EVALUATION CRITERIA FOR BAIT-TOXICANT EFFICACY AGAINST FIELD COLONIES OF SUBTERRANEAN TERMITES: A REVIEW

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Abstract—The applied objectives for bait-toxicant against subterranean termites are at minimum the suppression of foraging activity and ideally the elimination of the entire colony population. Subterranean termite colonies containing hundreds of thousands to millions of individuals may forage up to 150 m in soil. Effects of bait-toxicants against field colonies of subterranean termites are difficult to assess because of the cryptic nature of these insects. Use of toxicant-bait consumption to measure the effects of bait toxicant on foraging activity is misleading because it may only represent bait avoidance by termites. Measurement of the consumption of untreated baits placed in the vicinity of a target colony may be a more accurate reflection of the effects of bait-toxicants on overall foraging activity. Ideally, the interconnection between foraging populations found in toxicant-baits and untreated baits needs to be confirmed using dye markers or radioisotopes. The dye markers are also used to define foraging territories and population sizes of subterranean termites. Once the population of a target colony is characterized, the extent of colony suppression or elimination can be assessed.

INTRODUCTION

The monitoring/baiting procedure incorporating the chitin synthesis inhibitor, hexaflumuron, (Su 1994; Su *et al.*, 1995a) lead to the development of the first commercial bait for subterranean termites, the Sentricon^{TM} Colony Elimination System (DowElanco, Indianapolis, IN). The Sentricon system became available to the pest control industry in the United States in May 1995. Other termite baits containing metabolic inhibitors such as sulfluramid (First Line^{TM}, FMC Corp., Princeton, NJ), hydramethylnon, avermectin, and juvenoids such as fenoxycarb or pyriproxyfen, are expected to become commercially available in the near future.

Currently there is no standardized method for evaluation of termite bait efficacy. Unlike soil termiticides, the United States Environmental Protection Agency does not require efficacy data for registration of termite bait products. With several termite baits expected to be commercially available soon, there is a need to sort out the evaluation criteria so that these products can be compared objectively. This may aid the pest control industry and consumers to understand what is to be expected from a particular termite bait product. This paper reviews criteria used in evaluation studies of bait efficacy against field colonies of subterranean termites and provides guidelines for establishment of criteria in evaluation of field efficacy of subterranean termite baits.

OBJECTIVES OF TERMITE BAIT APPLICATIONS

The objectives of using slow-acting toxicants for termite control are to impact colony populations, either by suppression or elimination. Randall & Doody (1934), who reviewed the use of slow-acting arsenic dust in termite control, cited earlier work by Van Zwaluwenberg (1916) and Wolcott (1924) that colonies of the arboreal termite *Nasutitermes costalis* (Holmgren) were killed by applying powdered arsenic in their runways. Unlike arboreal or mound-building termites (Hänel & Watson, 1983) that are accessible for observing the effects of slow-acting toxicants on the entire colony populations, demonstration of population suppression or colony elimination for subterranean termites is difficult because the nesting structures and foraging galleries of these species are hidden.

Esenther & Gray (1968), who exposed wooden blocks impregnated with dechlorane (mirex) to field populations of the eastern subterranean termite, *Reticulitermes flavipes* (Kollar), suggested that slow-acting toxicants may be used to eliminate colonies of subterranean termites. Subsequent studies using this bait-block technique indicated that a continuous placement of toxic baits may

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suppress foraging activities (Beard, 1974; Esenther & Beal, 1974, 1978; Ostaff & Gray, 1975), but the effects of baiting on entire termite colonies were not assessed. Because the objectives for bait-toxicant control are to impact colony populations, either by suppression (i.e. population reduction) or elimination, evaluation studies need to demonstrate the effect of bait applications on foraging activity, territory, or population size.

EVALUATION CRITERIA

Of the 3 main variables, (1) foraging activity, (2) foraging territory, and (3) population size, used for evaluation of bait-toxicant effects on field populations of subterranean termites, the variable "foraging activity" was included by all studies (Table 1). One unique variable, caste proportion, was used by Jones (1989) to indicate the effect of insect growth regulators on colony populations.

Foraging activity

The simplest qualitative method was to describe foraging activities by the presence of termites in the treated bait medium (Rudolph *et al.,* 1994; Felix & Henderson, 1995), or in other untreated materials such as wood stakes or corrugated cardboards (Anonymous, 1995), nearby logs (Beard, 1974), or damaged wood members in nearby buildings (Gao *et al.*, 1985, French 1991, 1994). Numbers of termites in monitoring stations (not treated with toxicants) were also used to quantify the changes in foraging activity due to bait-toxicant applications (Su *et al.*, 1982, Myles *et al.*, 1994). Unless monitored frequently, the number of termites collected from a monitoring station may not be a reliable representation of termite foraging activity because termites tend to abandon a site when food is exhausted. Moreover, some termite species may readily abandon foraging sites with minimum disturbance, thus a frequent monitoring program may reduce termite catch.

Table 1. Variables used to evaluate bait-toxicant efficacy against field colonies of subterranean termites

Foraging Activity				Foraging Territory	Foraging Population	References
Presence or number of termites		Bait or food consumption				
Treated	Untreated[a]	Treated	Untreated			
+		+				Rudolph *et al.*, 1994 Felix & Henderson, 1995
	+					Su *et al.*, 1982; Gao *et al.*, 1985 French, 1991, 1994
	+	+				Beard, 1974; Ostaff & Gray, 1975
	+	+				Anonymous, 1995
		+	+			Esenther & Beal, 1974, 1978 Esenther & Gray, 1978*,
			+			Jones, 1989**
	+			+		Paton & Miller, 1980
	+			+	+	Lai, 1977; Myles *et al.*, 1994
			+	+	+	Su et al., 1991*, Jones, 1991, Su, 1994; Su *et al.*, 1995a, 1995b

aTermites in damaged wood in the vicinity or in untreated bait.
*Also compared with activity of nearby colonies that received no toxicant.
**Measured the proportion of intercaste, and compared with activity of nearby colonies that received no toxicant.

Another quantitative method is to measure the consumption rate of treated bait medium (Felix & Henderson, 1994), untreated stakes (Jones, 1989), untreated feeding blocks (Su *et al.*, 1991, Su 1994; Su *et al.*, 1995a, 1995b), or both treated and untreated baits (Esenther & Beal, 1974, 1978; Esenther & Gray, 1978; Jones, 1991). Measuring foraging activity in sites of toxicant-bait application (Rudolph *et al.*, 1994) or use of toxicant-bait consumption (Felix & Henderson, 1995) is misleading because it may only represent bait avoidance by termites. In a choice-test study using sulfluramid-treated bait blocks against field colonies of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, Su *et al.* (1995b), who reported that treated baits initially accepted by termites were later avoided, hypothesized an associative learning by the exposed populations to avoid feeding on the treatments. Because of the potential of confusing bait avoidance with reduction of foraging activity, the majority of studies that used toxicant-bait consumption in their evaluation criteria also included termite activity (presence or consumption) in untreated (control) baits in the vicinity of a target colony (Beard, 1974; Ostaff & Gray, 1975; Esenther & Beal, 1974, 1978; Esenther & Gray, 1978; Jones, 1991; Anonymous, 1995)

Delineation of foraging territory

Although many evaluation studies measured foraging activity from untreated (control) baits or sites, the majority of the studies prior to 1980 did not confirm the interconnection between toxicant application sites and control sites that received no toxicant. Even without confirming such an interconnection, one may reasonably assume that the reduction of foraging activity in nearby control sites following a toxicant-bait application may indicate toxicant effects on the overall population. If the reduction in activity was observed only from toxicant application sites but not the control sites, however, it is not certain weather termites simply avoided toxicant baits, or no connection existed between toxicant bait application sites and control sites; namely the control sites may belong to other adjacent colonies.

Lai (1977) was the first to delineate the foraging territory of *C. formosanus* using the dye marker, Sudan Red 7B, before field control trials with the entomogenous fungi, *Beauveria bassiana* (Balsamo), and *Metarrhizium anisopliae* (Metchnikoff). These fungi were highly toxic to laboratory groups of termites, but failed to impact field colonies because termites avoided the inoculation sites but remained active in untreated sites of the colony (Lai 1977). Paton & Miller (1980) used the radioisotope ^{140}La to confirm interconnections of foraging sites in trees or logs for colony populations of the subterranean termite, *Mastotermes darwiniensis* Froggatt. They demonstrated that, following the application of baits containing Mirex (dechlorane), termite activity (presence of live termites) in control sites (hence the overall foraging activity) was greatly reduced, and ultimately eliminated. As expected, a nearby colony of *M. darwiniensis* whose independent status was confirmed by the absence of radioactivity, was not affected by the bait application.

Following these pioneering studies by Lai (1977) and Paton & Miller (1980), many field evaluations of slow-acting toxicants used dye markers such as Sudan Red 7B or Nile Blue A to delineate foraging territory of target colonies before bait applications (Jones, 1991; Su *et al.*, 1991; Su, 1994; Myles *et al.*, 1994; Su *et al.*, 1995a, 1995b). To demonstrate that field colonies were eliminated by bait toxicant, and did not merely move out of the test site, population surveys need to be conducted in areas extending beyond the boundary of target colonies (Paton & Miller, 1980; Jones, 1991; Su, 1994; Su *et al.*, 1995a, 1995b). Such area-wide population surveys may result in the delineation of several field colonies in the survey areas, thus convincingly demonstrating the colony elimination of target colonies that received toxicant baits (Paton & Miller, 1980; Jones, 1991; Su, 1995a).

Population estimate

Lai (1977) was also the first to use the mark-recapture method to estimate the cryptic foraging populations of subterranean termites. The single mark-recapture method and its resultant Lincoln index estimate was adopted by Jones (1991) and Myles *et al.* (1995) in their field evaluation studies. Because of the large standard error associated with the simple Lincoln index estimate, a triple mark-recapture procedure with a weighted mean model (Begon, 1979) was used to improve the accuracy of the foraging population estimates (Su *et al.* 1991; Su, 1994; Su *et al.*, 1995a, 1995b).

Estimates of foraging populations may provide important information on target colonies, and may explain the amount of bait-toxicant consumed or time required for control. Population estimates, however, were not always needed as the evaluation variable (Lai, 1977; Jones, 1991; Su, 1994; Myles, 1995; Su *et al.*, 1995a). This is especially true when baited colonies were totally eliminated from the test sites. A comparison of foraging activity and territory before and after bait application, and especially a continuing monitoring of termite activity in baited sites, should be sufficient to demonstrate the elimination of target colonies (Su & Scheffrahn, in press).

The estimate of foraging population, however, is an important evaluation variable for demonstration of population suppression by toxicant-bait applications. In the field evaluation studies using metabolic inhibitors such as A-9248 (diiodomethyl para-tolyl sulfone, Su *et al.*, 1991) or sulfluramid (Su *et al.*, 1995b), neither foraging activity nor territory of baited colonies were reduced significantly to demonstrate the impact of bait applications. However, the triple mark-recapture procedure conducted following the 12-month baiting indicated that the target populations of *C. formosanus* were reduced 65–98% and 52–86%, by A-9248 and sulfluramid, respectively (Su *et al.*, 1991, Su *et al.*, 1995b).

CONCLUSION

Foraging activity is probably the single most important and most commonly used variable in the evaluation of bait-toxicant efficacy against field colonies of subterranean termites. Consumption of toxicant baits or activity in sites of toxicant-bait application, however, should not be used for the evaluation because it may only represent bait avoidance by termites instead of colony suppression or elimination. Measurement of consumption of untreated food or bait from sites that received no toxicant bait application should be used as the variable to represent foraging activity of target colonies. Foraging territory of the target colony should be delineated or at least the interconnection of treated and untreated sites needs to be confirmed so that the reduction of termite activity in untreated sites can be attributed to the overall reduction of foraging activity. The information on foraging population size is optional for demonstration of colony elimination, but may be essential in demonstration of population suppression by toxicant bait application.

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