Effective Use of Above-Ground Hexaflumuron Bait Stations for Formosan Subterranean Termite Control (Isoptera: Rhinotermitidae)

by

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ABSTRACT

Seven sites were selected with active Formosan subterranean termite infestations on the islands of Oahu and Kauai, Hawaii, to evaluate prototypes of the Recruit™ AG above-ground baiting system containing hexaflumuron. A number of new techniques were developed to facilitate termite control, including methods of installing bait stations above the soil surface at ground level and on the roofs of two multistory buildings where bait stations could not be installed directly into the soil. Methods were also developed to prevent water and ant infiltration, and to encourage termites into the stations when they could not be placed directly in contact with heavily infested wood or highly active termite mud tunnels. Total bait days at these sites ranged from 62 to 126 days. During this period, Formosan subterranean termites consumed 63.5 to 1,178mg of hexaflumuron and the rate of cellulosic bait matrix consumption ranged from 102 to 2,593mg per station per day.

INTRODUCTION

Prior to the introduction of above-ground baiting systems, remedial control methods for subterranean termites (Isoptera: Rhinotermitidae) in structural lumber were limited to localized treatments with liquid and dust insecticide formulations. Use of these conventional spot treatments only offered temporary control in limited areas, and often other areas of the structure would become infested after these treatments had been applied. Situations arise where thorough soil treatment is either impractical or not effective due to the occurrence of aerial termite nests, and above-ground insecticide treatments frequently appeared to only chase termites from one spot to another within the structure.

Following the commercial introduction of the Sentricon™ *Termite Colony Elimination System* in 1995 by Dow AgroSciences LLC, the Recruit* AG above-ground station was introduced in 1997 for the remedial control of subterranean termites directly within structures.

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Several station prototypes were tested by research cooperators and Sentricon System authorized operators in 24 states throughout the United States (Ryder *et al* 1998). However, there is little published information on application techniques for these prototypes or the present commercial model other than directions to apply the stations to mud tunnels and infested lumber indoors.

Su *et al.* (1997) eliminated four *Coptotermes formosanus* Shiraki termite colonies using an AG prototype they designed (Su *et al.* 1996c). The eastern subterranean termite, *Reticulitermes flavipes* (Kollar), was eliminated from the pedestal of the Statue of Liberty National Monument and surrounding areas with in-ground and above-ground Sentricon bait stations (Su *et. al* 1998). Similar results were obtained by Atkinson *et. al* (1998) when prototype and commercial versions of the Sentricon and Recruit AG bait stations were used to control *Heterotermes aureus* (Snyder) in Arizona. Thomas *et al.* (1999) took the application of Recruit AG stations one step further by incorporating the use of an acoustic emission device to locate termite activity pre- and posttreatment.

Interest in the development and testing of the Recruit AG station stemmed from the need to reduce or eliminate traditional remedial spot treatments within residential structures, and the possibility that the system would be a compliment to the in-ground system. Applying the bait directly to visible infestations rather than waiting for termites to locate in-ground stations, offers an expedient means of eliminating subterranean termites within structures. However, Recruit AG stations are only effective when applied to active termite infestations and mud tubes, and will not function as a preventive control method for subterranean termites. Our experiences indicate that successful implementation of Recruit AG stations requires that the technician be quite familiar with the biology and behavior of the termite species to be controlled, and be able to modify the bait station and/or application site to encourage termites into the station.

Several field trials have been conducted in Hawaii to evaluate the Recruit AG baiting system using prototype stations and the present commercial design. Trial sites with ongoing Formosan subterranean termite infestations included a 12-floor high-rise residential condominium building (Wilder), a large single-story United States Department of Agriculture (USDA) fruit fly rearing facility, a State Department of Agriculture (DOA) building complex and several structures on a hotel property. Another site where above-ground baiting proved helpful was a single-family residence that was under a Sentricon contract with a pest control company. All of these sites presented challenging above-ground baiting situations that required special techniques to mount the bait stations and/or create conditions that would enhance termite foraging into these stations. Moreover, most of these sites were in locations where in-ground baiting stations could not be installed. In this report, we share the techniques that were developed and implemented during these trials.

MATERIALS AND METHODS

Below, we describe the prototype Recruit AG bait stations and their application at each of our trial sites. Modifications to these stations and/or to the application site were performed under a Federal Experimental Use permit. As a matter of law, pest control operators authorized to use the Sentricon System cannot implement these application procedures until such time as they are included on the Recruit AG label.

High-rise condominium (Wilder)

A thorough inspection of this high-rise complex determined that the aerial infestation of Formosan subterranean termites was limited to the roof and two condominium units on the 12th floor. There was evidence that termites on the roof had penetrated the roofing membrane, and active mud tunnels were found along the rooftop parapet wall. Only one infested apartment on the 12th floor was accessible to us. In this unit, termites were found in a kitchen dish cabinet that was mounted to a wall and in contact with the kitchen ceiling. An active mud tunnel was also found along an aluminum window frame in one bedroom. The active sites on the roofing membrane were used to estimate the termite population and to install bait stations. The active sites on the parapet wall and within the condominium were provided with control stations that contained Douglas fir wood blocks. These stations functioned as independent monitors to assess the extent of termite control (Su 1995, Grace *et al.* 1996, Su & Scheffrahn 1996a, Su & Scheffrahn 1996b).

A considerable number of termites are needed to develop subterranean termite population estimates using mark-release-recapture techniques (Grace *et al.* 1996). An aggregation trap similar to that used by Grace *et al.* (1996) was developed and placed over active mud tunnels on the roofing membrane. Each trap contained two rolls of moist corrugated cardboard (Figs. 1a,b; p. 347), and one trap was placed over each of five active mud tunnels on the roofing membrane. We then followed the triple-mark-release-recapture (TMRR) procedures described by Su (1994) and Su & Scheffrahn (1988) to estimate the termite foraging population.

The application of hexaflumuron to this aerial infestation was accomplished with a plastic bait station (8cm x 8cm x 5.4cm O. D.). Each station had a watertight cover that could easily be fastened with four one-fourth-turn screws. Two perforated plastic canisters (3cm x 3cm x 7cm) that held known amounts of either 0.1% or 0.5% hexaflumuron treated paper matrix were placed into each station. Approximately 5ml water were added to each matrix canister before it was installed in the station. Both treatments were placed side-by-side in the bait station (Fig. 2, p. 348) to determine if there were feeding preferences. Bait stations were inspected once each week and both bait canisters were replaced with new canisters when termites had consumed approximately 70% of the matrix. Matrices that had been fed upon by termites were oven dried (90°C) for 24 hours, brushed clean of debris and weighed to determine bait consumption.

The bottom of the plastic bait station was not sealed and served as the opening for termites to forage into the station. Only two stations were hot-glued to the roofing membrane after the roofing chips (gravel) were removed. Termite activity ceased in the three other trap locations used to estimate the termite population when excess precipitation undermined the roofing membrane in those areas. Based on this observation, hot glue was chosen as a method to secure the bait stations to the membrane to prevent ants and rainwater from invading these areas. Su (1996c) experienced similar problems with weather and small animals when above-ground stations were used outdoors. An added advantage of using hot glue was that the complete seal provided by the glue also eliminated air movement within the station. Formosan subterranean termites are sensitive to air currents and will avoid or seal open areas. Inverted flowerpots were placed over the bait stations to further shield them from sunlight and precipitation, and the drainage holes in the sides near the bottom of the flower pots served as ventilators to minimize high temperatures within the bait stations.

USDA Fruit Fly Rearing Facility

Formosan subterranean termite infestations that originated from the ground at the USDA facility for rearing sterile fruit flies were found in two adjacent larval holding rooms, a security office, a site at the exterior perimeter of the building and a detached storage container in an adjacent parking lot. Five bait stations as described above were attached to a wall (Fig. 4, p. 349) in one larval holding room. Two monitoring stations were also included in this area and on an opposite wall 7 meters away in the adjacent larval holding room. Another monitoring station was installed in the security office 43 meters away, and at the exterior perimeter site 46 meters away from the bait stations. Modified in-ground stations (Grace *et al.* 1996) placed around an exterior shipping container also served as monitoring stations and were located approximately 56 meters from the bait stations in the larval holding room. All above-ground stations were provided with Douglas-fir wood blocks as termite food.

Once termites became established in all of these stations, four stations that were mounted on an infested wall in one larval holding room were selected to determine wood consumption. Each station was provided with a known amount by weight of *Pinus sp.* wood wafers and termites fed on these wafers until approximately 70% had been consumed. Consumed wafers were removed and replaced with new wood, and oven dried for 24 hours at 90°C. The dried remains of wood wafers were cleaned with a soft wire brush to remove soil and fecal material, and weighed to determine total wood consumption. This process was continued three times for each of the four bait stations. When this study was completed, the four stations, including an additional one that was mounted on the same wall, were each provided with moist 0.1% and 0.5% hexaflumuron treated matrices contained in perforated plastic canisters. Weekly inspections were made of all hard plastic stations, and treated matrices were replaced when required.

The installation of hard-shelled stations to the walls within the two larval holding rooms was challenging. The masonry block walls and concrete floors in these rooms were sealed with an elastomeric covering and all of these surfaces were disinfected and washed each week. These conditions required each station to be covered with a plastic sheet after it was hot glued to a location where termites had eaten through the wall covering. The stations were further secured to the walls with duct tape since hot glue did not totally adhere to the smooth and nonabsorptive surface of the elastomeric covering. The edges of the plastic sheet covering the stations were then sealed to the wall with duct tape to keep the stations dry. This method could also be used to secure stations that are mounted on exterior surfaces of buildings located in high precipitation areas.

The triple-mark-release-recapture method (Su 1994, Grace *et al.* 1996) was used to estimate the size of the termite population occupying the exterior in-ground monitoring stations. No dyed individuals were recovered from the above-ground stations, but the numbers present in the stations were small since it was not possible in this situation to mount larger aggregation traps on the walls.

Department of Agriculture (DOA) Complex

This building complex had evidence of Formosan subterranean termite infestation at several locations. Active Formosan subterranean termites were found in a storeroom and restroom door frame in the basement, two exterior locations in the lobby area at ground level, and a restroom door frame in one office at this same level. Mud tunnels in the storeroom were chosen as the site for baiting and all active sites were provided with the same hard plastic bait stations described above. Each of the three hard stations glued adjacent to a large termite mud tunnel in the storeroom were provided with pine wood wafers to determine wood consumption as described above. All other hard stations were provided with a Douglas fir wood block to establish termite activity prior to baiting. Unbaited stations served as independent monitors during and after baiting was completed.

Two modifications to the hard stations were necessary at this site to establish and maintain termite activity. In one area, termites were found in a 0.63cm. x 3.8cm. wooden molding. The opening at the bottom of the prototype hard station (8cm x 8cm x 5.4cm) was partially sealed with sheet metal glued to the bottom of the station. The remaining open end of the station was hot glued over the infested portion of the molding (Fig. 3a, p. 348). This additional seal was necessary to prevent ants from entering the station. To support the raised portion of the station a 0.63cm. plywood wafer was hot glued between the bottom of the station and the structural wall (Fig. 3b, p. 348).

The second modification was required to evaluate a new stackable hard station prototype (10cm x 10cm x 4cm OD) that contained 25gm of a layered bait matrix treated with 0.5% hexaflumuron. Our interest in evaluating the new hard station came after the first prototype stations were installed in the basement storeroom and already contained active termites. Rather than replacing each of the three active hard stations with the new prototype station, causing disturbance which could result in the loss of termite activity, new stations were connected to the old ones with 0.63cm tygon tubing fitted through holes that were drilled in the sides of both stations (Fig. 5, p. 349). Like the old prototype, the new hard station was hot glued to the concrete basement floor. Termites were enticed into the tygon tubing by placing a moistened paper towel wick into the end of the tubing closest to the station with active termites. This technique is also useful in directing termites into above-ground hard stations when it is not possible to place the stations directly adjacent to or over termite mud tunnels (Figs.6a, b; p. 350). Once connected, approximately 30 to 40ml of water were added to the layered matrix in each of the new hard stations and the cover was attached. Termites were observed in the new stations approximately one week later. Inspections of all hard stations were conducted weekly, and when about 70% of the bait matrix had been consumed in a bait station, the cover was discarded and a new hard station was stacked on top. Approximately 30-40ml water were added to each new station and stacking was limited to three stations. When feeding stopped and termites were no longer present in the bait stations, all traces of the bait matrix were recovered, oven dried and cleaned as described above to determine total matrix consumption.

As with the USDA facility, triple-mark-release-recapture methods (Su 1994, Grace *et al.* 1996) were used with the in-ground stations to estimate the foraging population, but these in-ground stations could not be definitively linked to the activity in the above-ground stations within the structure.

Hotel Property

The hotel property is located on the island of Kauai, Hawaii, and experiences an annual rainfall of approximately 112cm. The trial site had several Formosan subterranean termite infestations in areas where in-ground bait stations could not be placed. The above-ground bait stations and application methods were modified to function under extremely moist outdoor conditions and where ants were prevalent.

Bait stations used on this property included 10cm x 10cm x 4cm Recruit AG stations and the present commercial model that contains 70gm of 0.5% treated paper matrix formed as two tightly wound rolls. Approximately 40 to 50ml water were added to this matrix and the volume of water was split between the bottom and top (cover removed) exposed areas. Inspections were conducted once per week, and the matrices upon completion of the trial were collected and handled as described above. The specific test locations on the large hotel property included (1) a Banyan tree and adjacent art gallery and office, (2) the Kahili hotel tower, (3) a shipping container, and (4) a pool pump shed.

Banyan Tree

Formosan subterranean termites were infesting a Banyan tree, art gallery and an adjacent travel agency office. The gallery and office were approximately 12m from the tree, and the infestations in these rooms were not discovered until baiting had already commenced at the Banyan tree site. Nor was it determined if these infestations were being caused by termites from the same colony.

A single stackable bait station (10cm x 10cm x 4cm) was initially placed over termite mud tunnels on the trunk of the Banyan tree. However, the characteristic irregular trunk surface (Fig. 7, p. 351) made it extremely difficult to seal the bait station with duct tape. Even covering the station with plastic sheeting did not prevent precipitation from saturating the bait matrix or prevent ants from entering the station. The bait site was abandoned after several unsuccessful attempts and wood stakes were installed in the soil around the base of the tree. The stakes could only be imbedded into the soil approximately 3 inches due to the rock sub-base in this area.

Mounting a bait station at grade level over an infested stake was accomplished with a wooden box constructed from available untreated scrap lumber (2.5cm x 5.1cm, Fig. 8a, p. 352). The outer dimensions of the box were the same as the bait station and this facilitated hot gluing the flange at the bottom of the bait station to the one-inch dimensional lumber. The open-ended box served as a raised base to separate the bait matrix from soil. This minimized fungal contamination of the matrix and prevented the matrix from absorbing soil moisture. The station was also covered with plastic sheeting to divert precipitation. Formosan subterranean termites readily fed on the bait matrix and there was little evidence of feeding on the wooden box. A new and empty bait station could also be substituted for the wooden box.

Kahili Tower

Two unconnected infestations were found in this building. One grade-level infestation was found where wooden pallets and lumber were placed in contact with gravel that covered a rock and soil sub-base. Termites were also affecting ornamental plants nearby. Two bait stations were installed at locations where termites were visible in the gravel. The stackable hard stations were glued onto wooden boxes as described above and each station was covered with an inverted five-gallon bucket (Fig. 8b, p. 352) to divert precipitation from the bait stations.

An aerial termite infestation on the roof of this building was evident in four wooden blocks that supported air conditioning service lines and in a guestroom on the eighth floor. Water from precipitation was a serious problem at this site. The bait matrices in 10cm x 10cm x 4cm bait stations placed on infested wooden blocks were constantly saturated with water, and covering the stations with plastic sheeting was not a sufficient remedy for this problem. We later determined that the matrices were absorbing water directly from the damaged and water-logged wooden blocks.

In a second attempt to apply above-ground stations in this area, the damaged wooden blocks were removed and replaced with new blocks that were positioned adjacent to the infested areas. Live termites were observed in holes they had made in the roofing membrane. However, precipitation continued to be a problem when bait stations were placed over these holes and caulked to the membrane.

Water infiltration into the stations was finally prevented when bait stations were placed into wooden boxes constructed with 1.9cm untreated plywood (Fig. 9, p. 353). Each box was large enough to contain the bait station, and a 6.4cm hole was drilled through the bottom of the box to provide access for foraging termites. The base of the wooden box provided a larger surface area to seal to the roofing membrane and the thickness of the plywood separated the bait matrix from the hot roofing membrane. The cover for the wooden box was firmly attached with four wood screws placed at each corner. Similar stations were placed in three adjacent infested areas and each station was provided with untreated *Pinus sp.* wafers. These stations served as monitors during and after the baiting trial.

Shipping Container

Formosan subterranean termites were present in a shipping container used for storage. Active mud tunnels were found on one wall of the container and on the wooden floor beneath metal lath. The mud tunnel on the floor was congested with termites and was chosen as the baiting site. The current commercial above-ground bait station (15cm x 9cm x 5cm) was prepared by removing the plastic flange at one end with pliers to accommodate the raised mud tunnel. The opening through the base of the bait station was also covered with cardboard (Fig. 10, p. 353) except for the portion to be placed over the mud tunnel. The cardboard prevented air movement in the station and prevented ants from gaining access since the bait station had to be mounted on the metal lath. Once the bait station was placed in position and fastened to the wooden floor with wood screws, that portion of the mud tunnel that was in the bait station was broken with an inspection probe and the moistened bait matrix was positioned within. Additional stations were stacked. All remaining matrix after cessation of feeding was collected and handled as described above.

Pool Pump Shed

The plywood box method used on the Kahili Tower roof was also applied at this site at a cold-joint that was created when asphalt was installed adjacent to a below-grade hollow block wall (Fig. 11a, p. 354). A portion of the bottom of the wooden box was cut out along one edge. This enabled the box to be mounted over a mud tunnel at the cold-joint to give termites access to untreated wooden blocks within the box. This method was used to aggregate the termites within the box (Fig. 11b, p. 354) before applying the bait station since termite activity in the mud tunnels was low. The aggregation technique is extremely useful when initial termite activity is low or when termite activity has declined soon after above-ground bait stations have been installed. The latter situation can occur when the infested area is disturbed during the installation procedure. Consumption data for this site is not available since the baiting with 10cm x 10cm x 4.1cm stations was performed by a pest control company after the trials had been completed on this property.

Single Family Residence

In-ground Sentricon stations were installed around the perimeter of this dwelling by a pest control company, and a single commercial above-ground bait station was mounted on a baseboard in the basement laundry room. The termite activity in the baseboard was low and termites had not fed on the bait matrix in the station at its first mounting position nor at its second position approximately one foot away. The holes in the baseboard caused by the termites and the station mounting screws at the first position had not been sealed by the pest control technician when the station was repositioned. Formosan subterranean termites are extremely sensitive to air movements and will avoid these areas, and the holes could also have served as an access for ants. The pest control operator was advised to do the following: (1) Seal the holes in the baseboard at the first mounting position with duct tape, (2) discard the bait matrix in the station since there was evidence of mold, (3) add 2-3ml water into the baseboard where the station was presently mounted, and (4) add moist paper toweling to the station to aggregate the termites prior to replacing the bait matrix. The bait matrix was reinstalled into the now very active bait station approximately one week after the modifications were completed. An alternative to paper toweling as an aggregating medium could possibly be one bait matrix roll that has been partially unrolled prior to placement into the bait station. The unrolled matrix, as with the above recommendation for toweling, will increase the surface area within the station for termites to forage and feed.

RESULTS AND DISCUSSION

This study was conducted in cooperation with Dow AgroSciences to obtain developmental data for Recruit AG bait stations under the guidelines of a Federal Experimental Use Permit. However, experimental protocols were modified a number of times during the course of the trials. The initial protocol required data that represented termite population estimates, wood consumption and feeding preferences for 0.1% and 0.5% treated matrices (Wilder site). However, the length of time that would be required to complete this protocol at the Wilder site was considered unreasonable by the condominium association manager after the termite population estimate had been completed. Ryder (1998) reported similar problems with experimental sites and Weissling (1999) reports that mark-recapture methods are difficult, disruptive and labor intensive. Rather than abandoning this site in response to the manager's concerns, we chose to not pursue the determination of wood consumption for this particular aerial termite colony.

The characterization of subterranean termite colonies at several other experimental sites was based solely upon the rate of wood consumption prior to establishing feeding preferences for the two concentrations of hexaflumuron (USDA site). At the DOA site wood consumption was measured with the first prototype hard station; however, unlike the USDA site, matrix consumption was determined with a second stackable prototype bait station (10cm x 10cm x 4cm) that contained a layered matrix treated with 0.5% hexaflumuron. The final change in the experimental protocol required collection of data to represent the total baiting period, the total amount of 0.5% hexaflumuron bait matrix consumed during this period, and the rate of consumption of this bait matrix (Hotel property). Bait stations for this phase of the study included 10cm x 10cm x 4cm stations and the present commercial model.

Experimental data satisfying the requirements of the various protocols is summarized in Table 1. Due to the changes in procedures, bait station designs and matrix configurations, statistical comparison of matrix consumption data within sites was limited to the Wilder and USDA properties. The consumption of *Pinus* sp. at the USDA and DOA sites was not compared to the consumption of bait matrix since these did not represent side-by-side choice tests.

High-rise condominium

The termite foraging population was estimated at ca. 469,000 using mark-release-recapture methods (Su & Scheffrahn 1988, Su 1994).

The infestation was eliminated in 76 days (Table 1) following the simultaneous application of 0.1% and 0.5% hexaflumuron treated matrices to two bait stations. There was no significant difference in the total amount of bait consumed and the consumption rate for each of the two treated matrices during this period. Su (1995) and Su *et al.* (1997) also found that Formosan subterranean termites did not show preferences among four different concentrations of hexaflumuron. Termite activity in monitoring stations containing untreated wood wafers as a food source was also eliminated and there was also no evidence of live termites when the damaged roofing membrane was replaced.

USDA Fruit Fly Facility

Infestations in the two larval holding rooms were eliminated in 72 days. However, termites remained active in monitoring stations located in the security office, the exterior perimeter and around the storage container, indicating that multiple subterranean termite colonies were infesting this building complex. The exterior termite population occupying the in-ground stations was estimated by TMRR as ca. 2.2 million, but no dyed individuals were recovered from the above-ground stations. However, when hexaflumuron was applied to in-ground stations around the shipping container, all termites in both the in-ground stations and the remaining above-ground monitoring stations were eliminated. As with the Wilder site, there was no significant difference in the total amount of bait consumed or the rate of bait consumption when the bait matrix was treated with either 0.1% or 0.5% hexaflumuron. Termites ate a total of 189gm of *Pinus sp.* in 57 days at a consumption rate of

Table 1. Consumption of hexaflumuron treated matrix and pine wafers in above-ground bait stations by *C. formosanus* at field sites in Hawaii.

SITE	POP. EST. (TMRR)	NO.BAIT STN.	% A.I.	BAIT DAYS	TOTAL BAIT CONSUMED (gm)	TOTAL A.I. CONSUMED (mg)	MEAN BAIT CONSUMED (mg/stn/day)[4]
Wilder Roof	469 ± 52k	2	0.1	76	29.3	29.3	186a
			0.5	76	32.9	164	213a
USDA	[1,2]	5	0.1	72	96.1	96.1	372a
			0.5	72	96.4	482	362a
		4	*Pinus sp.*	57	189	0	814
DOA	[1,3]	3	0.5	66	210	1054	1077
			Pinus sp.	53	201	0	1133
Banyan Tree	[1]	1	0.5	126	151	757	1198
Kahili Ground	[1]	2	0.5	67	164	820	1223
Kahili Roof	[1]	2	0.5	62	12.7	63.5	102
Shipping Container	[1]	1	0.5	91	236	1178	2593

[1] Undetermined
[2] Foraging population of a second colony at the USDA site baited with in-ground stations on the exterior of the structure was estimated at 2.2 million (standard error=0.2 million).
[3] DOA=Dept. of Agriculture. Foraging population of a second colony at this site baited with in-ground stations on the exterior of the structure was estimated at 4.9 million (standard error=1.7 million).
[4] Wilder and USDA values within a column followed by the same letter are not significantly different determined by t-test under GLM (P=0.05).

approximately 814mg/station/day.

Department of Agriculture (DOA) Complex

Formosan subterranean termites readily fed on the layered matrices in the new prototype stations and consumed 210 grams in 66 days. Termite activity was eliminated in monitoring stations placed in the basement area, and in all but one station at the ground-level locations, and in several in-ground stations around the building perimeter. As with the USDA site, multiple termite colonies were infesting the DOA complex, and when in-ground stations were subsequently baited termite activity in all remaining above-ground monitoring stations was eliminated. In this case, the population size of the termite colony occupying the in-ground stations was estimated by TMRR to be ca. 4.9 million, and dyed termites were recovered from two of the latter above-ground stations.

The extensive termite feeding activity in the storeroom bait stations may be attributed to using a larger bait station that contained a loosely layered matrix. This design would sustain a larger number of termites in the station and the stackable feature minimized disturbance when more matrix was needed. The first prototype station employed at the Wilder and USDA sites was smaller and the matrix in the perforated plastic canisters was folded very tightly. When two of these canisters were placed in the hard station there was no room for termites to forage within the station until the matrix was partially consumed. Matrices were replenished by removing the canisters and placing new ones into the station. This procedure was disruptive and may have affected termite foraging and feeding behavior.

Banyan Tree

Termites were eliminated from the Banyan tree, art gallery and travel office in 126d when 151gm of bait matrix had been consumed.

Kahili Tower (Ground)

At this site termites consumed 164gm of bait matrix and were eliminated from pallets and ornamental plants in 67d.

Kahili Tower (Aerial)

Termites consumed only 12.7gm of the bait matrix in the one bait station over a 62d period. Live termites could not be found in monitoring stations or in the eighth-floor guestroom.

Shipping Container

The termites consumed 236gm of the matrix over 91d. There was no evidence of termite activity in other mud tunnels within the shipping container.

Based on visible evidence, Formosan subterranean termites were eliminated from all of the seven trial sites in 62 to 126 bait days (Table 1). The significance of differences in the total time required to eliminate an infestation is difficult to assess since population estimates were limited to only a few colonies, and the number of bait stations installed varied between trial sites. The different station prototypes and matrix configurations can also influence the rate of bait consumption and, therefore, also the time until elimination (Weissling *et al* 1999). Potter (1997) related the amount of bait matrix consumed to a popular question asked during termite litigation—how much can termites consume during a specified time? Intrinsic and extrinsic factors such as population size, number of colonies, species of termite, seasonal variation, and competitive food sources are some of the variables that make such determinations difficult. The mean time for termite elimination based on visible evidence of infested structures was 2.7 months (range 2.1 to 4.2mo) for all sites in this study. Su *et al.* (1997) reported a mean elimination period of 5.8mo for Formosan subterranean termites, and baiting of the same pest by Weissling *et al.* (1999) took 3.3mo. All of these studies had a mixture of in-ground and aerial infestations. Weissling *et al.* (1999) attributed their shorter baiting period compared to that of Su *et al.* (1997) to the non-particulate matrix in the bait stations used in the former study.

Analysis of data collected from 24 states (Ryder *et al.* 1998) summarized the median days to elimination when hard stations were used for Formosan subterranean termites as 76 days (2.5mo). However, when seasonal variation differentiating the periods of May to August and September to December was considered, the median days to elimination increased to 105 (3.5mo) and 123 (4.1mo), respectively. The increase in time during the May to August period can also be important in Hawaii since Formosan subterranean termites typically swarm during the early summer months. Adult alates trying to leave the colony invaded four of our monitoring stations at the USDA site. This would have been extremely disruptive had these adults accumulated in bait stations.

The total amount of bait matrix treated with 0.1% and 0.5% hexaflumuron that was consumed at each site during our trials varied from 12.7 to 236gm with a mean of 147gm/site. The corresponding total active ingredient (A.I., hexaflumuron) consumed ranged from 63.5 to 1,178mg with a mean of 663mg/site. This variability in consumption is also evident in other above ground bait station studies (Su *et al.* 1997, Su *et al.* 1998, Weissling *et al.* 1999). Su (1995) clearly demonstrated that seasons can influence the rate of consumption of wood by

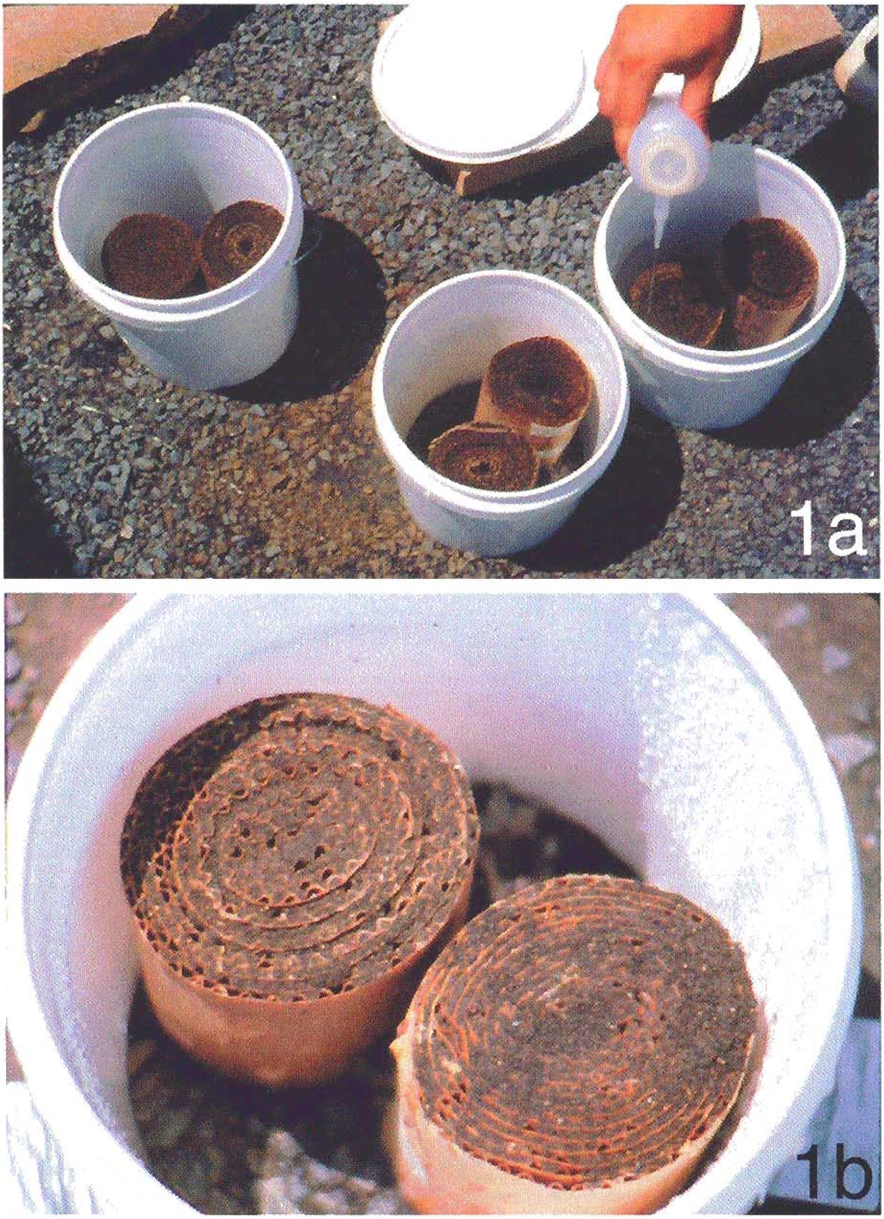

Fig. 1. Aggregation traps. a, Placed on high-rise pitch-and-gravel roof top for TMRR determination; b, Infested corrugated cardboard rolls within an aggregation trap.

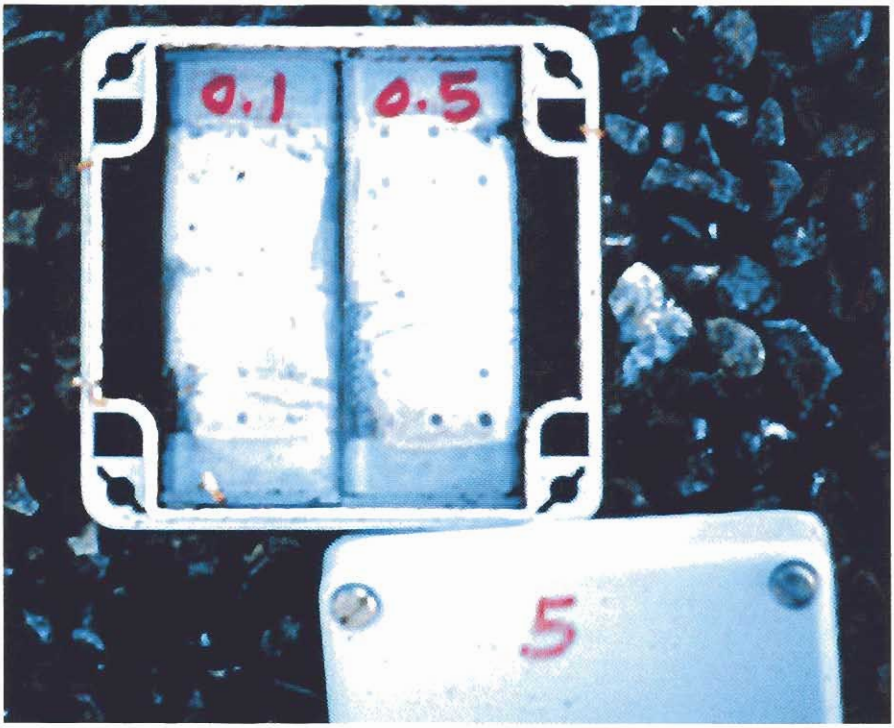

Fig. 2. Prototype plastic bait station with 0.1% and 0.5% hexaflumuron treated matrices contained in perforated plastic canisters.

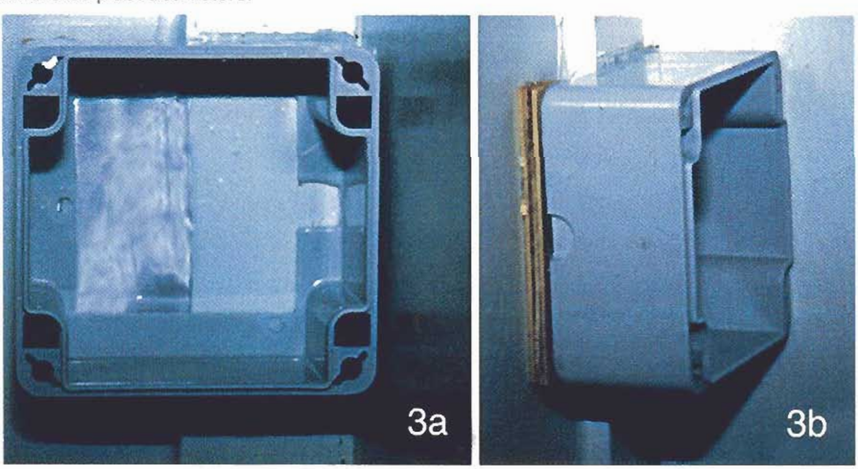

Fig. 3. a, Infested 0.63cm x 3.8cm wooden molding visible through open end of modified bait station, b, Plywood wafer (0.63cm) hot glued between bottom of bait station and structural wall for added station support.

Fig. 4. Bait stations hot glued to elastomeric wall covering in a larval holding room.

Fig. 5. Active prototype bait stations (along wall) connected to new prototype bait stations with 0.63cm tygon tubing.

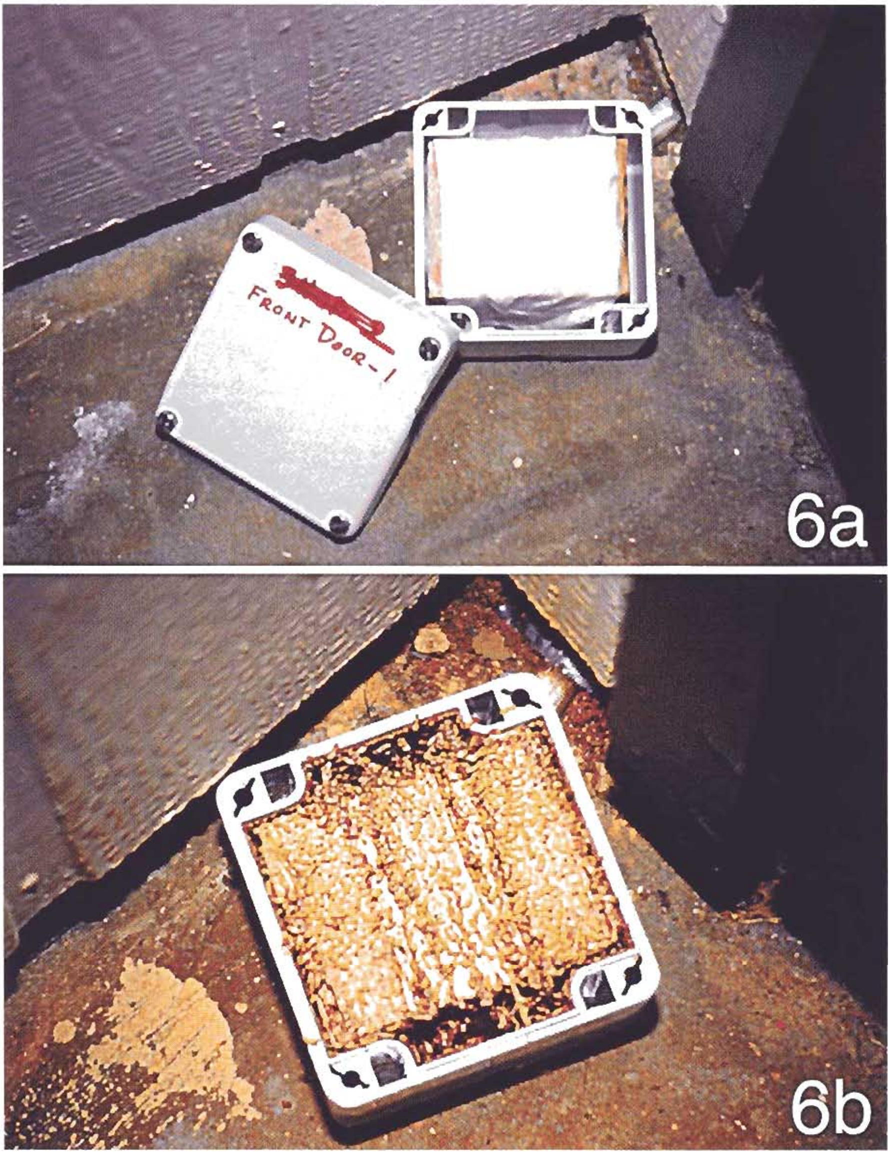

Fig. 6. a, Tygon tubing was used to divert termites into a bait station from an inaccessible mud tunnel and untreated wood blocks were wrapped in moistened hand towel; b, Active Formosan subterranean termites within the bait station.

Fig. 7. Mounting a bait station to an irregular shaped tree trunk with duct tape did not prevent entry by ants and precipitation.

Fig. 8. a, Wooden box spacer for separating bait stations from soil; b, Inverted plastic buckets to shield bait stations from precipitation.

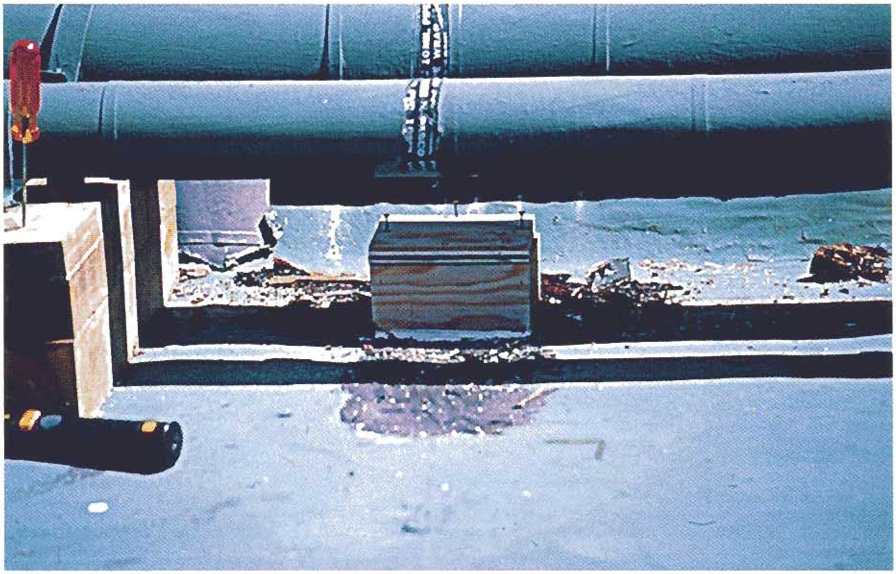

Fig. 9. Bait stations were placed into wooden boxes on a rooftop to prevent water infiltration.

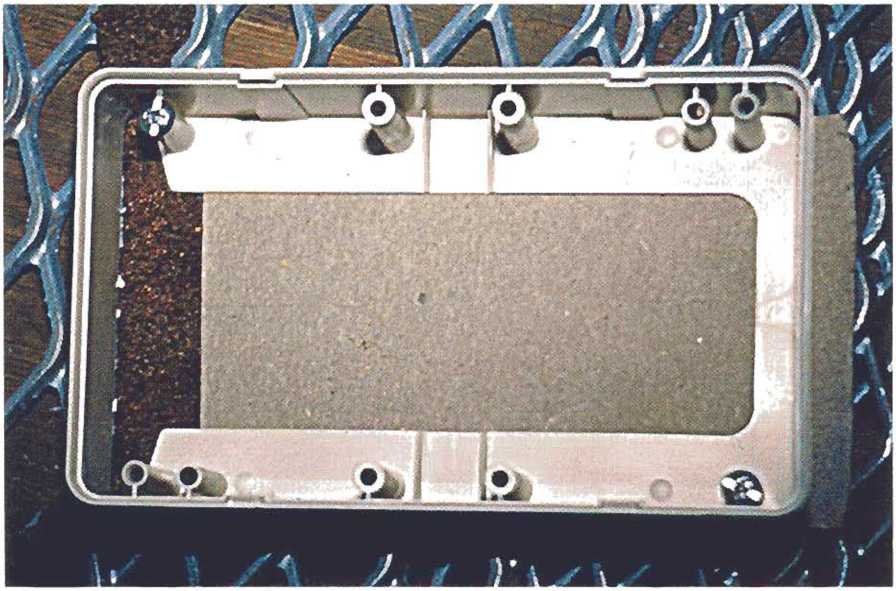

Fig. 10. Bait station modifications to accommodate a portion of a raised termite mud tunnel, and to prevent ant intrusion and air movement within the station.

Fig. 11. a, Formosan subterranean termites were aggregated in wooden boxes placed along a cold joint; b, aggregated termites within a wooden box just prior to baiting.

Formosan subterranean termites, although one colony he monitored did not reflect a decline in wood consumption during the winter months. Other extrinsic factors and intrinsic factors probably influenced the variation obtained in this Hawaii study, since seasonal variations are less pronounced in Hawaii then in temperate regions.

Our trials demonstrate that Recruit AG above-ground bait stations can eliminate infestations of Formosan subterranean termites from structures and can provide remedial control in situations where in-ground stations cannot be used. This can be accomplished with a single bait station if only one point of active infestation can be located. Baiting termites at the Banyan tree site, for example, led to the elimination of infestations both on the tree and in the art gallery and travel office. However, it is not advisable to bait only one location if multiple sites are available. It is reasonable to assume that using multiple bait stations will result in a shorter baiting period for a given termite colony. Multiple bait stations are also advantageous when termites from two or more colonies are attacking the same structure, an occurrence that can rarely be predicted accurately. This was evident at our USDA and DOA sites where baiting five and three stations, respectively, clustered in a single location at each of these sites eliminated infestations that were caused by one termite colony, but additional baiting in other distinct locations was necessary to control the other colonies encroaching upon the structure.

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