Foraging Behavior of the Formosan Subterranean Termite (Isoptera: Rhinotermitidae)

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ABSTRACT A field study was conducted to examine the foraging pattern of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki. A dye, Sudan Red 7B, was used as a marking material to identify foragers feeding at specific foraging sites. The results showed that the termites selected their foraging sites at random. No preferences in foraging site were observed. Since foraging sites were selected at random, all of the foragers in a given colony would visit a specific foraging site, given sufficient time. It is theoretically possible, therefore, to introduce a suitable control agent in a single foraging site and eliminate the entire colony.

THE REMEDIAL CONTROL of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, has generally been erratic and unsatisfactory. This is in part due to the large number of individuals in a colony (Tamashiro et al. 1980), the extensive (100 m or more) foraging range of a colony (King and Spink 1969, Li et al. 1976, Lai 1977), the cryptic habits of the species, and the utilization of the wrong type of insecticides when infestations are found (Su et al. 1982).

These factors make it almost impossible to discover more than a small part of the galleries and foraging sites of a colony. At present, there is no method to pinpoint the location of the main nest. Treatment for remedial control, therefore, is limited to the small part of the colony that is discovered. However, treatment of that small discovered part of the colony with most currently available termiticides evokes behavioral responses from the termites that negate the effect of the treatment (Su et al. 1982). Termiticides currently used in remedial control are either repellent or fast acting. These materials cause the termites to seal off the treated area so that there is no further contact with the termiticide. Termites in the untreated parts of the colony, therefore, remain active.

To eliminate effectively existing colonies of the termite, a nonrepellent, slow-acting termiticide that can be introduced into a portion of the colony and affect the entire colony is required. The termiticide may be introduced in a bait, dust, or other formulation. The primary requirement is that the foragers acquire the termiticide, leave the treated area, and die in some other part of the colony. If the forager passes on toxic levels of the termiticide by trophallaxis to other individuals in the colony before dying, it would enhance the effect of the treatment. This is probably the only feasible method of eliminating large, established colonies of *C. formosanus*.

However, the effectiveness of the method is dependent upon the foraging behavior of the termite. If the foragers have a site preference and feed at only one or just a few sites, then only those foragers that frequent the treated area will be affected. The method, therefore, would not eliminate the colony. On the other hand, if the termites had no foraging site preferences, and selected the foraging sites at random, then with time most of the foragers would visit the treated sites. This could eliminate the entire colony. Control could be enhanced by trophallaxis.

This study was initiated to determine whether foragers of *C. formosanus* select their foraging sites from the available sites in a random or nonrandom manner.

Materials and Methods

A marker was required to determine how foraging sites were selected and to determine whether there were differences in the frequencies at which specific foragers fed at specific sites. Although radioisotopes have been used to mark termites to study food transfer (Gösswald and Kloft 1963, McMahan 1963, 1969, Alibert 1963, 1965, Spragg and Fox 1974, Li et al. 1976, Spragg and Paton 1980) the technique was not applicable because radioisotopes can be transferred by trophallaxis. Transferring the marker from one termite to another would bias the results by increasing the number of marked termites. A marker that was not transferred or transferred in amounts that were visually undetectable was required. The oil soluble dye Sudan Red 7B (BASF Wyandotte Co., N.J.) possessed these desired characteristics.

Sudan Red 7B was found to be innocuous to the

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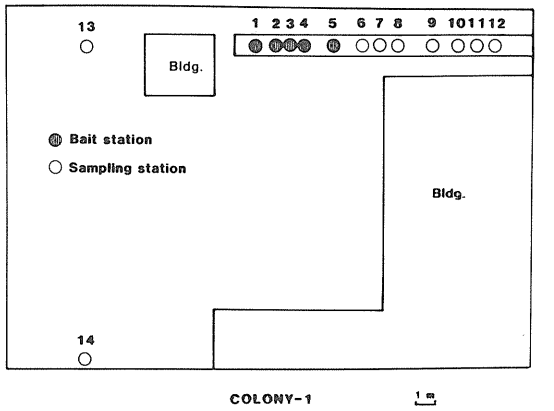

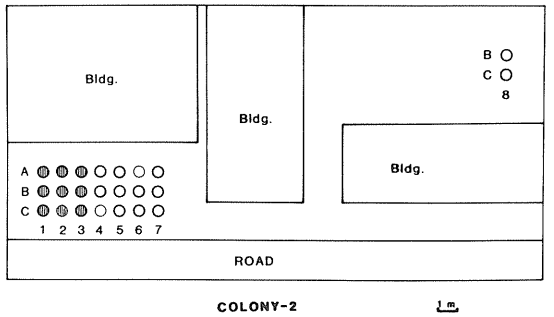

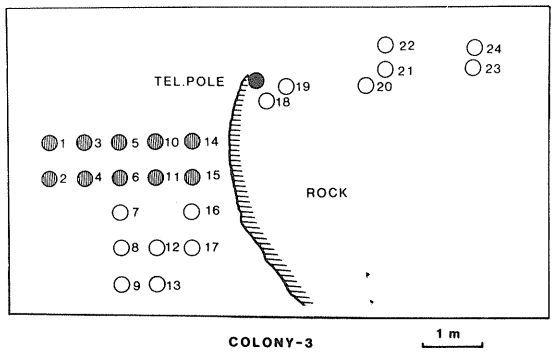

Fig. 1. A general layout of Colonies 1, 2, and 3 with bait and sampling stations.

termites and not transferred, or transferred at undetectable levels, by trophallaxis (Lai et al. 1983, Su et al. 1983). In addition, the concentrations of the dye in the termites could be quantified with a spectrophotometer and correlated with the amount of time termites forage on a dyed bait (Su et al. 1983).

Colonies and Trapping Method. Three colonies in the field were utilized in this study. The general layout of each colony and trap station is shown in Fig. 1. Colony 1 is located at Parker Place in Manoa Valley, Honolulu; Colony 2, on the University of Hawaii campus; and Colony 3, at Waahila Hill, Honolulu, Hawaii. The trapping method was similar to that described by Lai (1977).

Three months before beginning the studies on foraging behavior the populations of the colonies were estimated using the Lincoln Index (Begon 1979). Although there has been some criticism of the use of the mark-recapture method to estimate populations of social insects (e.g., Ayre 1962), it is the only practical method available in many situations (Baroni-Urbani et al. 1978). This is especially true in a species such as *C. formosanus*.

Sudan Red 7B was used to mark the termites using techniques developed by Lai et al. (1983). The marked termites were released directly into the galleries. The numbers of marked workers released in Colonies 1, 2, and 3 were 45,547; 18,573; and 19,730, respectively. Of these, 217, 272, and 105 were recaptured in Colonies 1, 2, and 3 when they were sampled 3 weeks after the marked workers were released. The total numbers of termites in the samples were 22,176; 34,934; and 9,586 for Colonies 1, 2, and 3, respectively.

The populations as estimated from these data were 4.4, 2.4, and 1.8 $\times$ 10^6 individuals for Colonies 1, 2, and 3, respectively. These were estimates of the foraging population of each colony since this technique just measured that part of the total populations. There are indications that the total population of the colony is much larger than just the foraging population, since there are many individuals that do not come out to forage.

Trap stations in each colony were designated as bait or sampling stations. In each of the bait stations, ten paper towels, 25 by 65 cm, containing 4% Sudan Red 7B (wt/wt) were rolled into a bundle and placed in a trap (Tamashiro et al. 1973) modified so that there was a hollow central core. The paper towels in the bait stations were stained by dipping the towels into acetone solutions of the dye. Bait stations were 1 through 5 for Colony 1; A1 through A3, B1 through B3, C1 through C3 for Colony 2; and 1 through 6, 10, 11, 14, and 15 for Colony 3 (Fig. 1).

In the sampling stations, the paper towel roll was modified to allow frequent sampling with a minimal disturbance of the termites. Approximately 20 sets of disposable chopsticks, 0.5 by 16 cm, were incorporated into the roll to separate the layers of paper in the roll. The roll was then slit longitudinally into two parts. The halves were held together with a piece of copper wire. When these rolls were sampled, the termites were easily separated from the paper after the wire was unfastened.

Foraging Site Preference. Colonies 1 and 2 were sampled every 3 days for 3 weeks, while Colony 3 was sampled at 1, 2, 4, and 8 days after the

stained baits were introduced into the traps, to determine the rate of increase of marked individuals in the colony. Colony 3 was not sampled for a longer period because most of the foragers in the sampling units were stained by the eighth day. The marked and unmarked individuals in each sample were visually separated and counted. After the counts were made, all the termites were returned to the colony on the same day via their respective sampling stations.

Foraging Frequency. The proposed control method using slow-acting, nonrepellent termiticides can be affected by the amount of toxin consumed by individual foragers. The amounts eaten can vary because some foragers may feed longer or return to feed more often than others.

Although the amounts of food eaten by an individual forager could not be directly quantified, the relative time that the foragers fed on the stained bait could be estimated using a technique developed by Su et al. (1983). Su et al. found that there was a direct correlation between the length of time that a forager fed on paper dyed with Sudan Red 7B and the residual dye left in the forager from 8 to 10 days after it was taken off the dyed food. Apparently, some of the tissues or parts of tissues took up or eliminated the dye at a slow and relatively constant rate. The amount of residual dye, and therefore the feeding duration, could be quantified with a spectrophotometer. A termite that fed longer would logically consume more food. This technique was used to determine whether there were foragers that consumed significantly more food than others.

Three weeks after Red 7B-stained papers were introduced into the colony, they were removed and replaced with sampling units. Termites were sampled from all units 9 days after the sampling units were placed in the colony. Fifteen dyed workers were selected at random from each station and homogenized singly in a microgrinder with 0.3 ml of acetone. The volume of acetone was reduced to increase the dye concentration. The grinder was centrifuged at 10,000 rpm at 0°C. One hundred eighty individuals from Colony 1 and 360 individuals from Colonies 2 and 3 were processed in this manner. A sipper system spectrophotometer (Beckman, Model 26) was used to handle the large number of samples. However, since the sipper system normally required 1 ml of solution, the system was modified by inserting a 0.28-mm polyethylene tube into the input tubing. With this modification, readings could be made accurately with volumes as low as 0.15 ml.

The absorbance reading for each individual was converted into a unit absorbance using the following equation:

$$A = 0.3A'/W$$

where A is the unit absorbance; A' is the actual absorbance reading from the spectrophotometer; and W, the weight of a single forager. The unit absorbance was the equivalent absorbance from 1 g of foragers in 1 ml of solution. The unit absorbance could be used to determine whether there were differences in the amount of dyed paper eaten by foragers.

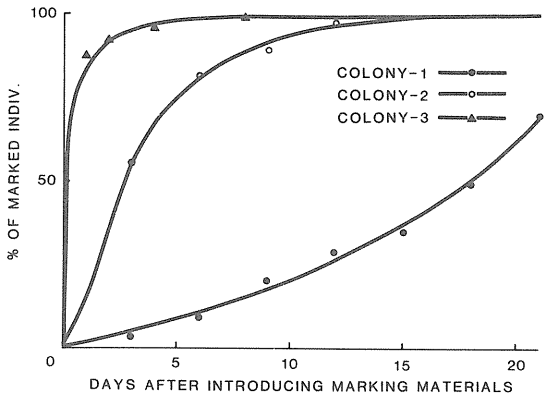

Fig. 2. Percentage of marked individuals caught at sampling stations during a 3-week period after dye was introduced into the colony via the bait stations.

Results and Discussion

The percentage of marked termites caught at the sampling stations increased with time in all three stations (Fig. 2), but the rate of increase differed among the colonies. The rate of marked individuals increased more rapidly in Colony 3 than in Colonies 1 or 2. One day after the dye was introduced into Colony 3, almost 90% of the foragers were stained. The factors affecting the rate of increase of dyed individuals included colony size, the ratio of bait stations to the total number of stations, and the number and distribution of bait stations in relation to the number and distribution of natural foraging sites.

Colony 3 was located in an area classified as rock land, where exposed rock covers 25 to 90% of the surface (Foote et al. 1972). The soil was very shallow and the vegetation was mostly koa haole, *Lecaena glauca* (L.), with some klu, *Acacia farnesiana* (L.) Willd, and kiawe, *Prosopis pallida* (Humb. and Bonpl. ex. Willd). These two shrubs and the tree do not offer a large amount of easily accessible food to the termites. The bait stations that had been established in the colony for several months had paper and wood that were easily accessible and were apparently preferred over the natural food. In addition, the bait stations for Colony 3 were probably abundant, well distributed and offered a larger foraging area per trap than the natural foraging sites. Thus, feeding was more extensive at the bait stations than at the natural sites.

The proportion of marked individuals in Colony 1, on the other hand, increased very slowly (Fig. 2). The percentage of marked individuals only reached ca. 70% during the observation period, although 100% marked termites probably would have occurred with time. With Colony 1, it is ap-

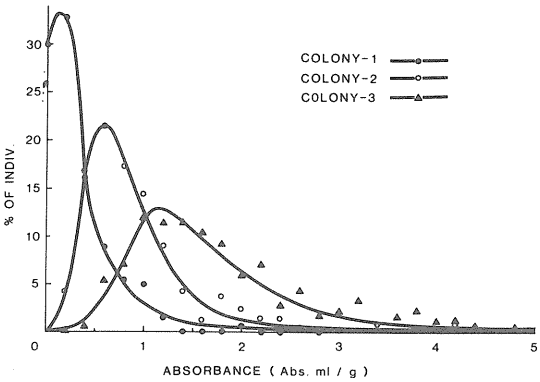

Fig. 3. Distribution of absorbance values for Sudan Red 7B from termites caught from the sampling stations during a 3-week period.

parent that there were very few bait stations in relation to colony size and they were poorly distributed in the area occupied by the colony. The curves for both Colonies 1 and 2 were normal and indicative of random occurrence of an event.

That marked termites were found uniformly distributed in all sampling stations showed that individual foragers were not restricted to one or a few foraging sites. They fed and moved out of the area, perhaps to return to the central nest to feed reproductives or young. The station to which they returned when they resumed feeding was apparently selected at random because stained individuals were caught with equal frequency at all sampling stations. If there had been differences or preferences, then the distribution curves for the absorbance values (Fig. 3) should have shown more than one peak per colony. The groups of foragers feeding at different frequencies or for different lengths of time on the dye would have shown up as different peaks.

These data offer evidence that foragers select their foraging sites from among available foraging sites at random and that there are no groups that feed more frequently or eat more than others. Because *C. formosanus* forages at random, each individual forager would have an equal opportunity to feed on or contact a slow-acting, nonrepellent toxic bait, dust, or other formulation introduced into a foraging site of the colony. Thus, if such a formulation were introduced into a colony, all of the foragers should eventually feed on or contact the toxin. The ultimate consequence would be that the entire foraging portion of the colony would be destroyed. Mortality would be enhanced if the foragers returned to the colony and exchanged the toxin with other nestmates. The consequence of feeding toxic materials at a few bait stations should be the demise of the colony.

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