Insecticidal and Behavioral Activity of Etofenprox Against the Formosan Subterranean Termite (Isoptera: Rhinotermitidae)

by

Minoru Tamashiro[1], J. Kenneth Grace[1,2] and Robin T. Yamamoto[1]

ABSTRACT

Etofenprox is an insecticide with relatively low mammalian toxicity. When applied topically to workers from several different colonies of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, the LD_{50} of etofenprox of 4.8 to 6.6 was in the same general range as soil termiticides currently in use. Etofenprox was a relatively quick acting termiticide, with most mortality occurring within 24 hours. In both vertical and horizontal laboratory tunneling assays, etofenprox concentrations as low as 10 ppm reduced termite penetration of crushed coral and silica sand, and consistent protection was achieved with concentrations of 100 ppm or greater. Termites avoided contact with the treated substrate and mortality was generally low, indicating that most termites did not contact the substrate often or long enough to acquire a lethal dose. These results indicate that it may be useful both as a contact insecticide for injection into active termite infestations within structures, and as a soil insecticide to prevent termites from entering structures. Although more research is required to establish the longevity of etofenprox in the soil under field conditions, our laboratory results indicate that 100 ppm in the soil is a reasonable minimum target concentration for field application.

INTRODUCTION

The Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae) is a serious pest of structures, trees, and crops in tropical and subtropical regions (Su & Tamashiro 1987). In Hawaii, it not only causes more economic losses than any other termite but is the most damaging pest in the state (Tamashiro *et al.* 1990b). The cost of preventing and controlling infestations and repairing the damage caused by this pest is conservatively estimated at more than US $100 million each year.

[1]Department of Entomology, University of Hawaii, 3050 Maile Way, Honolulu, HI 96822-2271, USA
[2]Author for correspondence and reprints

Over and above the economic damage, however, additional hazards to people and the environment are presented by attempts to stop this termite. At present, the remedial control of these pests involves injecting or spraying insecticides directly into and/or around infested buildings. This has the potential of exposing both applicators and building occupants to significant hazards and posing a threat to the environment. Obviously, it is desirable to use those insecticides which are least toxic to humans and the environment.

In the search for new termiticides, etofenprox (2-[4-ethoxyphenyl]-2-methylpropyl 3-phenoxybenzyl ether) (Mitsui Toatsu Chemicals, Inc., Tokyo, Japan) was found to have desirable characteristics. Etofenprox is related to synthetic pyrethroids but is composed of only carbon, hydrogen, and oxygen atoms, and does not have the halogen and/or CN group common to the pyrethroids (Udagawa 1988).

The mammalian toxicity of etofenprox is very low. In fact, the acute LD_{50} of etofenprox to mice, rats and dogs, was lower than the tolerable limits using oral, dermal, subcutaneous, or intraperitoneal routes of administration, and could therefore not be determined for these animals (Udawaga 1988). However, etofenprox is highly toxic to many insects.

Our study was initiated to determine (i) the toxicity of etofenprox to the Formosan subterranean termite (ii) its potential as a soil termiticide and (iii) its potential for use in remedial termite control.

MATERIALS AND METHODS

Topical toxicity

Technical etofenprox (334.7 mg) (2-[4-ethoxyphenyl]-2-methylpropyl 3-phenoxybenzyl ether) (Mitsui Toatsu Chemicals, Inc., Tokyo, Japan) was dissolved in 100 ml acetone to make a stock solution containing 3.347 mg etofenprox per ml. This stock solution was refrigerated, and aliquots were used for all dosage-mortality tests.

Three field colonies of *C. formosanus* located on the Manoa campus of the University of Hawaii were used in the tests. All three colonies have been monitored for at least 15 years, and all were considered very active. Termites were collected immediately before their use in laboratory assays to ensure that they were healthy and vigorous.

Termites were collected and extracted from wooden boxes set on the soil surface in a trapping technique described by Tamashiro *et al.* (1973). Five groups of 10 workers (pseudergates, or undifferentiated individuals older than the third instar) from each colony were weighed to obtain the average worker weight for each colony. Insecticide

dosages were calculated on the basis of amount of toxicant per unit weight of termite.

Before treatment, the termites were anesthetized by a brief exposure to carbon dioxide. The anesthetized termite was carefully held by the head capsule with a soft tweezer and 0.5 microliters of the test solution was placed on the dorsal part of the termite. Topical applications were performed with a Model 1002 Micro-jector (Houston Atlas Inc., Houston, Texas).

After topical application of insecticide, each termite was held for a short period until the acetone evaporated. It was then placed in a Petri dish containing a Whatman No. 1 filter paper moistened with distilled water to provide moisture and food. Treated termites were held in an incubator at 29°C, and checked daily for mortality. All dead termites were removed from each dish at each mortality count.

Tests were repeated at least twice, with five concentrations of etofenprox and acetone controls. Three replicates of 10 termites each were treated with each concentration of etofenprox for each test. Observations were terminated after 4 days, and data subjected to probit analysis (Finney 1962) using a commercial computer program (SAS Institute 1987).

Tunneling assays

Tunneling assays were conducted using two substrates, crushed coral sand and silica sand, and two different methods of exposure. Locally-purchased crushed coral sand was washed, oven dried and sifted to pass a U.S. 14-mesh (1.4 mm) sieve, with pH = 9.45 as determined by the method of Chapman & Pratt (1978). Silica sand (Silica S151 [Fine Granular Silicon Dioxide], Fisher Scientific, Fair Lawn, New York), with pH = 7.34, was sifted to pass a U.S. 40-mesh (0.425 mm) sieve and was stopped by a U.S. 100-mesh (0.15 mm) sieve. Termites were exposed to the substrates in tunneling assays consisting of either (i) a glass tube (Tamashiro *et al.* 1987, 1990a; Grace *et al.* 1993), or (ii) a "sandwich" formed by two microscope slides (Grace 1991; Grace *et al.* 1992). The tube test mimics vertical penetration by termites from beneath a building, while the sandwich test mimics horizontal tunneling by termites from the outside perimeter of the building.

In the tube test (Fig. 1), 4 cm of the test substrate was sandwiched between two pieces of 8% agar in an upright glass tube with an internal diameter of 13 mm, and capped top and bottom with metal faucet buttons. Crumpled paper toweling was provided at either end of the tube as food, and 150 termites (131 workers and 19 soldiers) were placed in the bottom of the tube, and the ends of the tube sealed with

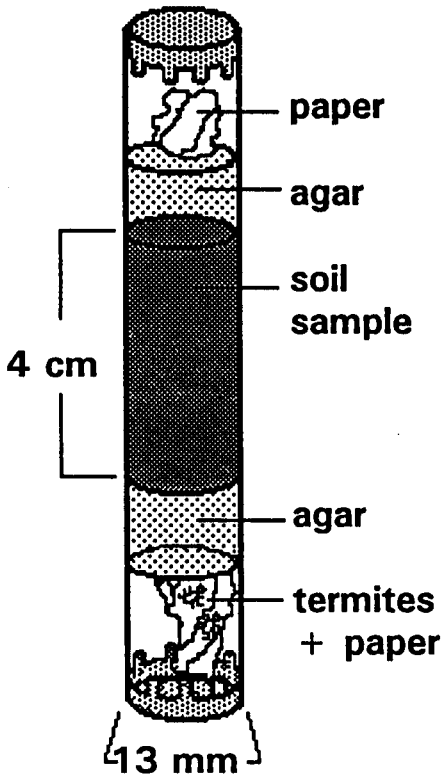

Fig. 1. Tube assay for measuring termite penetration vertically through insecticide-treated sand (after Grace *et al.* 1993).

metal caps. Termite mortality and the total vertical distance tunneled upward through the test substrate were recorded after four days of incubation in an unlighted temperature cabinet (29 ± 0.5°C). Percentage mortality and penetration data were transformed by the arcsine of the square root and subjected to analysis of variance (ANOVA), and means significantly different at the 0.05 level were separated by Duncan's multiple range test (SAS Institute 1987).

In the sandwich test (Fig. 2), the test substrate was placed in a horizontal tunneling arena consisting of two glass microscope slides (2.5 × 7.5 cm) spaced 3-4 mm apart and secured in a horizontal upright position along one edge by silicone rubber sealant to a base consisting of a third flat glass microscope slide. The ends of the tunneling arena were sealed with plastic spacers and silicone caulking, with a 1.5 cm long Tygon tube at the base of each end of the sandwich leading into the base of one of two 55 ml polystyrene vials, each containing *ca.* 15 g untreated sand, 3 ml water, and a 1.5 X 2.5 cm length of wooden tongue depressor as food. After *ca.* 7 g of the test sand and 1.5 ml distilled water was poured into the top of the tunneling arena, the top was sealed with plaster of paris, 100 termites (87 workers and 13 soldiers) were placed into one of the two vials, and the vials were sealed with plastic caps containing small air holes. Termite mortality and the total horizontal distance tunneled through the test substrate were recorded after four days of incubation in an unlighted temperature cabinet (29 ± 0.5°C), and analyzed in the same manner as the tube test.

In our first test, coral sand was treated with technical etofenprox to provide information on the repellency and toxicity of the active ingredient (a.i.) without emulsifying agents or carriers. Aliquots of a stock solution of technical etofenprox in acetone were diluted as necessary

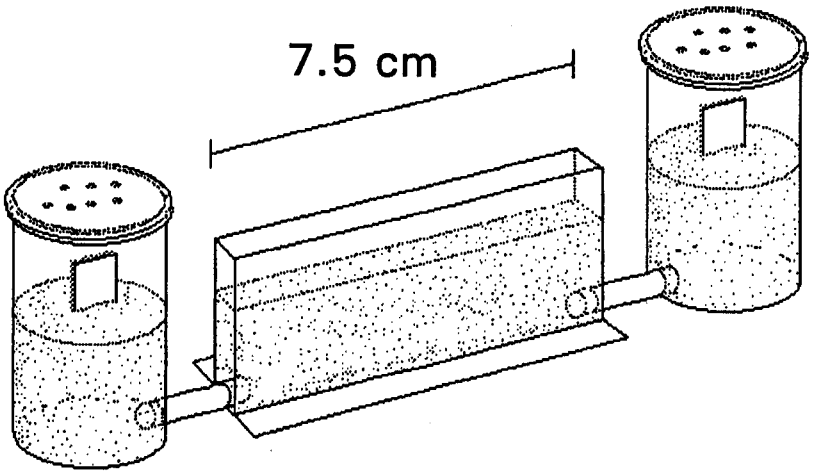

Fig. 2. Sandwich assay for measuring termite penetration horizontally through insecticide-treated sand (after Grace 1991).

and 15 ml of solution applied to 50 g of coral sand to achieve a.i. concentrations of 0 (acetone controls), 1, 10, 100, or 1000 ppm (weight of a.i. to weight of oven-dry sand) in the test substrates. After evaporation of the acetone in a fume hood, the treated sand was tested against *C. formosanus* using the tube test, as described above. As a follow-up to this test, termites were also placed directly on sand containing 100 or 1000 ppm etofenprox in Petri dishes in a forced-contact toxicity test.

In all of our subsequent tests, a formulated emulsifiable concentrate of etofenprox (Trebon 30EC) was diluted in distilled water as necessary to achieve the desired a.i. concentrations on a ppm basis (weight a.i. / weight sand). For initial bracketing of the concentration needed to prevent termite penetration, 80 g of coral sand and 100 g of silica sand were treated with 22 and 23 ml of emulsion respectively to achieve etofenprox concentrations of 1, 10, 100, or 1000 ppm. In tests to refine the necessary concentration, 150 g of coral or silica sand were treated with 30 ml or 29 ml respectively of the etofenprox emulsion to achieve a.i. concentrations of 10, 20, 50, 100 or 200 ppm.

RESULTS AND DISCUSSION

Topical toxicity

Although the topical toxicity of etofenprox to workers from each termite colony (Table 1, LD_{50} = 6.6, 5.4, 4.8 µg/g) was two to threefold less than that described by Khoo & Sherman (1979) for chlorpyrifos

Table 1. Toxicity of etofenprox topically applied to Formosan subterranean termite workers from three field colonies

Colony*	Mean worker mass (mg)	LD_{50} (µg/g)	95% fiducial limits	LD_{95} (µg/g)	95% fiducial limits	Slope
Miller	4.5	6.6	6.1-7.1	11.1	9.7-13.7	7.3
Pope	4.5	5.4	4.9-5.8	8.8	7.9-10.7	7.6
Andrews	3.1	4.8	4.3-5.2	8.6	7.5-10.9	6.5

*Colony names refer to adjacent buildings on the Manoa campus of the University of Hawaii.

(LD_{50} = 2.3, 3.2), or by Su & Scheffrahn (1990) for chlorpyrifos (3.4), fenvalerate (2.1) and permethrin (2.0), it is in the same general range as these insecticides. Termites from the three colonies differed slightly in their susceptibility to etofenprox. Individuals from the Miller colony had the highest LD_{50} (Table 1) and were significantly less susceptible to etofenprox (P = 0.05) than workers from the other two colonies. The basis of this differential susceptibility, which was not suggested by our preliminary tests, is not known, although colony differences have been noted in other studies (Su & LaFage 1988). Termites from the Miller colony were larger than those of the other two colonies, and size may be correlated with insecticide susceptibility, although dosages in this study were calculated on the basis of body weight. A more important variable than mass alone may be the smaller surface-to-volume ratio of larger individuals, which could reduce insecticide distribution over the cuticle following topical application and result in less, or slower penetration of the cuticle.

Countering any reduced susceptibility due to larger body size is the possible correlation of large worker size in a termite colony with reduced vigor due to colony senescence, as noted by Shimizu (1962) and Nakajima *et al.* (1964). In fact, increasing average body weight in the Pope colony over the past 15 years has been associated with an apparent slow reduction in the colony population size, generally supporting this correlation (Grace *et al.* 1995). This could explain why workers from the Pope colony, although equivalent in size to those from the Miller colony, were as susceptible to etofenprox as the smaller individuals found in the Andrews colony. However, differences in body size which do not appear to be attributable to senescence, but rather to some intrinsic colony characteristic, are also frequently observed among *C. formosanus* field colonies. In our 15-20 years of observations, individuals from the Miller and Andrews colonies have differed in size fairly consistently, with no significant increase in the size of the Miller colony workers over this

Table 2. Daily mean percentage mortality of *C. formosanus* workers from the Miller colony (mean individual mass of 4.5 mg) after topical treatment with etofenprox

Dosage µg/g	Daily percentage mortality				Total % mortality
	Day 1	Day 2	Day 3	Day 4	
10.2	80.0	13.3	3.3	0.0	96.6
8.2	50.0	23.3	0.0	6.7	80.0
6.6	23.3	6.7	0.0	6.7	36.7
5.1	16.7	6.7	3.3	0.0	26.7
4.1	6.7	0.0	3.3	0.0	10.0
0.0	0.0	3.3	3.3	6.7	13.3

period. At the time of this study, workers collected from all three colonies appeared active and vigorous, with none of the mottled white appearance that indicates urate retention and is often seen in sluggish laboratory termite colonies.

The small difference in susceptibility among the three colonies was significant only with respect to their LD_{50} values, and was not observed with the LD_{95}, dosages. There were also no significant differences in the slopes of the dosage-mortality curves among the colonies. However, the slopes for etofenprox obtained in our experiments (Table 1), were steeper than those for chlorpyrifos, permethrin and fenvalerate obtained by Su & Scheffrahn (1990). The slopes observed by Su & Scheffrahn (1990) tended to be flat, probably reflecting the heterogeneity of their test population, which consisted of termites from several colonies. These authors' slope for chlorpyrifos was 0.6, while Khoo & Sherman (1979) obtained slopes of 10.0 to 11.6 in their determinations.

The steeper slope means that etofenprox may require a lower dosage to attain the LD_{95} and LD_{99} levels than termiticides with flat slopes. This is significant in field use, since LD_{99} or better is the goal of such

Table 3. Daily mean percentage mortality of *C. formosanus* workers from the Pope colony (mean individual mass of 4.5 mg) after topical treatment with etofenprox

Dosage µg/g	Daily percentage mortality				Total % mortality
	Day 1	Day 2	Day 3	Day 4	
10.3	76.7	20.0	3.3	0.0	100.0
8.3	86.7	3.3	0.0	0.0	90.0
6.7	66.7	6.7	0.0	0.0	73.4
5.1	33.3	13.3	3.3	0.0	49.9
4.1	3.3	10.0	3.3	0.0	16.6
0.0	0.0	0.0	0.0	0.0	0.0

Table 4. Daily mean percentage mortality of *C. formosanus* workers from the Andrews colony (mean individual mass of 3.1 mg) after topical treatment with etofenprox

Dosage µg/g	Daily percentage mortality				Total % mortality
	Day 1	Day 2	Day 3	Day 4	
9.6	90.0	6.7	0.0	0.0	96.7
7.4	86.7	0.0	0.0	3.3	90.0
6.0	56.7	10.0	0.0	3.3	70.0
4.8	46.7	0.0	0.0	0.0	46.7
3.7	20.0	3.3	3.3	0.0	26.3
0.0	0.0	0.0	0.0	0.0	0.0

applications.

As with currently used termiticides, etofenprox was a relatively fast acting toxicant. As is apparent from the daily mortality patterns for individuals from each colony (Table 2, 3, and 4), most termite mortality occurred within the first 24 hours after treatment. Overall, the results of our topical toxicity tests indicate that etofenprox is similar in speed of action to, although slightly less toxic than, currently used termiticides, and sufficiently toxic for use against the Formosan subterranean termite.

Tunneling assays

Although treatment of coral sand with concentrations of technical etofenprox as low as 10 ppm stopped termites from completely penetrating 4 cm of coral sand in four days, concentrations of 100 ppm or greater were required to statistically differentiate the mean termite penetration from that observed in the controls (Table 5). Mortality was low at 100

Table 5. Mean percent penetration and mortality of Formosan subterranean termites tunneling through 4 cm of coral sand treated with an acetone solution of technical etofenprox in a vertical tube test.

Substrate	Concentration ppm	Percent Penetration*	Percent Mortality*
Coral	1000	12.5a	58.4a
	100	49.2ab	28.0ab
	10	75.0bc	13.6b
	1	100.0c	5.6b
	0	100.0c	6.2b

*Three replicates per concentration. Means within each column followed by the same letter are not significantly different at the 0.05 level.

Table 6. Mean percent penetration and mortality of Formosan subterranean termites tunneling through 4 cm of coral or silica sand treated with an emulsifiable formulation of etofenprox in a vertical tube test

Substrate	Concentration ppm	Percent Penetration*	Percent Mortality*
Coral	1000	14.2a	45.1a
	100	21.7a	6.7b
	10	87.5b	3.6b
	1	100.0c	4.2b
	0	100.0c	3.8b
Silica	1000	1.7a	60.9a
	100	4.2a	33.1ab
	10	26.7a	2.7b
	1	79.2b	3.6b
	0	100.0b	2.8b

*Three replicates per concentration. Means within each column and within each substrate followed by the same letter are not significantly different at the 0.05 level.

ppm (28%) and at 1000 ppm (58%), indicating that termites avoided contact with the treated sand. In contrast, the untreated (acetone only) controls were all completely penetrated within a few hours.

Repellency of the treated sand was confirmed by placing termites directly on etofenprox-treated sand in Petri dishes. When forced to

Table 7. Mean percent penetration and mortality of Formosan subterranean termites tunneling through 7.5 cm of sand treated with an emulsifiable formulation of etofenprox in a horizontal sandwich test

Substrate	Concentration ppm	Percent Penetration*	Percent Mortality*
Coral	1000	1.4a	18.3a
	100	16.7a	7.3ab
	10	90.5b	8.0ab
	1	100.0b	3.3b
	0	100.0b	3.7b
Silica	1000	1.9a	25.0a
	100	2.8a	17.3a
	10	79.0b	8.0b
	1	100.0b	4.0bc
	0	100.0b	2.0c

*Three replicates per concentration. Means within each column and within each substrate followed by the same letter are not significantly different at the 0.05 level.

Table 8. Mean percent penetration and mortality of Formosan subterranean termites tunneling through 4 cm of coral or silica sand treated with an emulsifiable formulation of etofenprox in a vertical tube test.

Substrate	Concentration ppm	Percent Penetration*	Percent Mortality*
Coral	200	20.0a	28.0a
	100	19.5a	22.8ab
	50	44.5b	18.8abc
	20	67.5bc	7.9bc
	10	76.0c	9.5bc
	0	100.0d	4.3c
Silica	200	14.0a	53.1a
	100	20.5a	58.0a
	50	44.5b	24.4b
	20	78.5c	10.0bc
	10	97.0d	4.8c
	0	100.0d	4.8c

*Five replicates per concentration. Means within each column and within each substrate followed by the same letter are not significantly different at the 0.05 level.

remain in contact with sand containing 1000 ppm etofenprox, all termites died within 24 hours, while those exposed to 100 ppm were all dead or moribund within four days.

Termites generally penetrated further in etofenprox-treated coral than in silica sand, suggesting that the higher pH and/or larger particle size of coral sand were detrimental to insecticide efficacy. However, the results obtained with both substrates indicated that the minimum concentration of etofenprox necessary to reduce to termite penetration to 1 cm or less lay between 10 and 1000 ppm, and probably close to 100 ppm. Thus, the range of concentrations for further tests was narrowed to 10 to 200 ppm.

Termite penetration of coral or silica sand did not differ significantly at 100 and 200 ppm etofenprox (Table 8 and 9), indicating that concentrations above 100 ppm provide maximum protection. Although concentrations as low as 10 ppm prevented complete termite penetration of the assay apparatus in some cases, termite penetration increased to unacceptable levels at etofenprox concentrations below 100 ppm.

In both vertical tube (Table 6) and horizontal sandwich (Table 7) tunneling assays with the emulsifiable formulation, termites reacted similarly as in tests with technical etofenprox. Thus, solvent and emulsifiers in the Trebon 30EC formulation did not affect the behavior

Table 9. Mean percent penetration and mortality of Formosan subterranean termites tunneling through 7.5 cm of coral or silica sand treated with an emulsifiable formulation of etofenprox in a horizontal sandwich test

Substrate	Concentration ppm	Percent Penetration*	Percent Mortality*
Coral	200	22.9a	8.4a
	100	50.6a	9.2a
	50	43.1a	9.6a
	20	78.6b	4.8a
	10	86.9b	3.4a
	0	100.0b	4.2a
Silica	200	2.9a	14.8a
	100	4.6a	10.6abc
	50	29.1b	8.2abc
	20	93.4c	7.6bc
	10	100.0c	12.2ab
	0	100.0c	5.6c

*Five replicates per concentration. Means within each column and within each substrate followed by the same letter are not significantly different at the 0.05 level.

of termites nor the toxicity of the active ingredient.

The vertical tube and horizontal sandwich tunneling assays yielded similar results, although termites generally tunneled further into the 7.5 cm horizontal sandwich than the 4 cm vertical tube at low etofenprox concentrations. Grace *et al.* (1992) hypothesized, from horizontal sandwich assays with silafluofen, that termites were able to minimize contact with the insecticide-treated sand by lining their tunnels with untreated sand imported from the adjacent vial. This defensive behavior was not possible in the vertical tube assay, where only treated sand was available, but is very likely to occur in the field, and may well explain apparent contradictions between the results of laboratory screening trials and observed termite penetration of insecticide-treated soil under field conditions.

Both tunneling assay methods have their respective advantages. The horizontal sandwich test may mimic field conditions somewhat better than the vertical tube test, and allow more critical observations of tunneling behavior due to the narrow gap between the sides of the tunneling arena. However, it is a more difficult test to initiate than the tube test and more subject to minor design variations among the individual replicates. The tube test is more standardized and simple to initiate with a large number of treatments or replicates. Termites occasionally tunneled directly through the center of the substrate

within the tube, hiding the tunnel from view; but, their thigmotropic behavior imparts a strong tendency to initiate tunnels between the substrate and the glass, where they are readily visible and easily measured.

SUMMARY AND CONCLUSIONS

Etofenprox is an insecticide with exceptionally low mammalian toxicity, but high toxicity to the Formosan subterranean termite. When applied topically to termite workers, the LD_{50} of 4.8 to 6.6 was in the same general range as termiticides currently in use for soil treatment and injection into termite galleries within structural lumber. Etofenprox was a relatively quick acting termiticide, with most mortality occurring within 24 hours.

Although etofenprox concentrations as low as 10 ppm reduced termite penetration of crushed coral and silica sand, consistent protection was achieved with concentrations of 100 ppm or greater in both vertical tube tests and horizontal sandwich tunneling tests. Termites avoided contact with the treated substrate and mortality was generally low, indicating that most termites did not contact the substrate often or long enough to acquire a lethal dose of etofenprox.

The low mammalian toxicity and high contact toxicity to termites of etofenprox suggest that it may be useful in remedial termite control as a contact toxicant, where direct injections of insecticide into active infestations in structural lumber are required. Resmethrin is applied in this manner in Hawaii for both Formosan subterranean termite and drywood termite (Kalotermitidae) control.

Etofenprox also appears to be a promising soil insecticide to prevent termites from entering structures. Although more research is required to establish the longevity of etofenprox in the soil under field conditions, our laboratory results indicate that such studies are warranted. To provide the necessary safety margin, field application rates should be designed to maintain a minimum of 100 ppm in the soil for the required period of longevity, which is generally at least five years under most soil types and environmental conditions.

ACKNOWLEDGMENTS

Journal Series No. 4179 of the Hawaii Institute of Tropical Agriculture and Human Resources. Preliminary results were reported to the 25th Annual Meeting of the International Research Group on Wood Preservation, Bali, Indonesia, 29 May - 3 June 1994. The authors gratefully acknowledge financial support of USDA-ARS Specific Cooperative Agreement 58-6615-4-037 and Mitsui Toatsu Chemicals, Inc.,

Tokyo, Japan. Mention of trade names is for informational purposes only and does not constitute an endorsement by funding agencies or the University of Hawaii.

REFERENCES

Chapman, H.D. & P.F. Pratt. 1978. Methods of Analysis for Soils, Plants, and Water. Univ. Calif. Div. Agric. Sci. Publ. No. 4034, p. 19.

Finney, D.J. 1962. Probit Analysis: A Statistical Treatment of the Sigmoid Response Curve, Second Edition. Cambridge: Cambridge University Press. 318 pp.

Grace, J.K. 1991. Response of eastern and Formosan subterranean termites (Isoptera: Rhinotermitidae) to borate dust and soil treatments. J. Econ. Entomol. 84: 1753-1757.

Grace, J.K., R.T. Yamamoto & R.H. Ebesu. 1992. Laboratory evaluation of the novel soil insecticide silafluofen against *Coptotermes formosanus* Shiraki (Isoptera, Rhinotermitidae). J. Appl. Entomol. 113: 466-471.

Grace, J.K., R.T. Yamamoto & M. Tamashiro. 1995. Relationship of individual worker mass and population decline in a Formosan subterranean termite colony (Isoptera: Rhinotermitidae). Environ. Entomol. 24: 1258-1262.

Grace, J.K., J.R. Yates, M. Tamashiro & R.T. Yamamoto. 1993. Persistence of organochlorine insecticides for Formosan subterranean termite (Isoptera: Rhinotermitidae) control in Hawaii. J. Econ. Entomol. 86: 761-766.

Khoo, B.K. & M. Sherman. 1979. Toxicity of chlorpyrifos to normal and defaunated Formosan subterranean termites. J. Econ. Entomol. 72: 298-304.

Nakajima, S., K. Shimizu & Y. Nakajima. 1964. Analytical studies on the vitality of colonies of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki. II. Seasonal fluctuations on the external characters of the workers, the ratio of caste-members and carbon dioxide in the nest of a colony. Bull. Faculty Agric. Univ. Miyazaki 9: 222-227.

SAS Institute. 1987. SAS/STAT Guide for Personal Computers, Version 6 Edition. Cary, North Carolina: SAS Institute Inc.

Shimizu, K. 1962. Analytical studies on the vitality of colonies of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki. I. Analysis of the strength of vitality. Bull. Faculty Agric. Univ. Miyazaki 8: 106-110.

Su, N.-Y. & J.P. LaFage. 1988. Differences in survival and feeding activity among colonies of the Formosan subterranean termite (Isoptera: Rhinotermitidae). J. Appl. Entomol. 97: 134-138.

Su, N.-Y. & R.H. Scheffrahn. 1990. Comparison of eleven soil termiticides against the Formosan subterranean termite and eastern subterranean termite (Isoptera: Rhinotermitidae). J. Econ. Entomol. 83: 1918-1924.

Su, N.-Y., & Tamashiro, M. 1987. An overview of the Formosan subterranean termite (Isoptera: Rhinotermitidae) in the world. Pp. 3-14 *in* Biology and Control of the Formosan Subterranean Termite (M. Tamashiro & N.-Y. Su, eds.). Hawaii Inst. Tropical Agric. Human Resources Res. Extension Series 083, Univ. Hawaii, Honolulu.

Tamashiro, M., J.K. Fujii & P.Y. Lai. 1973. A simple method to trap and prepare large numbers of subterranean termites for laboratory and field experiments. Environ. Entomol. 2: 721-722.

Tamashiro, M., J.R. Yates & R.H. Ebesu. 1987. The Formosan subterranean termite in Hawaii: problems and control. Pp. 15-22 *in* Biology and Control of the Formosan Subterranean Termite (M. Tamashiro & N.-Y. Su, eds.). Hawaii Inst. Tropical Agric. Human Resources Res. Extension Series 083, Univ. Hawaii, Honolulu.

Tamashiro, M., J.R. Yates, R.H. Ebesu & R.T. Yamamoto. 1990a. Effectiveness and Longevity of Termiticides in Hawaii. Hawaii Inst. Tropical Agric. Human Resources Res. Extension Series 119, Univ. Hawaii, Honolulu.

Tamashiro, M., J.R. Yates, R.T. Yamamoto & R.H. Ebesu. 1990b. The integrated management of the Formosan subterranean termite in Hawaii. Pp. 77-84 *in* Pest Control into the 90s: Problems and Challenges (P.K.S. Lam and D.K. O'Toole, eds.). Applied Sci. Dept., City Polytechnic of Hong Kong.

Udagawa, T. 1988. Trebon (etofenprox), a new insecticide. Japan Pesticide Information 53: 9-13.