Suppression of Foraging Populations of the Formosan Subterranean Termite (Isoptera: Rhinotermitidae) by Field Applications of a Slow-Acting Toxicant Bait

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ABSTRACT A-9248 (diiodomethyl para-tolyl sulfone) baits treated at 600 ppm (wt/wt) were introduced into selected trap stations of three colonies of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, in Hallandale, Fla., between November 1987 and November 1988. Termites did not avoid foraging at sites containing treatment and nor was feeding significantly reduced on the treated versus untreated baits. One year after bait application, foraging populations of three colonies that received A-9248 baits were reduced 65–98%. The results demonstrated that a toxicant bait can be used to suppress foraging populations of subterranean termite colonies and hence reduce their damage potential.

KEY WORDS Insecta, *Coptotermes formosanus*, diiodomethyl para-tolyl sulfone, control

BEFORE THE widespread use of chlorinated hydrocarbons as poison barriers for subterranean termite control during the 1950s, researchers observed that slow-acting toxicants like arsenic dusts reduced colony populations of termites (Randall & Doody 1934). Contemporary soil termiticides are applied to exclude soil-borne termites from structures. On the other hand, slow-acting toxicants are used to reduce the pest population. This is done by providing a means for individual termites to acquire a lethal dose of slow-acting toxicant at a given foraging site. The intoxicated individuals must not be so impaired at the onset of lethal exposure that their movement away from the toxicant acquisition site is prevented. The slow-acting characteristic of a toxicant is particularly important because accumulation of dead termites at the acquisition site will repel other nestmates from approaching the treatment zone (Su et al. 1982b). Ideally, the toxicant should be nonrepellent to termites, or at least be masked by other agents to prevent avoidance behavior by the foraging termites.

Results of earlier field tests of toxicant baits against populations of subterranean termites were either inconclusive or only partially successful (Esenther & Beal 1974, 1978, Paton & Miller 1980, Su et al. 1982a, Gao et al. 1985). More recently, Jones (1989) reported the reduction of foraging activities of *Reticulitermes* spp. when baits treated with fenoxycarb were exposed to field colonies.

Laboratory studies indicated that several insect growth regulators (IGRs) (Jones 1984, Su et al. 1985, Haverty et al. 1989, Su & Scheffrahn 1989) and other toxicants (Su et al. 1987; Su & Scheffrahn 1988a,b) have shown delayed activity against the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, and the eastern subterranean termite, *Reticulitermes flavipes* (Kollar). None of them has been tested fully in the field.

Previous work with A-9248 indicated that its latent toxicity and low repellency characteristics against *C. formosanus* warranted a field trial (Su & Scheffrahn 1988a). Here we report our evaluation of the effects of A-9248 treated baits against field populations of *C. formosanus*.

Materials and Methods

Field Colonies and Bait Application. The trapping method described by Su & Scheffrahn (1986) was used to monitor foraging activities of six field colonies of *C. formosanus* in Hallandale, Fla. Wooden stakes (*Pinus* sp., 2.5 by 4.0 by 28 cm) were driven into the soil of planters and lawns near buildings known to be or to have been infested by *C. formosanus*. Stakes were placed 5–10 m apart and were examined monthly. Infested stakes were replaced by underground wood baits surrounded by polyvinylchloride (PVC) collars (17 cm diameter, 15 cm high).

Toxicant baits comprised six pine (*Pinus* sp.) boards (7 by 13 by 2 cm). Each board was dried in an oven at 80°C for 48 h and cooled in a desiccator before weighing to obtain the accurate dry weight (± 0.1 mg). Three of the boards were vacuum-impregnated with acetone only and three were impregnated with an acetone solution of A-9248 at ≈600 ppm (wt [AI]/wt wood) (ASTM 1976). In a laboratory choice-bioassay we determined that, at the concentrations of 200–800 ppm, A-9248 caused delayed mortality of *C. formosanus* without eliciting significant feeding deterrence (Su & Scheffrahn 1988a). Concentrations were estimated based on the mean volume of acetone solution ab-

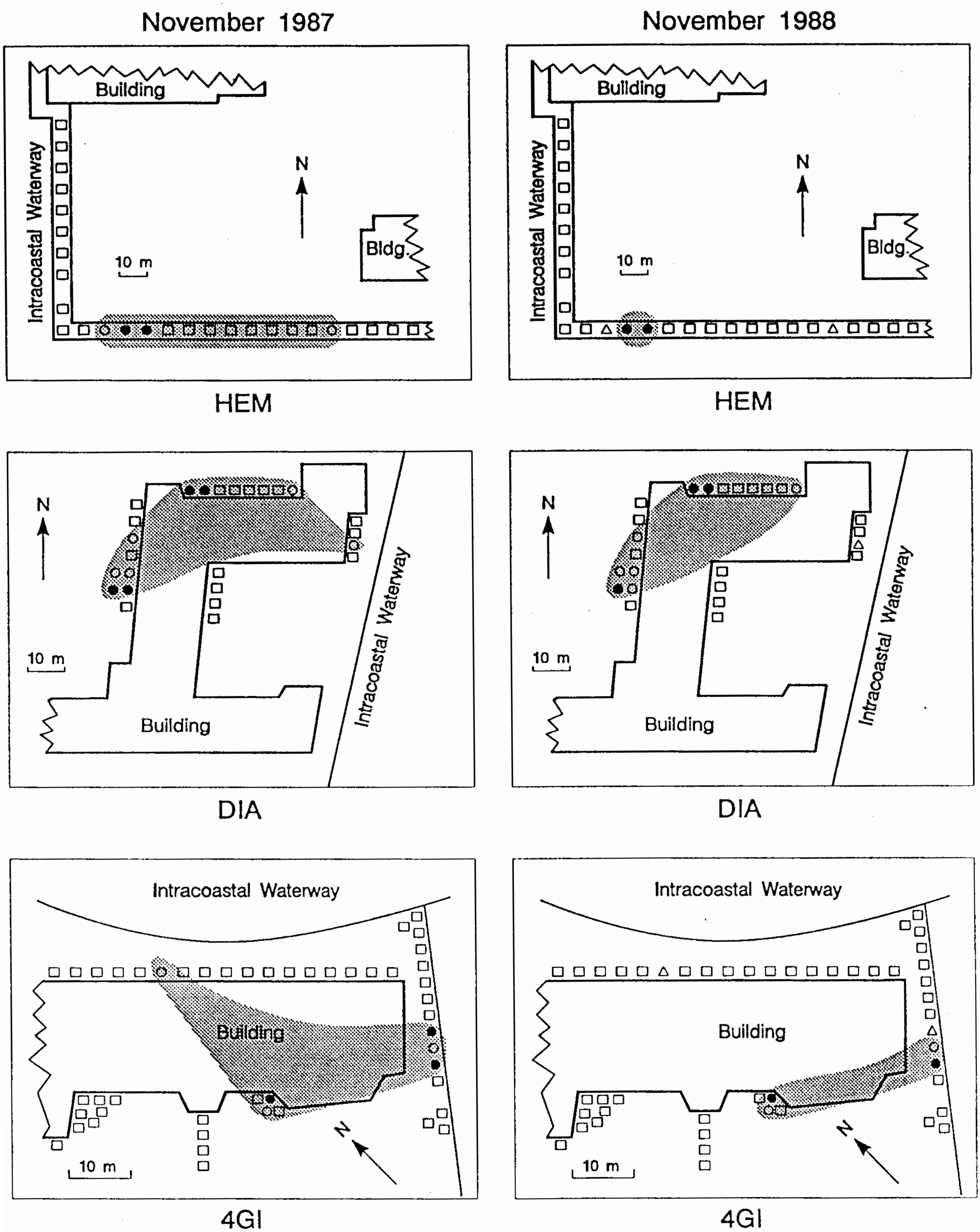

Fig. 1. Trap station locations of three colonies (HEM, DIA, and 4GI) that received baits treated with A-9248 between November 1987 and November 1988. The shaded areas, encompassed by interconnected trap stations, are defined as the foraging territories of each colony. Open squares represent uninfested wooden stakes used for the initial termite survey. Solid circles denote stations that received baits impregnated with A-9248; open circles denote stations that received similar baits without treatment. Open triangles indicate trap stations abandoned by termites in November 1988.

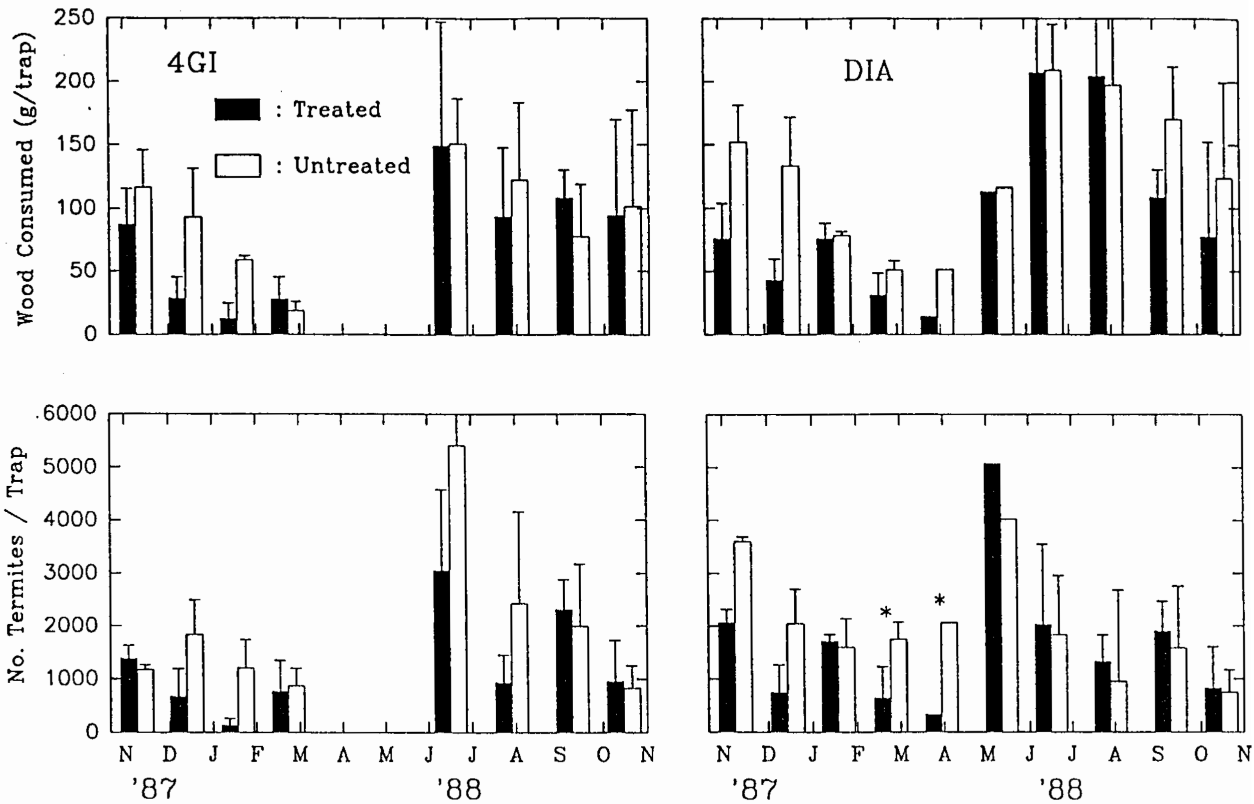

Fig. 2. Total amount of wood consumed by termites (sum of six boards, grams per trap), and numbers of termites collected in trap stations containing untreated baits or baits treated with A-9248, for colonies 4GI and DIA that received baits impregnated with A-9248. Asterisks denote significant differences in the wood consumption or numbers of termites between treated and untreated stations (t test, $\alpha = 0.05$), which implies a site preference for foraging termites.

sorbed by a pine board. In control baits, all six boards were treated with acetone only. Bait boards were fastened together with nails so that four were stacked atop each other and two were attached to each resultant 8-cm side.

Three colonies (HEM, DIA, and 4GI) were chosen to receive wood baits treated with toxicant; the other three (PT, HM, and GI) received untreated wood baits. These baits were placed in the trap stations from November 1987 to November 1988 and were collected and replaced every 30–40 d. Numbers of termites were determined. Wood remnants were rinsed with water to remove debris, placed in an oven at 80°C for 48 h, and cooled in a desiccator before they were reweighed to measure the loss of wood weight from feeding on each board.

Site Avoidance and Feeding Preference. Trap station locations of colonies 4GI, DIA, and HEM are shown in Fig. 1. For each of these three colonies, half of the trap stations were selected at random to receive baits treated with A-9248 (Fig. 1); the other half received control baits (Fig. 1). This test was done to determine if termites avoided foraging sites containing toxic baits. Variables used to evaluate foraging activities were wood consumption of each wood bait (sum of six boards) and numbers of termites collected from each station. A t test (SAS Institute 1987) was used to determine the significant difference ($\alpha = 0.05$) in wood consumption (grams per trap), and termites collected (number per trap) between trap stations that received toxic baits and those that received untreated wood. The site avoidance test was not done for colony HEM because there were insufficient replicates (two trap stations each for treated and untreated baits) for a t test (Fig. 1).

In addition to the site avoidance, we also examined within- trap feeding preference. For all of the trap stations that received toxic baits, wood consumption of three boards (grams per board) treated with A-9248 and three boards treated with acetone were compared with a t test ($\alpha = 0.05$; SAS Institute 1987).

Foraging Activity. Total wood consumed (grams per colony) and total numbers of termites (including all castes) from all of the trap stations of a colony were tabulated for each collection date throughout the bait application period. These two variables were used to represent the general foraging activity of each colony.

Foraging Population and Territory. Foraging populations of the six colonies were estimated before and after the introduction of toxicant baits with a multiple mark–release scheme described by Su & Scheffrahn (1988c). *C. formosanus* workers collected from a trap station with heavy activity were stained with 1% (wt/wt) Sudan Red 7B (Lai et al. 1983) for 10 d before being released back to the same station. Traps in the vicinity were collected 1 wk after the initial release. Termites collected from traps containing marked termites were 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 error (SE):

$$N = (\Sigma M_i n_i)/[(\Sigma m_i) + 1];$$

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

where for each ith cycle, n_i is the number captured, m_i is the number of marked individuals among captured termites, and M_i is the total number of marked individuals up to the ith cycle. Foraging territories of colonies, defined as the areas encompassed by interconnected trap stations, were determined by the presence of marked termites (Fig. 1). Foraging population surveys were done annually in the summer when termite activity was greatest. Colonies 4GI, PT, and GI were surveyed in 1986, 1987, and 1989; colonies DIA, HEM, and HM were surveyed in 1987 and 1989. The mark–release program was not done in 1988 to avoid unnecessary disturbance of the test populations during bait applications.

Results and Discussion

Site Avoidance and Feeding Preference. *C. formosanus* of colony 4GI did not avoid foraging in trap stations containing A-9248 treated wood (Fig. 2). Throughout the bait application, there was no significant difference in wood consumption or in numbers of foragers between stations that received treated wood and those that received untreated wood (Fig. 2). With the exception of March and April of 1988, when more DIA foragers were found in trap stations that received untreated wood (Fig. 2), the difference in wood consumption by workers of the DIA colony or the difference in the numbers of foragers between treated and untreated bait stations were not significant. Our results indicated that *C. formosanus* generally did not avoid foraging at trap stations containing A-9248 treated wood at 600 ppm.

Workers of colonies HEM and DIA preferred feeding on boards treated with acetone compared with those treated with A-9248 during the initial 1–2 mo (Fig. 3). However, there was no consistent tendency of one-sided preference between boards treated with A-9248 and those treated with acetone only. This is evident in some cases (e.g., DIA in April and 4GI in August), where termites fed significantly more on wood treated with A-9248 (t test, $\alpha = 0.05$). With the lack of a consistent pattern of feeding preference, we concluded that baits treated with A-9248 (at 600 ppm) were accepted as much as untreated wood by *C. formosanus*.

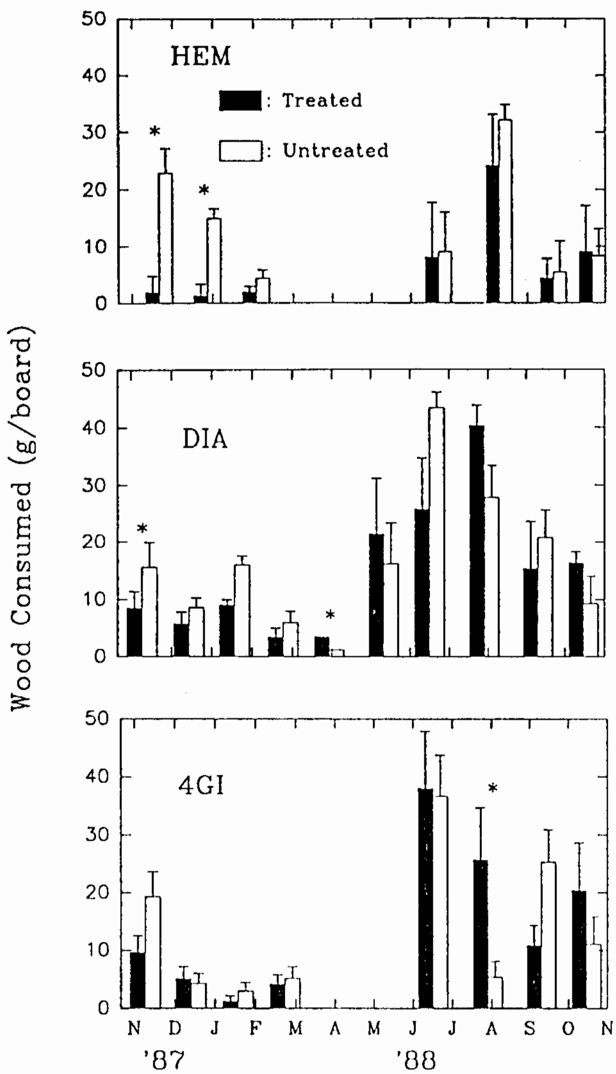

Fig. 3. Difference in wood consumption for boards impregnated with 600 ppm A-9248 placed in stations of colonies HEM, DIA, and 4GI. Asterisk denotes significant difference in wood consumption between boards treated with A-9248 and those treated with acetone only (t test, $\alpha = 0.05$).

Foraging Activity. Foraging activities of the three colonies that received toxicant baits, expressed by the total wood consumption and total numbers of termites collected per colony, steadily declined from November 1987 to April 1988 (Fig. 4). Activities of two colonies (DIA and HEM) were reduced to zero for 2–3 mo; those of untreated colonies (PT, HM, and GI) were elevated throughout the study period. A sudden surge of activity in May–June 1988 that occurred in the three treated colonies coincided with the swarming season. The foraging activity of treated colonies generally decreased again from the summer of 1988 to the end of the

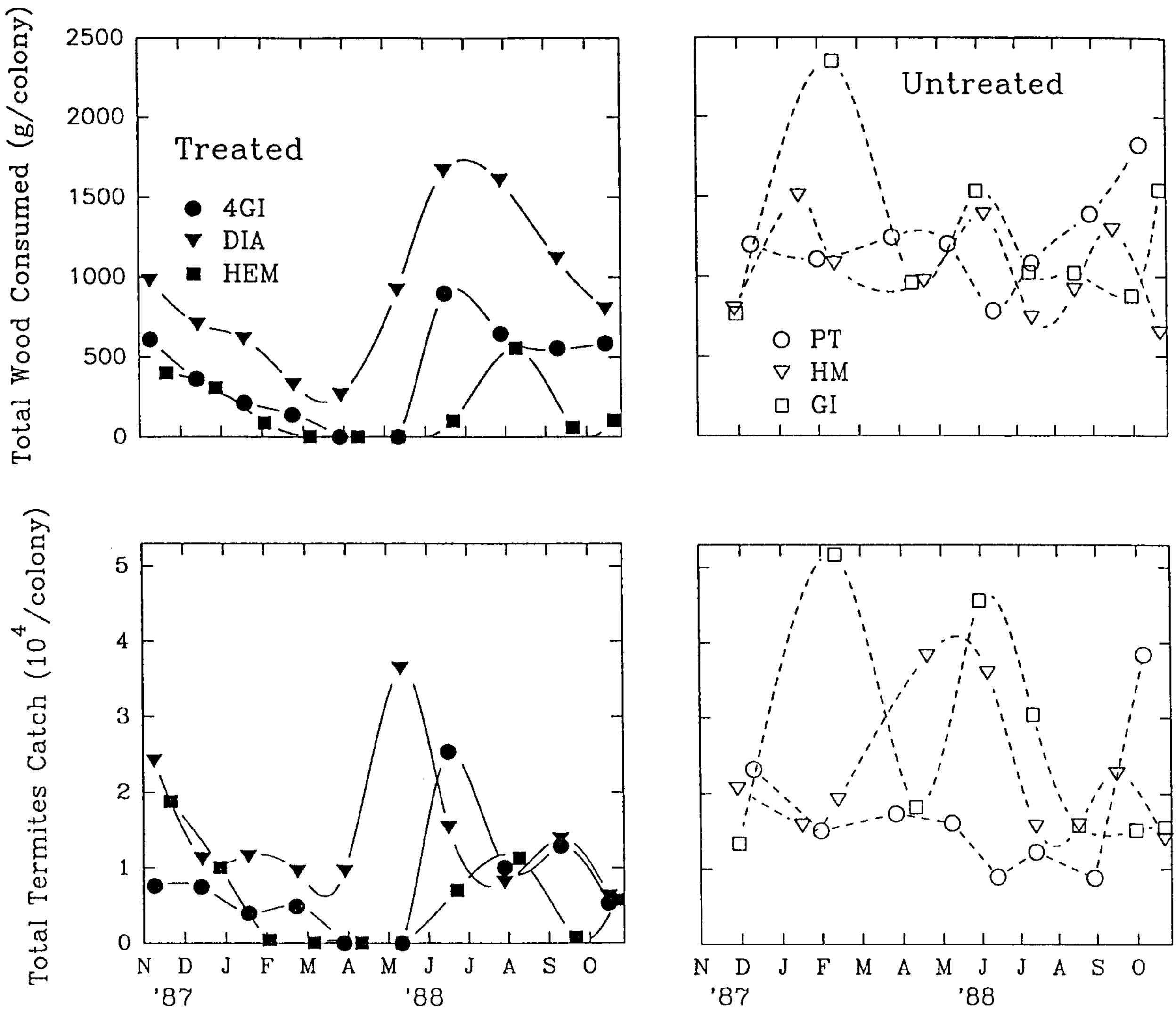

Fig. 4. Foraging activities as expressed by the total wood consumed (grams per colony) and total numbers of termites collected from three colonies that received baits treated with A-9248 (4GI, DIA, and HEM), and three colonies that received similar baits without treatment (PT, HM, and GI) between November 1987 and November 1988.

bait application. Foraging activities of colonies that received untreated wood also fluctuated (PT, HM, GI, Fig. 4). In the untreated colonies, however, no steady decline of foraging activity like that shown in colonies that received A-9248 treated baits occurred.

Foraging Population and Territory. Comparisons of the foraging activities between treated and untreated colonies suggested that A-9248 affected foraging activities of *C. formosanus* colonies. The extent of effects was further demonstrated in the changes of foraging populations before and after A-9248 treatment (Fig. 5). The foraging population (± SEM) of colony DIA declined drastically from 3.6 (± 0.5) million in 1987 to 68,000 (± 5,600) in 1989 after receiving baits treated with A-9248 for 1 yr in 1988. This treatment also reduced foraging populations of colonies 4GI and HEM from 4.2 (± 0.3) and 4.0 (± 0.5) million in 1987 to 1.2 (± 0.5) and 1.4 (± 0.1) million in 1988, respectively. During the same period, foraging populations of three colonies that received untreated wood increased (PT and HM) or did not change (GI) (Fig. 5). Foraging territories of three colonies that received A-9249 baits were reduced (Fig. 1), whereas those of the three untreated colonies remained unchanged.

Because of the cryptic habit of subterranean termites, effects of slow-acting toxicants against field colonies of subterranean termite has been difficult to evaluate. Radioisotopes were successfully used to monitor foraging activities of *C. formosanus* (Li 1976) and to evaluate mirex baits for control of *Mastotermes darwiniensis* Froggatt (Paton & Miller 1980). However, for safety reasons, use of radioisotopes in highly populated urban areas is not acceptable in the United States. In earlier control attempts, researchers used ground stakes to monitor

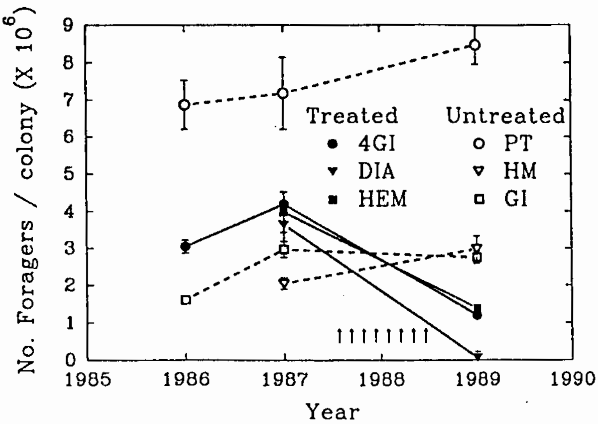

Fig. 5. Foraging population sizes of six *C. formosanus* colonies before and after the application of baits treated with A-9248 (shown as ↑). Solid symbols and lines denote populations of colonies that received treated baits; open symbols and broken lines denote those that received untreated wood baits.

termite activities (Esenther & Beal 1974, 1978; Su et al. 1982a; Jones 1989). Gao et al. (1985) examined the presence of dead termites after the bait application at sites previously containing live termites. The lack of termite activities in ground stakes or at a foraging site, however, may not necessarily be due to the decline of termite activities because termites may have been repelled by a treatment or simply shifted their foraging activities to different sites. As demonstrated in our study, foraging populations should be estimated before and after the bait application to adequately verify the effects on termite colonies.

Current soil termiticide treatments are designed to exclude soil-borne termites from structures. Because they are not likely to reduce the existing subterranean termite populations, severity of infestation by *C. formosanus* in areas such as Honolulu, Hawaii, and New Orleans, La., has escalated in recent years. Results of our study indicate that foraging populations of *C. formosanus* colonies were reduced 65–98% by the application of baits treated with A-9248. A toxicant bait, therefore, might provide a long-term control by suppressing subterranean termite foraging populations and hence reduce their damage potentials.

Various approaches have been taken to apply slow-acting toxicants for control of termite populations. Arsenic dust was applied directly into active foraging routes within infested structures (Randall & Doody 1934). The toxicant dust was spread throughout the foraging populations by social grooming. Gao et al. (1985) applied an edible paste formulation of mirex into active foraging galleries in infested structures. Edible baits containing slow-acting toxicants were also applied in established feeding sites outside of structures (Su et al. 1982a, Jones 1989), or applied within foraging territories but not at a feeding site (Esenther & Beal 1974, 1978). The probability of affecting larger portions of a foraging population increases when more toxicant baits are accessible to the target populations. To maximize the efficiency of bait acquisition by termites, different formulations and delivery systems of a slow-acting toxicant should be developed for application under the various conditions in the field.

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