Characterization of Slow-acting Insecticides for the Remedial Control of the Formosan Subterranean Termite (Isoptera: Rhinotermitidae)

NAN-YAO SU,[1] MINORU TAMASHIRO, AND MICHAEL I. HAVERTY[2]

Department of Entomology, University of Hawaii,
Honolulu, Hawaii 96822

ABSTRACT   We describe a method to examine time trends in mortality of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, exposed to insecticides. Slow-acting toxicants required a longer time to kill termites at low concentrations than at high concentrations. The level of mortality and the speed of death were dependent on concentration. With acute toxicants, the time required to kill termites was similar at high or low concentrations, while the mortality levels were concentration-dependent. This speed of death at various concentrations of an insecticide can be quantified for comparison purposes using the proposed effective lethal time 90% (ELT_{90}), defined as the amount of time required for an insecticide to kill 90% of the treated individuals within a maximum 14-day span. Slow-acting toxicants were characterized by ELT_{90} values that spanned a broad range of time, while acute toxicants exhibited a narrow range of ELT_{90} values.

KEY WORDS   *Coptotermes formosanus*, time trends, slow-acting insecticides, effective lethal times

ONE STRATEGY FOR the remedial control of subterranean termites is the use of a slow-acting, nonrepellent toxicant in a bait or as a dust (Su et al. 1982). This strategy is based on the premise that an entire colony of subterranean termites can be destroyed even if only a small part of the existing gallery system is treated, because the toxicant is distributed to the entire colony by social interactions (trophallaxis and grooming) with the exposed foragers. The technique also requires that the foragers select their feeding sites at random so the same foragers do not feed at the same site. These underlying assumptions have been shown to be fundamentally correct. Recently, Su et al. (1984) demonstrated that the Formosan subterranean termites, *Coptotermes formosanus* Shiraki, select feeding sites at random, which means that given sufficient time, a large proportion of foragers would visit specific bait sites. Use of a slow-acting poison is probably the only feasible method of eliminating the established colonies of *C. formosanus,* which may contain as many as 10 million individuals (Tamashiro et al. 1980) with foraging galleries extending 100 m from end to end (King & Spink 1969, Li et al. 1976, Lai 1977).

Dechlorane (mirex), an example of a slow-acting poison, has been shown to suppress foraging activities of *Reticulitermes* colonies in the south-eastern United States (Esenther & Beal 1974, 1978). Mirex baits have been successfully used to control termite infestations in the forests in China (Gao et al. 1985). Mirex, however, is no longer available in the United States, and the search for an alternative slow-acting toxicant continues.

Control of the red imported fire ant, *Solenopsis invicta* Buren, with baits also requires the use of slow-acting toxicants. In screening tests of such compounds against *S. invicta,* the delayed toxicity was defined as <15% mortality at 1 day and >89% at the end of the test period, which was usually 14 days (Stringer et al. 1964). This definition was later adopted for recognizing potential bait poison for *S. invicta* (Lofgren et al. 1967) and has been used in more recent screenings with slight modification (Williams et al. 1980, Williams & Lofgren 1981, Williams 1983, Vander Meer et al. 1985).

Dell et al. (1983) used the Weibull function to define time trends for the proportion of an insect population with an altered physiological state (e.g., death, ecdysis). This technique was applied to estimate the amount of time required to achieve 90% mortality (LT_{90}) at a fixed concentration in screening for fast-acting insecticides to control the pine cone beetle, *Conophthorus ponderosae* Hopkins (Haverty & Dell 1984). LT_{90} values estimated by the Weibull function were comparable with those estimated by probit analysis. Although they sought fast-acting toxicants, the method described by Dell et al. (1983) is also applicable for identification of slow-acting toxicants.

While a protracted time frame for the onset of

[1] Current address: Ft. Lauderdale Res. and Educ. Cent., Univ. of Florida, IFAS, 3205 College Ave., Ft. Lauderdale, FL 33314.

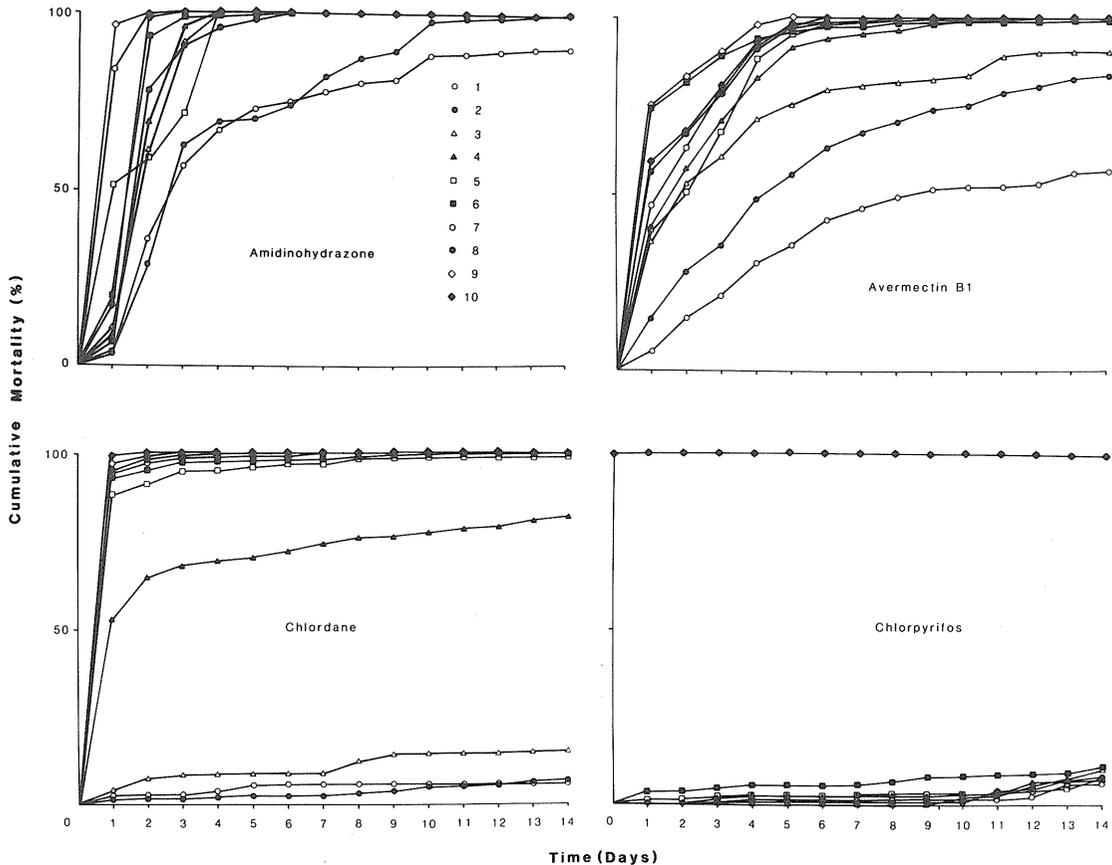[2] Pacific Southwest Forest and Range Exp. Stn., USDA For. Serv., P.O. Box 245, Berkeley, CA 94701.

Fig. 1. Cumulative mortality curves of *C. formosanus* workers exposed to amidinohydrazone, avermectin B_1, chlordane and chlorpyrifos. Ten concentrations were tested: 2,000–20,000 ppm in 2,000-ppm increments for amidinohydrazone; 20–200 ppm in 20-ppm increments for avermectin B_1; 10 and 20–180 ppm in 20-ppm increments for chlordane; and 1–10 ppm in 1-ppm increments for chlorpyrifos. Increasing numbers and associated symbols correspond to increasing concentrations.

poisoning is desirable for chemicals used against *C. formosanus*, slow-acting toxicants have not been characterized quantitatively. Moreover, the effects of concentrations of various poisons on the LT_{90} also have not been adequately examined. Reducing the concentration of a fast-acting toxicant may cause it to act as a slow-acting material.

In this study we examined the time trends in mortality of four insecticides at various concentrations on *C. formosanus* to define the time required to reach the desired level of mortality.

Materials and Methods

Ten concentrations were tested for each of four compounds; 2,000–20,000 ppm at 2,000-ppm increments for amidinohydrazone; 20–200 ppm at 20-ppm increments for avermectin B_1 (80% B_{1a} and 20% B_{1b}); 10 and 20–180 ppm at 20-ppm increments for chlordane; and 1–10 ppm at 1-ppm increments for chlorpyrifos. All chemicals tested were technical-grade materials.

One hundred fifteen termites (100 workers or undifferentiated larvae of at least the third instar plus 15 soldiers) collected from a field colony were introduced into a petri dish (60 mm in diam by 1.5 mm high) containing two pieces of Whatman No. 1 filter paper (55 mm in diam). The papers had been treated 24 h before with an acetone dilution of one of the four compounds and air-dried before being moistened with 0.55 ml deionized water. All treatments were replicated three times. Three untreated control units were included, for a total of 123 experiment units. Exposed termites were stored at 29 ± 1°C for 24 h, after which survivors were transferred to similar units containing untreated filter papers, and stored at the same temperature. Dead or moribund workers were counted daily for 14 days and excluded from each test unit. Soldier mortality was not recorded. Abbott's (1925) formula was used to correct for control mortality.

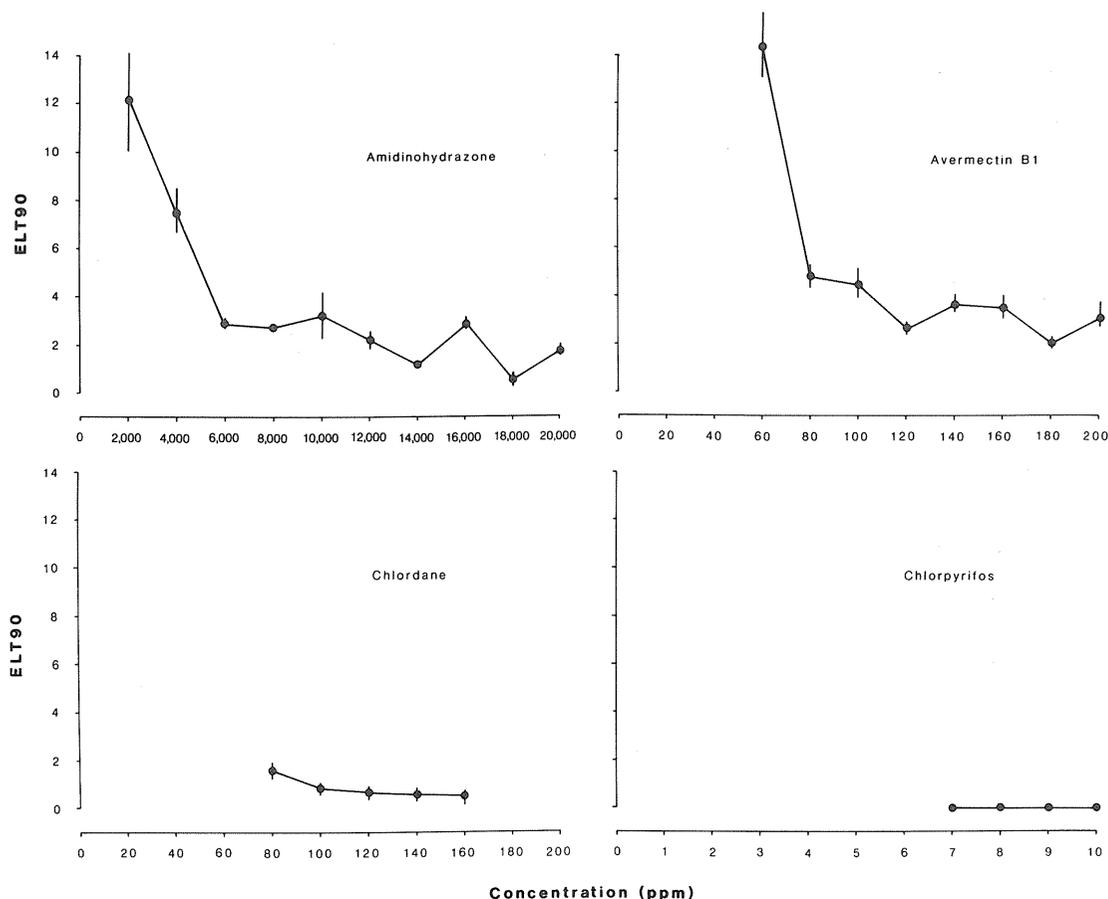Probit analysis (SAS Institute 1982) was performed with time instead of dosage as the inde-

Fig. 2. $ELT_{90} \pm 95\%$ FL for four insecticides tested against *C. formosanus*.

pendent variable, with concentrations attaining at least 90% mortality at 14 days. The analysis estimated the amount of time required to achieve 90% mortality (lethal time 90% [LT_{90}]). Because the estimated LT_{90}'s excluded observations below our assigned limit of >90% mortality at 14 days, the estimates were further termed *effective lethal time 90%* (ELT_{90}), which we defined as amount of time required to cause 90% mortality by a fixed concentration of a toxicant that killed at least 90% of termites in 14 days. ELT_{90} estimates were plotted against concentration for each compound for comparison.

Results and Discussion

Mortality curves for *C. formosanus* workers exposed to one of the ten concentrations of the four test compounds are shown in Fig. 1. At the lowest concentration of amidinohydrazone (2,000 ppm), a large proportion (60–70%) of termites died 3–5 days after exposure. Mortality reached ca. 90% after 10 days. Approximately 60% of workers exposed to 4,000 ppm amidinohydrazone also died by day 3. Mortality, however, increased at almost

a constant rate thereafter and reached ca. 100% by day 10. As amidinohydrazone concentrations increased, the rate of mortality also increased and 100% mortality was attained on an earlier date.

At high concentrations of avermectin B_1 (80–200 ppm), most of the mortality occurred 1–4 days after the initial exposure (Fig. 1). Termites exposed to 20, 40, and 60 ppm avermectin B_1 showed delayed mortality which reached ca. 50, 80, and 90%, respectively by day 14.

Regardless of the concentration of chlordane tested, the maximum mortality was generally achieved 1–2 days after the exposure (Fig. 1). Only slight additional mortality was observed after 2 days. As concentrations decreased, mortality decreased but there was no corresponding increase in the time required to achieve maximum mortality, as was observed among termites exposed to amidinohydrazone or avermectin B_1.

Chlorpyrifos exhibited its effects even more rapidly than chlordane (Fig. 1). With chlorpyrifos, almost all termites that died from the treatment did so within the first day. Generally, those that did not die on the first day survived to the end of the experiment.

The apparent difference among tested compounds was that, as the concentration was decreased, slow-acting toxicants (amidinohydrazone and avermectin B_1) required a longer period for their effects on termites to be expressed fully, while acute toxicants (chlordane and chlorpyrifos) simply resulted in lower mortality. This mortality time relationship was clearly seen when ELT_{90} was plotted against concentration (Fig. 2). By our definition, 'slow-acting toxicants are those with a broad range of ELT_{90}'s (1.5–12 days for amidinohydrazone and 2–14 days for avermectin B_1), while acute toxicants are those with a narrower range of ELT_{90} (0.2–2 days for chlordane and 0–1 day for chlorpyrifos).

LT_{90}, from which ELT_{90} was derived, is defined as time required after exposure to achieve 90% mortality. This is similar to the definition used by Dell et al. (1983) and Haverty & Dell (1984). It is different, however, from LT_{90} used in determining the resistance of insects to insecticides (World Health Organization 1970), in which *time* is exposure time and is regarded as interchangeable with concentration. Lethal dosage, lethal concentration and lethal time where *time* is exposure time are universally used to represent toxicity of insecticides. These estimates are usually measured at a set standard time after exposure. Estimates of the amount of time required to achieve certain levels of mortality can provide useful information in studies where postexposure time trends are of primary interest (Dell et al. 1983). As shown in this study, when set levels of mortality are to be achieved within a specified period of time, ELT can be used to characterize an insecticide.

Acknowledgment

References Cited

Abbott, W. S. 1925. A method for computing the effectiveness of an insecticide. J. Econ. Entomol. 18: 265–267.

Dell, T. R., J. L. Robertson & M. I. Haverty. 1983. Estimation of cumulative change of state with the Weibull function. Bull. Entomol. Soc. Am. 29: 38–40.

Esenther, G. R. & R. H. Beal. 1974. Attractant-mirex bait suppresses activity of *Reticulitermes* spp. J. Econ. Entomol. 67: 85–88.

1978. Insecticidal baits on field plot perimeters suppress *Reticulitermes*. J. Econ. Entomol. 71: 604–607.

Gao, D., B. Zhu, B. Gan, S. He & S. Yuan. 1985. A new toxic bait for the control of forest-infested termites. J. Nanjing Inst. For. 3: 128–131 (in Chinese, with English summary).

Haverty, M. I. & T. R. Dell. 1984. Time trends in mortality of *Conophthorus ponderosae* Hopkins exposed to insecticide residues. Pestic. Sci. 15: 369–374.

King, E. G. & W. T. Spink. 1969. Foraging galleries of the Formosan subterranean termite, *Coptotermes formosanus*, in Louisiana. Ann. Entomol. Soc. Am. 62: 537–542.

Lai, P. Y. 1977. Biology and ecology of the Formosan subterranean termite, *Coptotermes formosanus*, and its susceptibility to the entomogenous fungi, *Beauveria bassiana* and *Metarrhizium anisopliae*. Ph.D. dissertation, Univ. of Hawaii, Honolulu.

Li, T., K. H. He, D. R. Gao & Y. Chao. 1976. A preliminary study on the foraging behavior of the termite, *Coptotermes formosanus* (Shiraki) by labelling with iodine[131]. Acta Entomol. Sin. 19: 32–38 (in Chinese, with English summary).

Lofgren, C. S., C. E. Stringer, W. A. Banks & P. M. Bishop. 1967. Laboratory tests with candidate bait toxicants against the imported fire ant. U.S. Dep. Agric. Agric. Res. Serv. 81-14.

SAS Institute. 1982. SAS user's guide: statistics. SAS Institute, Cary, N.C.

Stringer, C. E., Jr., C. S. Lofgren & F. J. Bartlett. 1964. Imported fire ant toxic bait studies: evaluation of toxicants. J. Econ. Entomol. 57: 941–945.

Su, N.-Y., M. Tamashiro, J. R. Yates & M. I. Haverty. 1982. Effect of behavior on the evaluation of insecticides for prevention of or remedial control of the Formosan subterranean termite. J. Econ. Entomol. 75: 188–193.

1984. Foraging behavior of the Formosan subterranean termite (Isoptera: Rhinotermitidae). Environ. Entomol. 13: 1466–1470.

Tamashiro, M., J. R. Yates, P. Y. Lai, J. K. Fujii & N.-Y. Su. 1980. Size and structure of *Coptotermes formosanus* Shiraki colonies in Hawaii., p. 311. *In* Proceedings, 16th International Congress of Entomology, Kyoto, Japan.

Vander Meer, R. K., C. S. Lofgren & D. F. Williams. 1986. Fluoroaliphatic sulfones: a new class of delayed action insecticides. J. Econ. Entomol. 79: 1190–1197.

Williams, D. F. 1983. The development of toxic baits for the control of the imported fire ant. Fla. Entomol. 66: 163–172.

Williams, D. F. & C. S. Lofgren. 1981. Eli Lilly EL-468, a new bait toxicant for control of the red imported fire ant. Fla. Entomol. 64: 472–477.

Williams, D. F., C. S. Lofgren, W. A. Banks, C. E. Stringer & J. K. Plumley. 1980. Laboratory studies with nine amidinohydrazones, a promising new class of bait toxicants for control of red imported fire ants. J. Econ. Entomol. 73: 798–802.

World Health Organization. 1970. Insecticide resistance and vector control. W.H.O. Tech. Rep. Ser. No. 443.