	1.78	0.58	—	—	1.40	0.25	—	—

using classical ANOVA methods appropriate for continuous variables. The Mann-Whitney rank sum test, a nonparametric test, was used to compare the two wood types with a discrete hit rating scale. All statistical analyses were performed with MINITAB, release 12, 1997.

RESULTS AND DISCUSSION

Structural Protection Sites

Ventana Canyon Residence

After September 27, 1995, when in-ground stations received Recruit II termite bait, and Recruit AG above-ground stations were installed, termites immediately began rapid consumption of the new matrix and consumed a total of 6.74 g of hexaflumuron from in-ground and above-ground stations (Table 1). By July 1996, no new activity was seen inside the building and none has been observed since that time. No activity was observed inside monitoring stations in the ground from the end of January 1997 to the summer of 1998. In July 1998, new *H. aureus* activity was detected in a single monitoring station, which is currently being baited. Beginning in July 1997, inspections have been made by a local authorized operator.

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San Xavier del Bac Mission

After September 27, 1995, when in-ground stations received Recruit II termite bait, and Recruit AG above-ground stations were installed to beams in the chapel and museum where feeding had been observed, termites immediately began rapid consumption of the new bait matrix and consumed a total of 6.24 g of hexaflumuron from in-ground and above-ground stations (Table 2). Most of the bait was consumed prior to the end of the year. By March 1996, no new activity was seen inside the building, and the last activity in in-ground stations occurred between April and May of that year.

TABLE 2. History of the Sentricon System at the San Xavier del Bac Mission.

Activity	1995				1996								1997		
	2/14	3/23	7/12	9/27	2/13	3/27	5/13	6/12	7/29	8/29	9/20	10/8	1/22	3/19	4/9
In-ground stations															
Total number of stations	12	16	16	16	16	16	16	16	16	15	15	15	15	15	15
Number of active stations	—	—	6	6	8	2	—	—	—	—	—	—	—	—	—
Number of baited stations	6	2	3	—	3	5	2	1	—	—	—	—	—	—	—
New Baitube devices	—	3	—	3	4	—	—	—	—	—	—	—	—	—	—
Hexaflumuron consumed (g)	—	—	—	0	3.30	0.74	—	—	—	—	—	—	—	—	—
Above-ground stations															
Total number of stations	—	—	—	14	14	15	—	—	—	—	—	—	—	—	—
New stations added	—	—	—	—	9	0	—	—	—	—	—	—	—	—	—
Hexaflumuron consumed (g)	—	—	—	—	1.60	0.59	—	—	—	—	—	—	—	—	—
Total															
Hexaflumuron consumed (g)	—	—	—	—	4.90	1.34	—	—	—	—	—	—	—	—	—

The in-ground stations have been serviced and inspected, and the above-ground stations in the interior of the mission have been inspected on a quarterly basis since May 1996. No activity of *Heterotermes aureus* has been observed in above-ground stations inside the structure since late May 1996. No activity has been observed in in-ground monitoring stations since May 1996. Formerly, new termite activity was invariably seen upon inspecting the chapel and museum areas. The ceiling and in-ground monitoring stations have been checked on a quarterly basis to confirm the lack of termite activity.

Previous documented studies of structural protection through baiting with hexaflumuron have fully or partially characterized the colonies involved through the use of mark-recapture techniques. Colony elimination including cessation of activity in the soil and inside the structure has been documented when bait was delivered only in in-ground stations (1,2,6,9,10,13,23,28, 29,31,35) as well as when bait was delivered only in above-ground stations (33). In one study, colony elimination was documented by direct observation of species with visible nests at the soil surface (22).

The studies discussed in this article differ from those cited above in that they basically followed methods similar to those used in actual commercial practice. The number of colonies and their foraging territories were not actually determined. In this regard our studies do not meet the criteria for rigorous evaluation of a bait system listed by Su and Scheffrahn (30):

1. A subterranean termite colony is characterized according to its foraging population size and foraging territory using a mark-release-recapture method and an extensive system of non-lethal monitoring sites (wooden stakes, plastic stations, etc.)
2. Baseline data on the colony's feeding rate over a prolonged period have been obtained in some cases.
3. Bait containing the active ingredient is delivered to the foraging termites, and consumption is documented.
4. Monitoring of colony feeding (quantitative and qualitative) continues during the baiting process and for at least 1 year after the date of last observed activity to confirm elimination of the colony.

Based on the abundant information available on documented colony eliminations with hexaflumuron and the Sentricon System, our studies offer results completely consistent with previous work which supports the conclusion of colony elimination. In our study the criteria for evaluation were:

1. Monitoring stations are placed around the entire perimeter of an infested structure.
2. The structure is inspected for current and past termite activity. Probable feeding sites elsewhere on the property such as landscape timbers are also checked.
3. Bait consumption is documented after termite feeding begins in stations.
4. After bait consumption ceases and all other evidence of termite activity in and around the structure is absent, monitoring and inspection continues for at least 1 year to confirm that the termite colony(ies) have in fact been eliminated.

It is important to emphasize that "commercial" trials of a termite bait active ingredient or system can be interpreted only if basic work on characterized colonies has previously been done. Recent reports of field work with sulfluramid (7), abamectin (8), and zinc borate (8) cannot be evaluated in terms of structural protection because of this critical data gap. Evaluations of commercial or prototype baiting systems are essentially meaningless in the absence of supporting data because positive results (i.e., the termites went away)

TABLE 3. Probability of termite activity and amount of monitoring device consumption, Tucson, AZ, August 2–September 26, 1995.

Treatment	Replications (n)	Number of devices hit[a]	Odds ratio[b]	Hit rating[c]	Average weight loss[c] (g)
SYP	12	8	—	1.67 a	1.95 a
Grooved SYP	12	7	–0.36	1.17 a	0.35 b
H_2O+SYP	12	9	0.41	2.08 a	2.64 a
Wrapped SYP	12	9	0.41	2.53 a	1.80 a
Cardboard	12	10	0.92	3.92 b	NA[d]

[a]*A "hit" indicates that termites found the station and fed on the monitoring device.*

[b]*Odds ratio is the probability of a hit upon a given treatment vs. the probability of a hit upon the standard SYP treatment. A negative ratio means that activity is less likely; a positive ratio means that activity is more likely.*

[c]*Treatments followed by the same letter are not significantly different at the 0.05% level.*

[d]*Data not available.*

TABLE 4. Probability of finding live termites and subjective ratings of numbers of termites, Tucson, AZ, August 2–September 26, 1995.

Treatment	Replications (n)	Number of devices hit[a]	Live termites	Odds ratio[b]	Average termite rating[c]
SYP	12	8	6	—	1.75 a
Grooved SYP	12	7	5	–0.33	1.00 a
H_2O+SYP	12	9	7	0.33	1.50 a
Wrapped SYP	12	9	3	–1.10	0.67 a
Cardboard	12	10	2	–1.67	0.00 b

[a]*A "hit" indicates that termites found the station and fed on the monitoring device.*

[b]*Odds ratio is the probability of a hit upon a given treatment vs. the probability of a hit upon the standard SYP treatment. A negative ratio means that live termites are less likely; a positive ratio means that live termites are more likely.*

[c]*Treatments followed by the same letter are not significantly different at the 0.05% level.*

cannot be meaningfully interpreted. In addition, commercial recommendations can vary according to different manufacturers. All "commercial" trials are not necessarily comparable.

Monitoring Device Tests

1995 Tucson Test

Because of scheduling difficulties the stations were checked at 2 months rather than at 1 month during a period of very active foraging (16,21). This probably had the effect of obscuring some of the dynamics of the differences among treatments. Nonetheless, significant differences among treatments were observed.

Table 3 summarizes data on the probability of foragers of *H. aureus* finding a particular monitoring device and subsequent intensity of feeding. Grooves were added to standard monitoring devices on the assumption that the increased surface area and the addition of narrow channels into the surface might stimulate feeding. Actually, the opposite was noted. Stations with grooved monitoring devices were less likely to be hit than those with standard devices, and the average weight loss was significantly lower. The addition of water to the station at the time of installation (H_2O+SYP) slightly increased the probability of activity within a station, but did not have any significant effect on the overall amount of wood consumed (direct weight loss or subjective rating).

The addition of corrugated cardboard as a wrapping around a pine monitoring device slightly increased the odds of activity, but had a negligible effect on actual consumption. In fact, termites tended to consume most of the cardboard and some wood but abandon the station subsequently, as indicated by the absence of live termites in the stations (Table 4). A monitoring device consisting entirely of tightly wrapped corrugated cardboard showed the greatest likelihood of activity based on subjective rating (Table 3). In almost all cases where termites had found the cardboard monitoring devices, these devices were completely consumed. Because of an error in data recording, complete weight loss data were not available for cardboard rolls. However, consumption for four stations for which data were available averaged 16.06 g, much higher than for any other treatment.

In the Sentricon System, bait containing the active ingredient hexaflumuron is only applied in monitoring stations where live termite foragers are found. Adding grooves to SYP monitoring devices actually decreased the likelihood that termites would be present inside stations (Table 4). As mentioned previously, while corrugated cardboard increased the likelihood of hits and the amount of consumption, termites tended to consume it quickly and abandon the station, making cardboard a less desirable material. Under normal conditions, when a structure is known to be infested, Dow AgroSciences recommends that monitoring stations be checked monthly. However, during extended monitoring following termite colony elimination, stations are normally monitored on a quarterly basis. In the event that new activity is observed in a station, the success of the subsequent baiting depends strongly on having active foraging at the time of monitoring.

MD499 vs. Southern Yellow Pine

Table 5 summarizes comparisons of hit rate, feeding intensity, and likelihood of live termites. Data are shown as of the second observation period. Activity was much higher by the second date, and only one station had activity or had been hit on February 22 that was not still active on March 18. MD499 outperformed SYP in all aspects including likelihood of a hit, likelihood of live termites present, subjective hit ratings, and amount of wood consumed. Interestingly, this test was run during a period of the year when surface activity of *Heterotermes aureus* is considered low (16,21). This study supports the commercial decision to replace SYP monitors with MD499 as a part of Dow AgroSciences' commercial offering.

SUMMARY AND CONCLUSIONS

The results obtained in these studies with the Sentricon System against *Heterotermes aureus* are comparable to those reported for species of *Reticulitermes* in other parts of the world. At the San Xavier del Bac Mission, Recruit II termite bait was introduced into in-ground Sentricon stations at the same time that Recruit AG above-ground stations were installed. All detectable termite activity at these stations ceased within 6 months. At the Tucson residential site, Recruit AG above-ground stations were installed before Recruit II termite bait was introduced to in-ground Sentricon stations because of low activity in in-ground stations. All detectable termite activity at the stations installed at the Tucson residence ceased within 16 months. In both cases, detectable activity persisted in the ground longer than inside structures.

The studies involving monitoring devices showed that the addition of corrugated cardboard wrapping, grooving of the monitoring device, or addition of water to stations did not significantly affect the like-

TABLE 5. MD499 test, Scottsdale, AZ, January 20–March 18, 1997.

Monitoring device	Number of devices hit	Average weight loss (g)[a]	Number of devices with live termites	Average number of live termites	Average hit rating
MD499	9	3.08	8	86.25	2.00
SYP	4	0.27	2	30	1.75
Statistic	odds ratio (SYP/MD499=0.17)	ANOVA (F=13.13)	odds ratio (SYP/MD499=0.10)	not analyzed	Mann-Whitney (W=178)
p	0.037	0.002	0.011	—	0.0874

[a]*ANOVA performed with cube root transformation of data.*

lihood of termite activity within the monitoring stations. Although the monitoring device constructed of tightly wrapped corrugated cardboard did show increased termite activity, the fact that it was often entirely consumed would preclude its use as a monitoring device.

The monitoring device constructed of MD499 showed increased termite activity and increased wood consumption when compared to the conventional device made of southern yellow pine.

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