Population Suppression of Subterranean Termites by Slow-Acting Toxicants[1]

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Abstract: Historic background and the concept of slow-acting toxicants for population suppression of subterranean termites are reviewed. Information needed for development of bait-toxicants and studies needed to generate such information are summarized.

Current control measures for subterranean termites rely exclusively on soil termiticides, primarily organophosphates and pyrethroids. They are used as toxic or repellent barriers between soil-borne termite colonies and structures requiring protection. La Fage (1986) estimated that soil termiticides are applied at a rate of ca. 390 kg/ha beneath treated structures compared to agricultural rates of 2.17 kg/ha (Pimentel and Levitan 1986). The withdrawal from use of chlorinated hydrocarbon termiticides in 1987 reflects public concern over the use of these persistent chemicals in highly populated urban environments.

Despite the large quantities of pesticides used, soil treatments do not affect termite populations but only provide barriers to separate structures from soil-borne termites. Colonies of subterranean termites, especially those of the Formosan subterranean termite (Coptotermes formosanus Shiraki) which may forage as far as 100 m from the central nest, remain viable near the structures even after treatment (Su and Scheffrahn 1988a). Because of the inability of current control techniques to reduce existing subterranean termite populations, the severity of infestations by C. formosanus in areas such as Honolulu, Hawaii, and New Orleans, Louisiana, has increased in recent years.

Researchers in the early 1900's first observed that the slow-acting arsenic dusts could be used to reduce colony populations of subterranean termites (Randall and Doody 1934). The principle of suppressing colony populations is to provide 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 exposure that they cannot move away from the toxicant acquisition site to die. The slow-acting characteristic of a toxicant is particularly important because accumulation of a large number of dead termites at the acquisition site will repel other nestmates from approaching the toxicant (Su and others 1982a). Ideally, the toxicant has to be nonrepellent to termites, or at least be masked by other agents to prevent avoidance behavior by the foraging termites. Under this premise, the toxicant can be incorporated into a bait (feeding acquisition) or tracking powder (contact and grooming acquisition). In this paper, we will primarily discuss the bait concept.

Beard (1974) suggested the use of bait toxicants as a possible strategy to eliminate established colonies of the subterranean termites, Reticulitermes spp. Dechlorane (mirex) baits have been used to suppress activity of field colonies of Reticulitermes in the United States (Esenther and Beal 1974, 1978), and to kill field colonies of an Australian subterranean termite, Mastotermes darwiniensis Frogg. (Paton and Miller 1980). Gao and others (1985) also reported successful field control of termite infestations with mirex baits in China.

Laboratory studies indicated that hydramethylnon (Amdro®), avermectin B_1 (Su and others 1987), A-9248 (Su and Scheffrahn 1988b), sulfluramid (Su and Scheffrahn 1988c), and insect growth regulators (IGRs) such as methoprene, fenoxycarb, and S-31183, have shown delayed toxicity against C. formosanus and the eastern subterranean termite, Reticulitermes flavipes (Kollar) (Jones 1984, Su and others 1985, Haverty and others 1989, Su and Scheffrahn 1989). A field trial with hydramethylnon baits, however, resulted

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POPULATION SUPPRESSION OF SUBTERRANEAN TERMITES BY SLOW-ACTING TOXICANTS

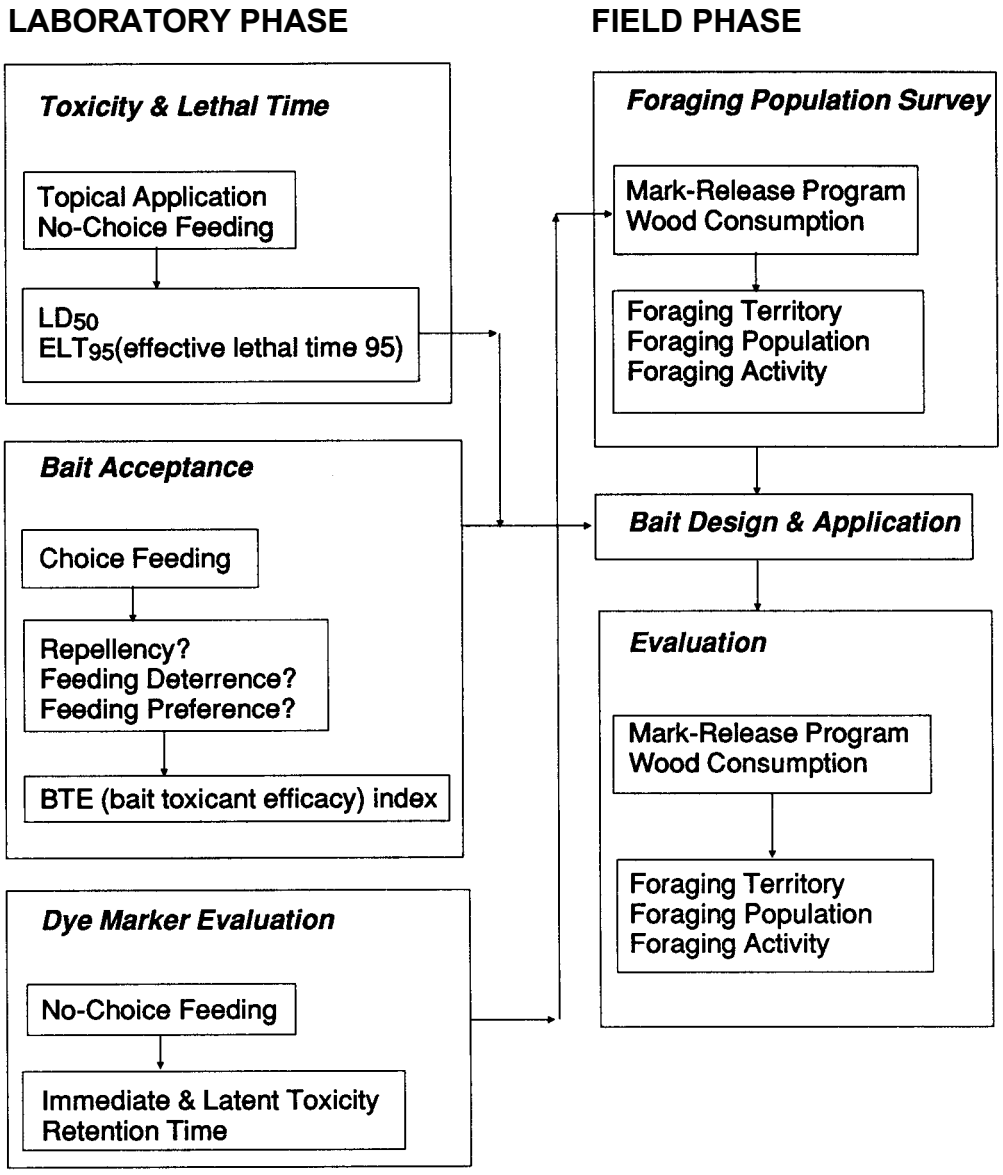

Figure 1--Studies needed to establish information for development of bait toxicants to suppress populations of subterranean termites.

only in partial control of C. formosanus colonies (Su and others 1982b).

INFORMATION NEEDED FOR DEVELOPMENT OF A SLOW-ACTING BAIT

Development of a bait toxicant requires numerous, interconnected laboratory and field studies followed by a rigorous evaluation phase (Figure 1).

Laboratory Phase

Toxicity and Lethal Time

Oral or topical LD_{50} or LD_{95} should be calculated to estimate the gross quantity of toxicant needed for control of entire colonies. This information can also be used to compare the relative toxicity among toxicants.

Lethal time of a toxicant is concentration dependent. A bait toxicant should be used at a concentration that causes protracted behavioral impairment and latent mortality so that termites, having fed on bait, will disperse throughout their foraging territories before succumbing to the toxicant. Su and others (1987) defined an effective lethal time 90% (ELT_{90}) as the amount of time required by a fixed concentration of a toxicant to kill at least 90 percent of termites. ELT_{90} can be used to assess the feasibility of a candidate compound as a bait toxicant and to predict the time frame required for control. Lethal time (ELT_{90}) of candidate toxicants can also be used to compare toxicants.

Bait Acceptance

In field trials, a bait must be competitive with other termite food resources. Termites should not be repelled (Su and others 1982a) or their feeding deterred by bait additives (Su and Scheffrahn 1988b). In the past both choice (Su and Scheffrahn 1988b) and no-choice bioassays (Scheffrahn and Su 1987; Grace, in press) were used to determine concentration-dependent feeding on treated substrates. Table 1 summarizes interpretations of no-choice and choice bioassay under various hypothetical experimental outcomes. Although both no-choice and choice feeding bioassays can detect concentration-dependent repellency and feeding deterrence, only a choice bioassay can determine that the toxicant-treated food source is more or less accepted by termites than identical untreated food substrate. Because the behavioral responses of termites toward treated baits are concentration-dependent, it is vital that a choice bioassay be used to determine the acceptable concentration of a candidate toxicant before it is used in field trials.

The two important characteristics, slow-acting and no feeding deterrence, are concentration dependent (Su and others 1987 , Su and Scheffrahn 1988b). A desirable toxicant should be accepted by termites at efficacious concentrations to cause significant delayed mortality. An index combing these three parameters, concentration, delayed mortality and feeding deterrence, therefore, can be used to evaluate the potential of a toxicant. We propose here a Bait Toxicant Efficacy (BTE) index which is defined as the quotient of bait acceptance threshold concentration (BATC) and the threshold concentration to produce significant delayed mortality (DMTC); namely BTE = BATC/DMTC. A toxicant with BTE • 1 (such as pyrethroid, Su and others 1982a) cannot be used in a bait, while BTE > 1 indicates a bait-toxicant potential. Using this criterion, BTE index for the slow-acting A-9248 (dihaloalkyl arylsulfone) against C. formosanus was 3 (600 ppm [BATC] ÷ 200 ppm [DMTC]) (Su and Scheffrahn 1988c). Similarly, BTEs' for mirex and sulfluramid against C. formosanus were 9 (90 ppm ÷ 10 ppm) and 2.5 (10 ppm ÷ 4 ppm), respectively. BTE values for sulfluramid (30 ppm ÷ 18 ppm) and mirex (15 ppm ÷ 9 ppm) are identical (1.7) against R. flavipes (Su and Scheffrahn, in press).

Dye Marker Evaluation

Dye markers are useful to determine foraging territories and to estimate foraging populations of subterranean termite colonies. There has been criticism of the application of the capture-recapture technique for population estimation of social insects (Ayre 1962). The criticism was based on the argument that individuals in insect colonies do not distribute randomly in space, and thus one of the basic assumptions of mark-recapture model is violated. For example, most of the younger (1-2 instar) termites do not move to distant foraging sites. Baroni-Urbani and others (1978), however, pointed out that the mark-recapture technique is often the only practical method for studying the population dynamics of some insects. This is especially true for the cryptobiotic insects such as subterranean termites.

Su and others (1984) demonstrated that C. formosanus workers chose foraging sites at random; thus all of the released marked foragers should distribute evenly within the population. Moreover, only foragers can be captured using the prescribed trapping system (Su and others 1984, Su and Scheffrahn 1986, 1988a). The mark-recapture technique, thus, is an effective method of quantifying the populations and movements of subterranean termite foragers.

Sudan Red 7B (or Oil Soluble Red 7B) was first used by Lai and others (1983) to estimate the size of colonies of C. formosanus in Hawaii. Laboratory studies showed that Sudan Red 7B was not trophallactically transferred by C. formosanus (Su and others 1983) or R. flavipes (Su and others 1988). This dye was subsequently adopted as the standard dye to determine foraging territory and population of C. formosanus in Florida (Su and Scheffrahn 1988a), and R. flavipes in Toronto (Grace, in press). Jones (in press) also used Sudan Red 7B to define foraging boundaries

Table 1. Potential results of no-choice and choice bioassay and data interpretations.

Results		Interpretations	
Feeding compared to control	Mortality compared to control	No choice bioassay	Choice bioassay
_	=	Not feeding deterrent Not repellent Not toxic (UNDESIRABLE)	Non-preference Not toxic (UNDESIRABLE)
_	>	Not feeding deterrent Not repellent Toxicant (DESIRABLE)*	Non-preference Toxicant (VERY DESIRABLE)
<	=	Feeding deterrent or repellent Not toxic (UNDESIRABLE)**	Unpreferred substance Not toxic (UNDESIRABLE)
	>	Feeding deterrent or repellent or Mortality due to contact toxicity? or starvation? (VERY UNDESIRABLE)	Unpreferred substance Contact toxicant (VERY UNDESIRABLE)
>	=	Feeding stimulant Not toxic (Potential additive-masking agent)	Preferred substance (Potential additive masking agent)
>	>	Feeding stimulant Toxicant (VERY DESIRABLE)	Preferred substance (IDEAL BAIT TOXICANT)

* Theoretically, this scenario should not occur because higher mortality would result in over all lower feeding.

** Theoretically, this result cannot be obtained because lower feeding would eventually cause higher mortality by starvation.

of Heterotermes aureus (Snyder) in Arizona. Sudan Red 7B, however, does cause mortality of C. formosanus (10-15 percent) during staining, and causes a latent mortality of R. flavipes (30-80 percent mortality at 2-8 weeks after being stained with 0.5 percent dye for 10 days) (Su and others 1988).

In a laboratory screening test, we (Su and others, unpublished data) have identified two dyes, Nile Blue and Neutral Red, that have even better potential than Sudan Red 7B as markers for C. formosanus and R. flavipes. Currently, we are testing the color fastness of these dyes in mixed groups of marked and unmarked foragers.

Field Phase

Foraging Population Survey

To adequately evaluate results of field trials, foraging activity, foraging population size, and foraging territory of subterranean termites must be monitored before the introduction of a bait. Esenther and Beal (1974, 1978) reported

successful suppression of field colonies of Reticulitermes spp. with mirex baits. However, the activity of these field populations of Reticulitermes had not been monitored before bait application. It is uncertain whether the field populations were repelled from the test site or whether the populations were indeed suppressed.

Ideally, the colony activity should be monitored for a few years before the application of bait toxicants. The process of marking, counting, releasing, and recapturing is a laborious task. A more sophisticated model than the simple Lincoln index for estimating the foraging population provides more information with the same effort. The weighted-mean model using a multiple mark-release procedure enabled us to obtain estimates with a relatively low standard error (Su and Scheffrahn 1988a). However, the procedure required three months to complete. Moreover, it takes another three months for the last stained termites to totally lose their marking before another cycle of multiple mark-release procedures can be initiated. Because of foraging inactivity during cool months in southeastern Florida, the mark-release program is implemented from April to November. Realistically, therefore, only one mark-release program per colony is possible per annum.

Although the size of the foraging populations can be estimated only once annually, foraging activity can be monitored all year by counting the number of termites in the traps and measuring wood consumption during monthly or bi-monthly trap changes. Although the boundary of a foraging territory is defined before bait application, change in foraging activity and territory should be monitored throughout the bait toxicant evaluation period.

Bait Application

The trapping system described by Su and Scheffrahn (1986) can be used for bait field trials. Trap stations within a colony monitoring system should be selected at random to receive toxicant baits, while the others receive similar baits without toxicant. The difference in activity (number of termites and wood weight loss) between treated and untreated stations then can be compared to detect termites' preference in visiting baits with or without toxicant.

In our field trials (Su and others, unpublished data), we use a toxicant bait composed of six pieces of pine (Pinus spp.) board (7 cm by 13 cm by 2 cm thick), three of which were vacuum impregnated with toxicant while the others were treated with impregnation solvent only. The dry weight of each wood piece was determined before bait assembly. After the baits were exposed to termites, the wood weight loss of toxicant-treated and solvent control boards was compared to ascertain termite feeding preferences.

Evaluation

During the field trial, the foraging preference by termites between treated and untreated sites (i.e., number of termites collected per trap) and feeding preference between treated and untreated wood pieces should be monitored. The mark-release program, which would have to be interrupted during the trial because of the potential negative effects of the dye marker, should be reinstituted after the termination of the bait toxicant exposure to determine the effects of the bait toxicant on the foraging populations.

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