# Field Evaluation of a Hexaflumuron Bait for Population Suppression of Subterranean Termites (Isoptera: Rhinotermitidae)

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**ABSTRACT** A baiting procedure that incorporated a matrix containing a chitin synthesis inhibitor, hexaflumuron, was evaluated against field colonies of the eastern subterranean termite, *Reticulitermes flavipes* (Kollar), and the Formosan subterranean termite, *Coptotermes formosanus* Shiraki. Wooden stakes were first driven into the soil to detect the presence of termites. Bait tubes were placed in soil where termites were detected. A *self-recruiting* procedure, in which termites collected from wooden stakes were forced to tunnel through the matrix in the bait tubes, significantly increased bait intake by termites. Approximately 4–1,500 mg of hexaflumuron was needed for 90–100% reduction of field populations containing 0.17–2.8 million foragers per colony.

**KEY WORDS** Formosan subterranean termite, eastern subterranean termite, chitin synthesis inhibitor

SUBTERRANEAN TERMITES account for an 80% share of the ≈$1.5 billion spent annually for termite control in the United States (Su 1991a). Remedial control of subterranean termite infestations is extremely difficult because of their large population sizes and foraging territories. Colonies of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, may contain 1–7 million foragers, with foraging territories extending up to 100 m (Su & Scheffrahn 1988a). Recent mark–release studies indicated that foraging populations of the eastern subterranean termite, *Reticulitermes flavipes* (Kollar), contain ≈0.2–5 million termites per colony and can forage a linear distance of 79 m (Grace et al. 1989, Su et al. 1993). Galleries of the subterranean termite populations include many nesting structures (main nest and satellite nests) or foraging sites interconnected by tunnels. Damage to houses occurs when termite activity moves above the soil surface (Su 1991b).

Esenther & Gray (1968) proposed that a slow-acting toxicant might be used to eliminate established colonies of subterranean termites, *Reticulitermes* spp. Bait blocks impregnated with dechlorane (mirex) and buried in the soil suppressed field activities of *Reticulitermes* colonies (Esenther & Beal 1974, 1978). Mirex was also used in baits to kill field colonies of the Australian subterranean termite, *Mastotermes darwiniensis* Frogg (Paton & Miller 1980). Several slow-acting toxicants including hydramethylnon (Su et al. 1982), avermectin $B_1$ (Su et al. 1987), A-9248 (diiodomethyl para-tolyl sulfone) (Su & Scheffrahn 1988b), and sulfluramid (Su & Scheffrahn 1991) have been identified as potential candidates for use in baits. One of the toxicants, A-9248, was used in a field study by Su et al. (1991a) to suppress foraging populations of colonies of *C. formosanus*.

Another group of chemicals that can be incorporated in baits includes the insect growth regulators, because of their apparent slow action (Jones 1984, Su et al. 1985, Haverty et al. 1989, Su & Scheffrahn 1989). Juvenile hormone analogs (JHAs) are known to significantly induce presoldier formation of *Reticulitermes* spp. that contain small (1–2%) soldier proportions (Su & Scheffrahn 1990). One of the JHAs, fenoxycarb, was used in baits to suppress foraging activity of field colonies of *Reticulitermes* spp. (Jones 1989).

In laboratory evaluations, a chitin synthesis inhibitor, hexaflumuron, appeared to be promising for use in baits against both *R. flavipes* and *C. formosanus* (Su & Scheffrahn 1993). In the study described here, I evaluated a baiting procedure that incorporated a matrix containing hexaflumuron against field populations of *R. flavipes* and *C. formosanus*.

## Materials and Methods

**Characterization of Subterranean Termite Colonies' Foraging: Activity, Population, and Territory.** Three field colonies each of *R. flavipes* and *C. formosanus* were selected for testing. Wooden-stake surveys (Su & Scheffrahn 1988a) were done in areas of known termite activity. Survey stakes (*Picea* spp.; 2.5 by 4.0 by 28 cm) were driven into soil adjacent to structures or dead trees known to be infested with termites and were examined monthly. Infested stakes were replaced by underground monitoring stations that included wooden blocks surrounded by plastic collars measuring 17 cm diameter by 15 cm high, as described by Su & Scheffrahn (1986). These blocks were composed of 10 wooden boards (four boards [each 2.0 by 6.0 by 12.5 cm] encircling six boards [0.5 by 6.0 by 12.5 cm]) nailed together. The six thinner boards were separated by wooden applicator sticks (2 mm diameter) used as spacers to maximize the surface area available to foraging termites. Wooden blocks were dried at 80°C for 48 h and weighed (±0.1 g) before placement in monitoring stations. Termites readily entered wooden blocks in the stations and were separated from debris as described by Tamashiro et al. (1973). Wooden block remnants were rinsed under running water, oven dried, and weighed as described above. Weight loss of a wooden block was determined monthly or bimonthly to assess foraging activity of the subterranean termite colony being tested. Termite activity was measured 0.5–2 yr before the introduction of baits treated with hexaflumuron.

After the establishment of five or more monitoring stations for each colony, a triple mark–recapture procedure (Su & Scheffrahn 1988a) was used to estimate the foraging territory and the population. Worker termites collected from a station with high activity (>5,000 termites) were fed on filter disks (Whatman no. 1, 5.5 cm) stained with 0.05% (wt/wt) Nile Blue A (Su et al. 1991b) for 3 d before being released back to the same station. This blue marker remained visible in termites 6 mo after staining. Termites were collected at monitoring stations 1 wk after the release of stained termites. Termites collected from stations containing marked termites from the first release were counted and again stained and released to their respective stations. The mark–release–recapture cycle was repeated three times for each colony. The numbers of marked and unmarked workers were recorded for each cycle. A weighted mean model (Begon 1979) was used to estimate the foraging populations ($N$) and associated standard errors (SE) $N = (\Sigma M_i n_i)/[(\Sigma m_i) + 1]$;

$$SE = N\sqrt{[1/(\Sigma mi + 1] + [2/(\Sigma mi + 1)^2] + [6/(\Sigma mi + 1)^3]}$$

where for each $i$th cycle, $ni$ is the number captured, $mi$ is the number of marked individuals among captured termites, and $Mi$ is the total number of marked individuals up to the $i$th cycle. The foraging territory of each colony, defined as the area encompassed by interconnected stations, was determined by the presence of marked termites.

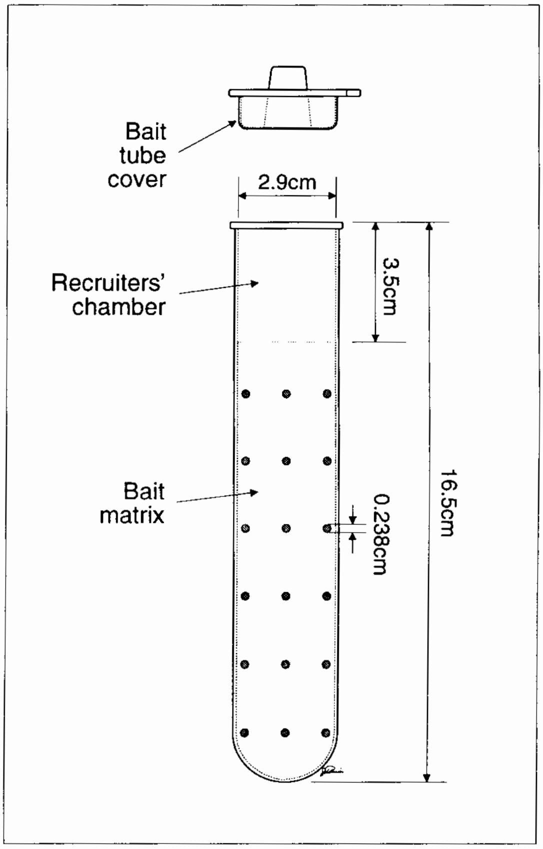


**Fig. 1.** A bait tube containing hexaflumuron-treated bait matrix (sawdust and Methocel or agar) and a "recruiters' chamber."

**Bait Tube.** Pine (*Pinus* spp.) or spruce (*Picea* spp.) sawdust was impregnated with an acetone solution of hexaflumuron to yield desired concentrations (500, 1,000, 2,500, or 5,000 ppm wt [AI]/dry wt sawdust) upon evaporation of acetone. These four concentrations were used for all colonies except colony I (*R. flavipes*), which was the first colony to be field tested with 750 ppm (AI). The treated sawdust was bound into a bait matrix composed of 20% (wt/wt) sawdust and 80% agar or Methocel (A4M Methylcellulose, Dow Chemical, Midland, MI) solution (2% wt/wt). Methocel, a water-soluble cellulose ether, was used as a binder and water retention agent. A plastic tube (2.9 cm inside diameter by 16.5 cm high; one end rounded, the other capped) was filled with ≈80 g of bait matrix, leaving a void (= recruiters' chamber) ≈3.5 cm high in the capped end (Fig. 1). The wet weight (±0.1 g) of bait matrix in each tube was determined before use. Six rows of nine holes (0.238 mm diameter) were predrilled into the walls of the tube (Fig. 1).

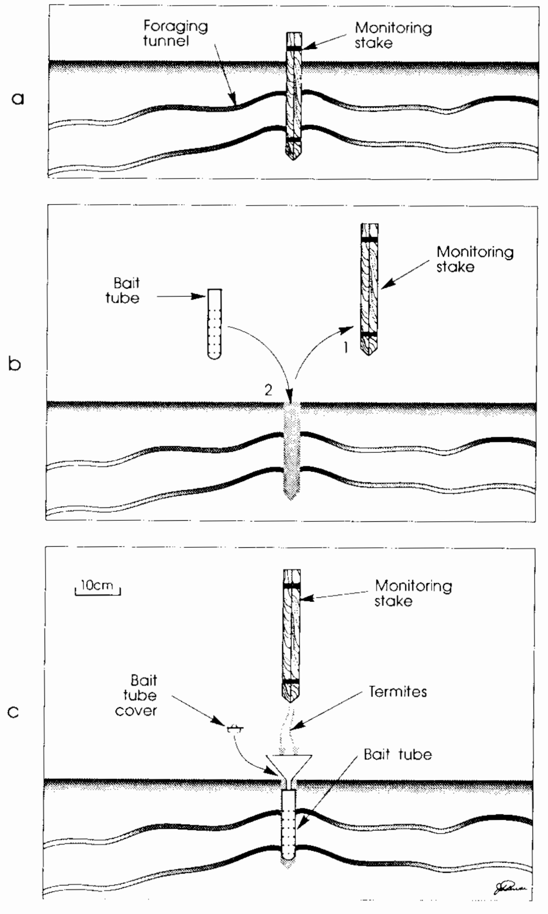


**Fig. 2.** Monitoring and baiting procedure. (a) A wooden stake is driven into the ground. (b) Once infested by termites the stake is gently pulled out of the soil, and a bait tube is inserted into the hole. (c) Termites in the stake are dislodged into the *recruiter's chamber* in the bait tube.

**Baiting Procedure.** The baiting procedure is illustrated in Fig. 2. Four stakes (*Picea* spp.; two pieces 1.7 by 3.4 by 30 cm taped together) were driven 20–25 cm into the soil evenly surrounding each active monitoring station (denoted by solid circles in Figs. 3 and 4) at ≈30-cm radii and were examined monthly. Once infested by termites, each wooden stake was gently pulled out of the soil, leaving an intact hole into which a bait tube was inserted. The infested stake was split into two pieces by cutting the binding tape and gently tapped to dislodge termites into a funnel inserted in the recruiters' chamber of a bait tube. The bait-tube lid was attached and covered with soil. Bait tubes were examined monthly and replaced with new tubes when termite activity was observed; those without termite activity were replaced with survey stakes. At the time of each monthly inspection, newly infested survey stakes also were replaced with bait tubes. Bait tubes were retrieved monthly from the field regardless of the bait consumption. Bait matrix in each tube was removed, separated from soil, and reweighed (wet weight) to determine the amount of bait matrix consumed by termites.

I hypothesized that greater bait consumption would result from the *self-recruiting* procedure because the extracted termites tunneled through the matrix to enter established foraging tunnels in soil, thus leaving the colony specific semiochemical cues in the matrix. To compare the efficacy of the self-recruiting procedure in enhancing the bait intake, the procedure was omitted in some bait tubes. Except for colony I, the amount of bait matrix consumed by termites from each bait tube was subjected to an analysis of variance using a 4 (concentrations) by 2 (inclusion or omission of the self-recruiting procedure) factorial design ($P < 0.05$; SAS Institute 1985). The analysis was done independently for each termite species.

Termite activity in monitoring stations was measured (by the wood weight loss of a block) throughout the baiting program. The baiting program ended when I found no termites in bait tubes. When termites remained in the monitoring stations after the baiting program was terminated, another triple mark–recapture cycle was done to estimate the population size of the baited colony.

## Results and Discussion

**Effects of Concentrations and Self-Recruiting Procedure on Bait Matrix Consumption.** I detected no significant difference in bait matrix consumption among four concentrations (500, 1,000, 2,500, and 5,000 ppm) for either *R. flavipes* ($F = 2.42$; df = 3, 65; $P > 0.05$) or *C. formosanus* ($F = 1.84$; df = 3, 65; $P > 0.05$). These results indicated that even the highest concentration of hexaflumuron (5,000 ppm [AI] wt/dry wt sawdust) did not deter termite feeding.

Significantly more bait matrix was consumed from bait tubes in which termites collected from the detection stakes were placed (self-recruited bait tubes) than tubes in which no termites were placed. The mean weight of bait matrix consumed by *R. flavipes* from self-recruited tubes was 39.2 g per station, whereas that of tubes without a self-recruiting procedure was 17.2 g per station ($F = 6.73$; df = 1, 65; $P < 0.05$). For *C. formosanus*, the mean weight of consumed bait matrix was 35.8 and 6.5 g per station for self-recruited tubes and tubes without a self-recruiting procedure, respectively ($F = 5.51$; df = 1, 65; $P < 0.05$).

**Effects of Hexaflumuron Baits on Field Colonies.** Foraging populations and territories of three colonies each of *R. flavipes* (I, II, and III) and *C. formosanus* (IV, V, and VI) estimated

**Table 1. Foraging populations of *R. flavipes* and *C. formosanus* colonies before the introduction of hexaflumuron baits**

| Species | Colony | Worker wt, mg, mean ± SEM | No. of active monitoring stations | Estimated foraging population (× $10^3$, mean ± SEM) | Max distance,[a] *m* | Foraging territory, $m^2$ | Foraging biomass,[b] *kg* |
|---|---|---|---|---|---|---|---|
| *R. flavipes* | I | 1.86 ± 0.09 | 6 | 476 ± 4 | 9 | 31 | 0.89 |
| | II | 2.00 ± 0.28 | 6 | 730 ± 17 | 15 | 40 | 1.46 |
| | III | 2.03 ± 0.13 | 13 | 2,847 ± 70 | 71 | 2,361 | 5.78 |
| *C. formosanus* | IV | 4.22 ± 0.16 | 8 | 1,047 ± 37 | 100 | 1,614 | 4.42 |
| | V | 3.47 ± 0.18 | 6 | 2,431 ± 136 | 30 | 143 | 8.44 |
| | VI | 3.68 ± 0.17 | 10 | 1,225 ± 40 | 185 | 2,189 | 4.51 |

[a] Maximum linear distance between two monitoring stations containing marked termites.
[b] Foraging biomass = estimated number of foraging termites × mean worker weight.

before introduction of baits are summarized in Table 1 and Figs. 3 and 4.

*Colony I.* Infestations of colony I were found in the door and door frame of a nearby building in 1989 (Fig. 3). The foraging population of this *R. flavipes* colony was estimated (mean ± SEM) at 476,000 ± 4,000 in September 1990 (Table 1). Foraging activity of colony I in monitoring stations during 1990–1992 is shown in Fig. 5. Wood weight loss from the six monitoring stations was ≈2 g per station per day during the summer of 1990. The feeding activity declined to ≈0.5 g per station per day during the winter. Three bait tubes (two in January, one in February) were introduced in the spring of 1991. By April 1991, I found no termite activity in any of the monitoring stations or bait tubes (Figs. 3 and 5). A total of 25.8 g bait matrix was consumed by this *R. flavipes* colony (Table 2). Because of the absence of termite activity after April 1991, I concluded that the entire colony (>400,000 termites) was eliminated by the consumption of 3.9 mg hexaflumuron within 3 mo (Table 2).

*Colony II.* The foraging population of this *R. flavipes* colony was estimated (mean ± SEM) at 730,000 ± 17,000 in September 1990 (Table 1). Colony II was located in a nonresidential area (Fig. 3). Termites were found in trees and fallen logs of ficus (*Ficus laevigata* Vahl), pine (*Pinus* sp.), and oak (*Quercus virginianus* Michaux). Throughout 1990 and the spring of 1991, wood weight loss from the six monitoring stations was ≈2 g per station per day (Fig. 5). I introduced 11 bait tubes in April 1991. In May 1991, termite activity was 1.8 g per station per day. By July 1991, however, the activity was reduced to 0 g per station per day (Fig. 5). During the baiting period from April to June, a total of 122.0 g bait matrix was consumed (Table 2). I have recorded no termite activity in this location during monthly surveys since July 1991 (Figs. 3 and 5). Therefore, I concluded that the colony of 730,000 termites was eliminated by consuming 20.3 mg of hexaflumuron (Table 2).

*Colony III.* Structural infestation by this *R. flavipes* colony had persisted in a two-story apartment building (≈597 $m^2$ floor space) since 1987 (Fig. 3). Residents reported annual spring swarming from the structure for 5 consecutive yr (1987–1991). Annual soil termiticide treatments were applied by a pest control firm from the time of building construction in 1986 until 1991. Despite the repeated soil termiticide treatments (the total amount of soil termiticides [chlorpyrifos and permethrin] used was estimated at a rate of ≈60 kg [AI]), the foraging population of this *R. flavipes* colony was estimated to be (mean ± SEM) 2,847,000 ± 70,000 in May 1991 (Table 1). Foraging territory was ≈2,361 $m^2$. Mean wood weight loss from the 13 monitoring stations ranged from 2 to 4 g per station per day (Fig. 5). After the introduction of 27 bait tubes in August 1991, the activity was reduced to 0.1 g per station per day in September 1991. However, termites remained active in bait tubes in October and November of 1991. By December 1991, I detected no termite activity from any of the monitoring stations or bait tubes (Fig. 5). During the 4-mo baiting period (August–November), a total of 69 bait tubes was administered. From these, 2,966.7 g bait matrix and 1,538.9 mg hexaflumuron were consumed by this *R. flavipes* colony (Table 2). Residents of the building reported that the spring of 1992 was the first season since 1987 that they did not see swarming termites. No soil termiticide treatment was done in 1992. In March 1992, termites were collected in one of the monitoring stations (Fig. 3). A triple mark–recapture program conducted in March–April 1992 resulted in an estimate of 260,000 ± 16,000 foraging termites in the colony (Table 2). Assuming these termites were the remaining population of the baited colony, I concluded that the baiting program conducted in August–November 1991 had eliminated >2.5 million termites.

*Colony IV.* Foraging activity of this *C. formosanus* colony has been monitored since 1986 when structural infestations were found in an 11-story high rise (Fig. 4). Numerous treatments with soil termiticide were done to prevent structural infestation by the colony. The foraging population was estimated to be (mean ± SEM) 1,047,000 ± 37,000 in September 1990 (Table 1). The foraging territory covered 1,614 $m^2$. Mean

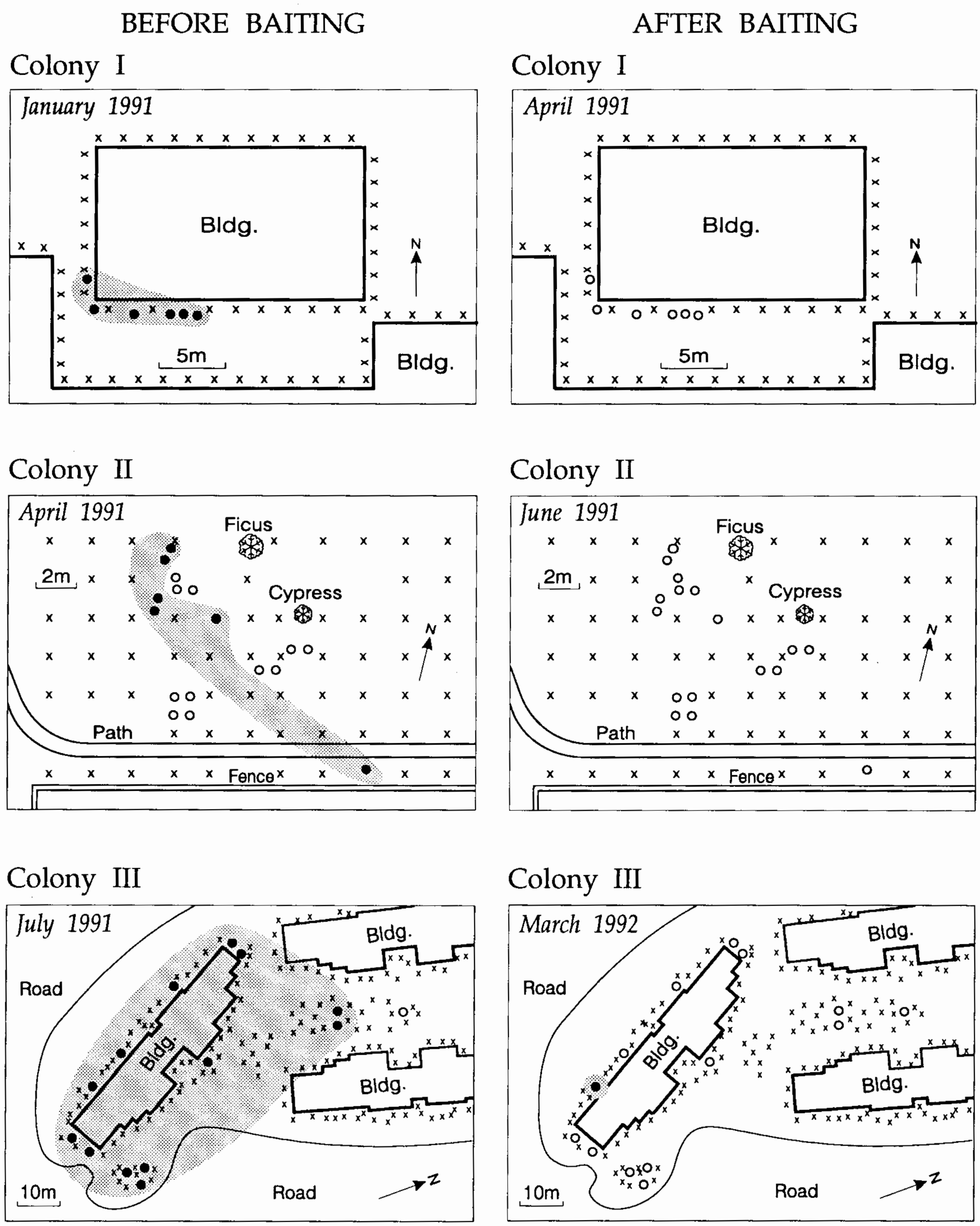


**Fig. 3.** Foraging territories (shaded areas) of three field colonies of *R. flavipes* (I, II, and III) before and after receiving bait matrix containing hexaflumuron. Each X denotes a survey stake, the solid circles denote underground monitoring stations with termite activity, and the open circles denote monitoring stations without termite activity. Survey stakes without termite activity and outside the colony territory are not shown in the figure.

wood weight loss was 2–4 g per station per day in 1989 (Fig. 6). The foraging activity typically declined in winter but peaked during summer months in 1990 (5–10 g per station per day). Five bait tubes were first introduced in April 1991. The foraging activity was reduced to <2 g per station per day in July 1991 and remained at a similar low level until October 1991. By Novem-

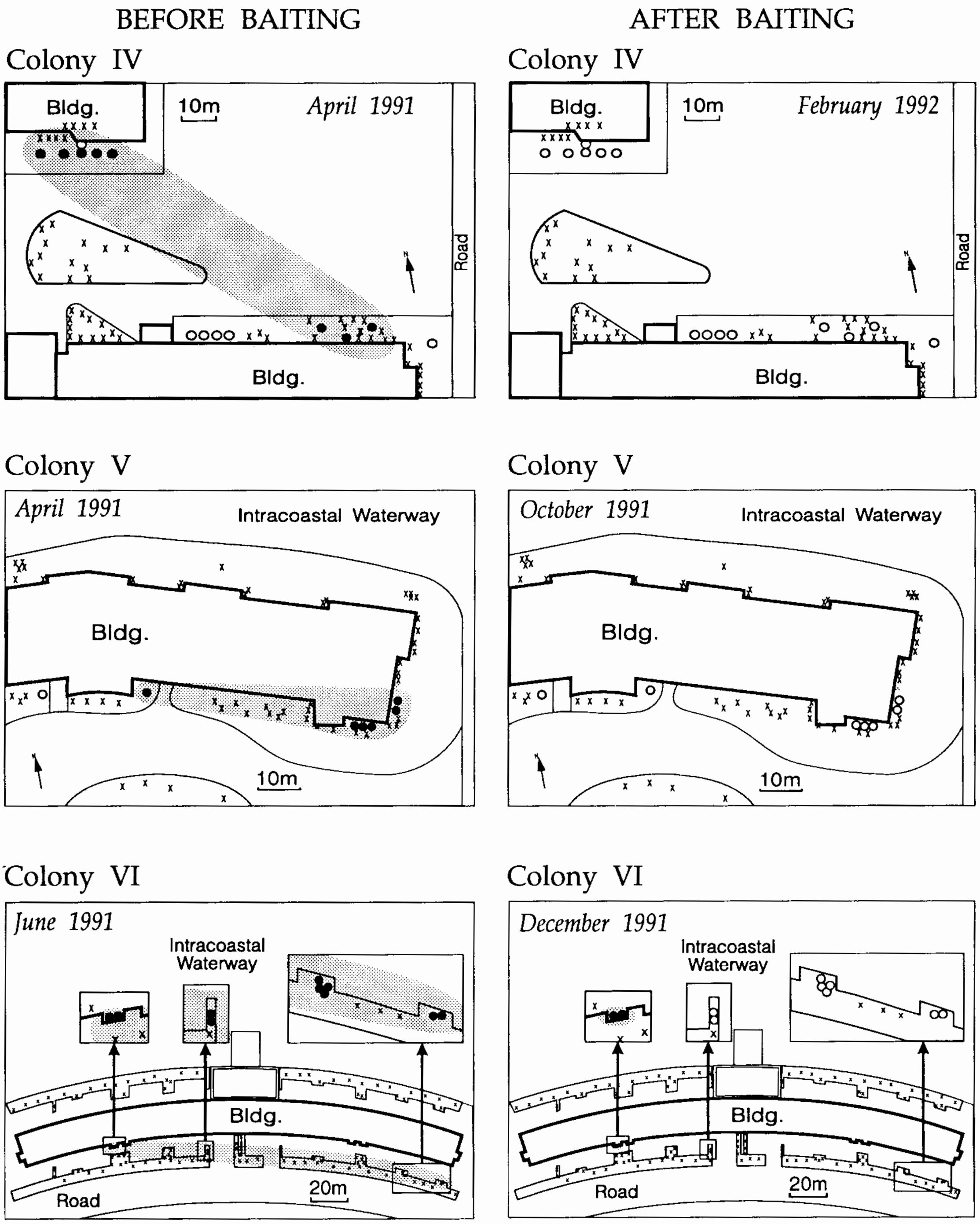


**Fig. 4.** Foraging territories (shaded areas) of three field colonies of *C. formosanus* (IV, V, and VI) before and after receiving bait matrix containing hexaflumuron. Each X denotes a survey stake, the solid circles denote underground monitoring stations with termite activity, and the open circles denote monitoring stations without termite activity. Survey stakes without termite activity and outside the colony territory are not shown in the figure.

ber 1991, no termites were found in the monitoring stations, but I observed slight feeding activity in a few bait tubes until January 1992 (Fig. 6). No termites were found in any of the stations from February 1992 until the final sample date (October 1992) (Fig. 4). During the baiting period (April 1991–January 1992), a total of 40 bait tubes was used; 846.7 g of bait matrix was con-

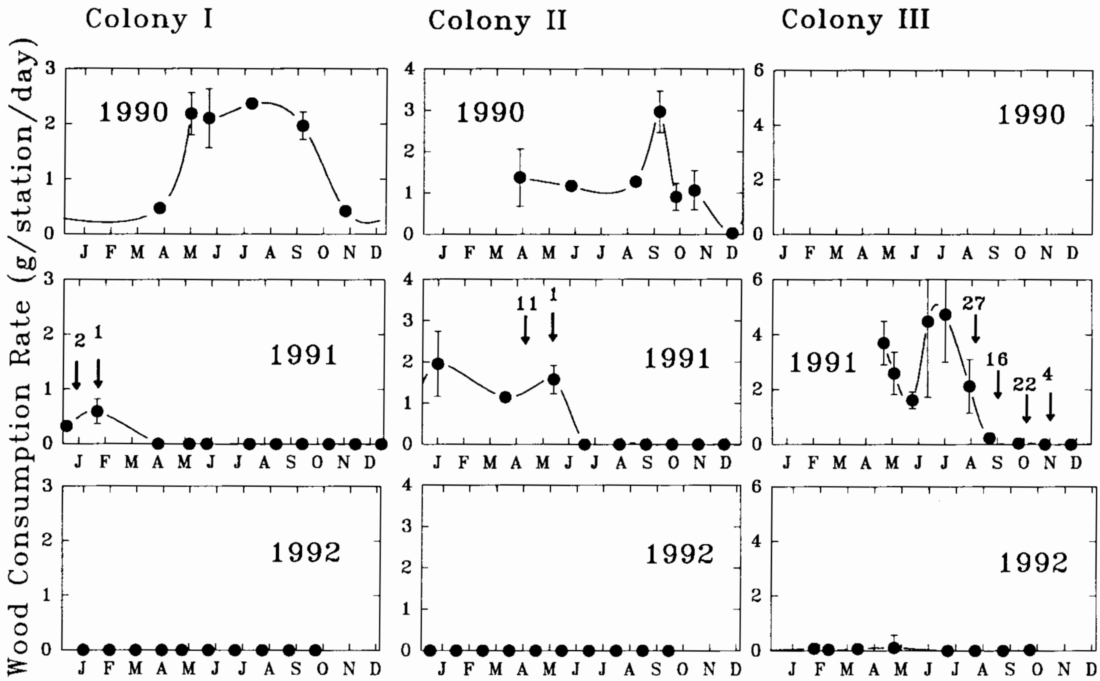


**Fig. 5.** Foraging activity (g wood consumed per station per day) of three *R. flavipes* colonies before, during, and after a baiting program using bait matrix containing hexaflumuron. Arrow(s) indicate bait applications. Numbers associated with each arrow are numbers of bait tubes used for each bait application.

sumed by this *C. formosanus* colony (Table 2). I concluded that the colony of 1.0 million termites was eliminated after consuming 233.1 mg of hexaflumuron over a 9-mo period.

*Colony V.* Despite repeated soil termiticide treatments and a fumigation after the discovery of structural infestations by this *C. formosanus* colony in a high rise in 1987 (Fig. 4), foraging activity remained strong between 1989 and 1991 (mean wood weight loss: 6–10 g per station per day) (Fig. 6). Activity of this *C. formosanus* colony did not decline even in winter months. The foraging population was estimated to be (mean ± SEM) 2,431,000 ± 136,000 in March 1991 (Table 1). More than 90% of the bait matrix of the eight bait tubes introduced in April 1991 was consumed within 2 wk. Foraging activity in April–June was reduced slightly to ≈5 g per station per day (Fig. 6). Subsequently, the mean wood weight loss declined to near zero between July and October 1991.

In October 1991, residents reported that *C. formosanus* swarmed in the first floor of the building. Because *C. formosanus* generally swarms in the spring (April–July), this unseasonal swarming may have been caused by the deteriorated colony conditions induced by the baiting. Since November 1991, I have detected no termite activity in any of the stations (Fig. 4). During the 7-mo baiting period (April–November), a total of 89 bait tubes was used; from these, 3,405 g of bait matrix was consumed (Table 2). I concluded that the colony of 2.4 million termites was eliminated by the consumption of 742.3 mg hexaflumuron (Fig. 4).

*Colony VI.* Infestations by this *C. formosanus* colony were found in the utility room of a high-rise condominium. Foraging activity was de-

**Table 2. Summary of baiting programs using matrix containing hexaflumuron and their effects on the foraging populations of three colonies each of *R. flavipes* and *C. formosanus***

| Species | Colony | Initial population (× $10^3$) | No. bait tubes used | No. baiting required | Bait matrix consumed, g | AI consumed, mg | Final population (× $10^3$) | Baiting period (mo) |
|---|---|---|---|---|---|---|---|---|
| *R. flavipes* | I | 476 | 3 | 2 | 25.77 | 3.87 | 0 | 3 |
| | II | 730 | 12 | 2 | 121.99 | 20.26 | 0 | 2 |
| | III | 2,847 | 69 | 4 | 2,966.70 | 1,538.85 | 260 | 4 |
| *C. formosanus* | IV | 1,047 | 40 | 9 | 846.68 | 233.08 | 0 | 9 |
| | V | 2,431 | 89 | 7 | 3,405.40 | 742.26 | 0 | 7 |
| | VI | 1,225 | 42 | 4 | 1,182.20 | 259.34 | 104 | 4 |

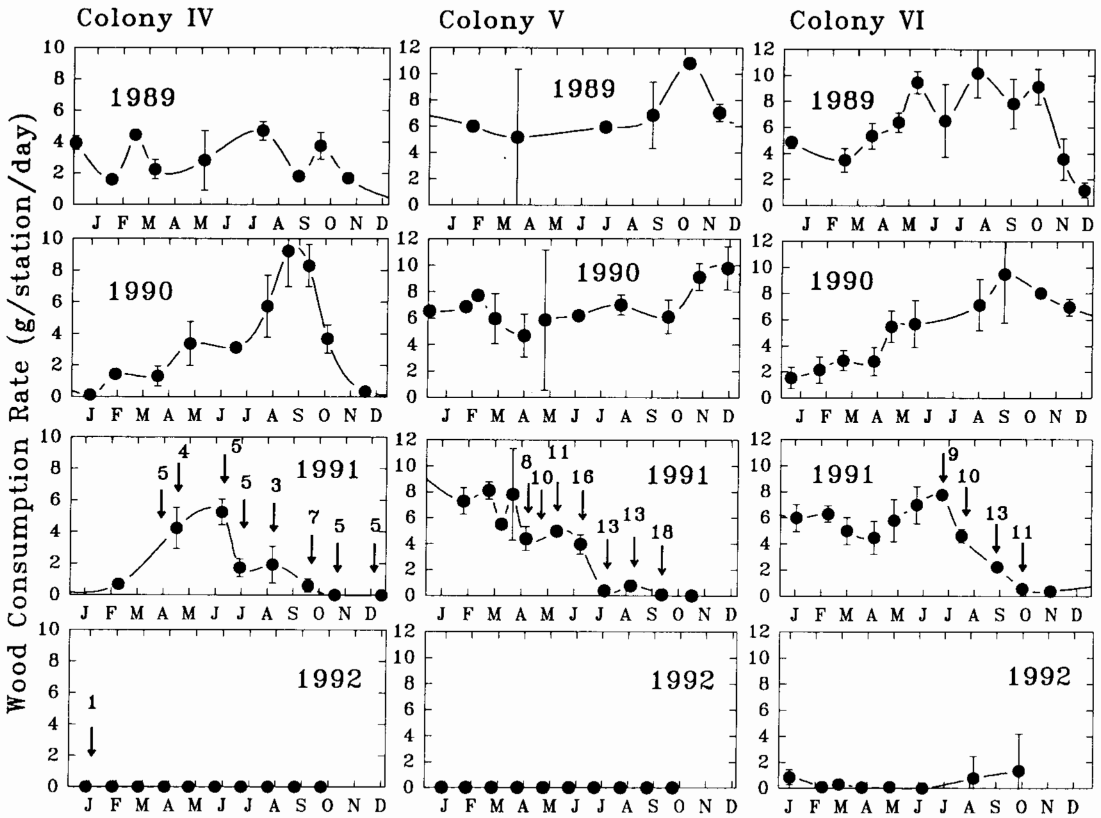


**Fig. 6.** Foraging activity (g wood consumed per station per day) of three *C. formosanus* colonies before, during, and after a baiting program using bait matrix containing hexaflumuron. Arrow(s) indicate bait applications. Numbers associated with each arrow are numbers of bait tubes used for each bait application.

tected along the front yard of the building, with a maximum linear foraging distance of 185 m (Fig. 4). During the summer of 1989 and 1990, this *C. formosanus* colony consumed wood at a rate of ≈5–10 g per station per day from the 10 monitoring stations (Fig. 6). Foraging activity declined in winter of 1989. Foragers of colony VI, however, were active during the winter months of 1990. The foraging population was estimated to be (mean ± SEM) 1,225,000 ± 40,000 in April 1991 (Table 1). After the introduction of nine bait tubes in July 1991, foraging activity declined steadily to near zero in October 1991. The baiting program was terminated in November 1991 because I found no termites in the bait tubes. Since October 1991, slight termite activity (<1 g per station per day) remained in two monitoring stations (Figs. 4 and 6). Using termites collected from these two stations, I did a triple mark–recapture program in March 1992 and estimated the remaining population to be (mean ± SEM) 104,000 ± 5,000 termites (Table 2). A total of 42 bait tubes was used during the 4-mo baiting period (July–October); from these, 1,182.2 g of bait matrix was consumed (Table 2). I concluded that the consumption of 259.3 mg hexaflumuron during the 4-mo period reduced the population size of this colony from 1.2 million termites in April 1991 to 104,000 in March 1992.

Results of this study demonstrated that ≈4–1,500 mg hexaflumuron was needed to reduce foraging populations of subterranean termites by 90–100%. Approximately 5–10 kg (AI) of soil termiticide is used currently for barrier treatments of a typical single-family house. In contrast to the conventional one-step application, this baiting procedure included both monitoring and baiting. If a similar procedure is adopted by the pest-control industry, pesticides will be used only when termites are present. Because a minimal amount of pesticide is needed and because pesticides are not used in the absence of termites, this procedure might drastically reduce the amount of termiticides used for subterranean termite control.

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