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Probit Analysis of Pesticide Toxicity to Aphids on Guam

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Abstract—Three common crop aphid pests on Guam, *Aphis craccivora* Koch, *Aphis gossypii* Glover, and *Toxoptera citricida* (Kirkaldy) were examined in laboratory dip test bioassays using three commonly used insecticides, dimethoate, diazinon, and malathion. The LD_{50}, LD_{90}, lethal dose ratios and 95% confidence limits were computed for each aphid-insecticide combination. The LD_{50} and LD_{90} for each aphid-insecticide combination were generally low, although there were differences in lethal doses among aphids collected at different sites on Guam. Analysis of the slopes and intercepts of the probit regressions suggests that different detoxification mechanisms or site-specific factors may be operating. Analysis of lethal dose ratios using the lowest lethal dose in an experiment as a baseline suggest that there is little to no detectable insecticide resistance in the aphid populations studied on Guam.

Introduction

Aphids are serious pests of a variety of crops on Guam, which cause serious damage and yield loss in crops and ornamental plantings, and vector a number of harmful viral diseases. The cosmopolitan array of aphid species now present on Guam was likely inadvertently introduced over the years from areas outside of the Mariana Archipelago (Swezey 1942, 1946, Bellar 1948, Blackman & Eastop 1984). Aphid infestations on beans, melons, taro, and bananas grown in the Mariana Islands are almost inevitable if insecticides are not used, causing severe cosmetic damage and yield reduction.

Though pesticides are commonly used to control aphids on Guam (Yudin & Butz 1998), little work has been done to categorize use patterns, efficacy, and the build-up of insecticide resistance. Such information is critical to the formulation of integrated pest management (IPM) programs seeking to reduce the environmental impact of pesticides and enhance the incorporation of alternate pest management strategies (Croft & Morse 1979). The project described hereafter constitutes the first effort to examine the development of insecticide resistance on Guam, and provides baseline information for future comparisons.

Materials and Methods

Populations of three of the most common pestiferous crop aphids on Guam, the melon aphid, *Aphis gossypii* Glover, the cowpea aphid, *Aphis craccivora* Koch, and the brown citrus aphid, *Toxoptera citricida* (Kirkaldy) were assayed for the development of insecticide resistance against dimethoate (Cygon), diazinon, and malathion. These insecticides are the most frequently used compounds against aphids on a variety of crops grown on Guam (L.S. Yudin, CALS-ANR, University of Guam, unpublished data).

Aphids were collected from colonies on screenhouse plants and from farmers' fields located at various sites on Guam within 24 hours prior to dip-testing in the laboratory. Collected aphids were maintained in a controlled temperature chamber at 24 C until tested. Only reproductively mature adult female aphids were selected for dip tests. Aphids were determined to be mature if they possessed fully developed caudal processes (Blackman & Eastop 1984) and were of normal adult size when examined under a stereomicroscope.

In the dip tests, apterous female aphids were positioned on their backs in two rows of five on the uppermost side of double-sided poster tape fastened to a glass microslide. Once all test aphids were positioned on the microslide, the microslide was totally immersed in the test solution for one second. Excess liquid was removed from the slide by gently tapping the edge of the slide on a paper towel. Microslides were then placed on a paper towel inside a plastic container with the lid left slightly ajar. The temperature within the container was maintained at 24º C with a relative humidity of 65%.

Five microslides containing ten aphids collected were tested at each of four insecticide concentration levels and with a distilled water control. Residual toxicity of insecticides was determined at 24-hour intervals following exposure. After 24 hours, a soft-bristled brush was used to stimulate movement in the aphids, with individuals showing no voluntary movement upon stimulation being judged dead. The number of dead aphids was recorded for each slide.

Dose response curves were computed for each of the three insecticides using a separate series of dip tests for each aphid species collected from each locale. Aphid survivorship was scored 24 hr following exposure using dip-test procedures described previously. Probit analyses (Finney 1962) were performed using Polo-PC (LeOra Software 1994). Lethal dose ratios and associated significance tests were performed as described in Robertson & Preisler (1992).

Results

Residual toxicity effects of pesticides for each of the three aphid species examined are shown in Table 1. Percent mortality in each pesticide treatment level and in controls increased substantially for all aphids over time. Mortality observations made after 24 hours generally ranged from near 0% to greater than 50%, though in some cases near 90% mortality was observed. Mortality at all treatment

Table 1. Residual toxicity of insecticides to aphids at 24 hr intervals after exposure in dip tests.

		% Mortality after treatments ± SD			
Treatment	Rate (%)	24 hr	48 hr	72 hr	96 hr
			Aphis craccivora		
Dimethoate	0	0a	28 ± 14.83b	92 ± 8.37c	100d
	0.0021	2 ± 4.47a	42 ± 8.37b	94 ± 5.48c	100d
	0.0042	4 ± 5.48a	44 ± 13.42b	100c	100c
	0.021	20 ± 7.07a	76 ± 8.94b	100c	100c
	0.042	36 ± 15.17a	86 ± 5.48b	100c	100c
	0.21	42 ± 14.83a	86 ± 11.40b	100c	100c
Diazinon	0	0a	28 ± 13.04b	72 ± 17.89c	100d
	0.0016	2 ± 4.47a	54 ± 8.94b	82 ± 19.24c	100d
	0.0032	4 ± 8.94a	46 ± 19.49b	84 ± 11.40c	100d
	0.016	44 ± 8.94a	70 ± 7.07b	94 ± 5.48c	100d
	0.032	54 ± 5.48a	76 ± 15.17b	94 ± 5.48c	100c
	0.16	98 ± 4.47a	98 ± 4.47a	100a	100a
Malathion	0	0a	38 ± 21.68b	98 ± 4.47c	100c
	0.0019	4 ± 5.48a	48 ± 13.04b	98 ± 4.47c	100c
	0.0038	8 ± 4.47a	68 ± 8.37b	100c	100c
	0.019	20 ± 10.00a	62 ± 16.43b	98 ± 4.47c	100c
	0.038	42 ± 13.04a	74 ± 11.40b	100c	100c
	0.19	62 ± 4.47a	74 ± 5.48b	100c	100c
			Aphis gossypi		
Dimethoate	0	6 ± 8.94a	72 ± 8.37b	94 ± 5.48c	100c
	0.0021	12 ± 10.95a	70 ± 7.07b	98 ± 4.47c	100c
	0.0042	12 ± 13.04a	64 ± 5.48b	98 ± 4.47c	100c
	0.021	20 ± 7.07a	70 ± 15.81b	100c	100c
	0.042	10 ± 7.07a	72 ± 8.37b	100c	100c
	0.21	74 ± 5.48a	100b	100b	100b
Diazinon	0	4 ± 5.48a	96 ± 5.48b	100b	100b
	0.0016	22 ± 14.83a	80 ± 12.25b	100c	100c
	0.0032	42 ± 8.37a	84 ± 11.40b	100c	100c
	0.016	68 ± 8.37a	98 ± 4.47b	100b	100b
	0.032	72 ± 10.95a	98 ± 4.47b	100b	100b
	0.16	88 ± 8.37a	100b	100b	100b
Malathion	0	6 ± 8.94a	24 ± 11.40b	98 ± 4.47c	100c
	0.0019	10 ± 10.00a	30 ± 14.14b	96 ± 5.48c	100c
	0.0038	8 ± 13.04a	48 ± 17.89b	96 ± 5.47c	100c
	0.019	22 ± 13.04a	84 ± 13.42b	98 ± 4.47c	100c
	0.038	30 ± 10.00a	96 ± 5.48b	100c	100c
	0.19	62 ± 16.43a	100b	100c	100c
			Toxoptera citricida		
Dimethoate	0	4 ± 5.48a	54 ± 5.48b	94 ± 8.94c	100c
	0.0021	2 ± 4.47a	16 ± 8.94b	80 ± 10.00c	100c

	0.0042	4 ± 5.48a	22 ± 10.95b	90 ± 7.07c	100c
	0.021	6 ± 5.48a	72 ± 19.23b	100c	100c
	0.042	18 ± 13.04a	98 ± 4.47b	100b	100b
	0.21	50 ± 20.00a	94 ± 4.47b	100b	100b
Diazinon	0	0a	38 ± 8.37b	100c	100c
	0.0016	2 ± 4.47a	36 ± 20.74b	100c	100c
	0.0032	4 ± 8.94a	44 ± 18.17b	100c	100c
	0.016	42 ± 4.47a	98 ± 4.47b	100b	100b
	0.032	50 ± 10.00a	98 ± 4.47b	100b	100b
	0.16	62 ± 13.04a	100b	100b	100b
Malathion	0	0a	80 ± 12.25b	100c	100c
	0.0019	2 ± 4.47a	72 ± 8.37b	100c	100c
	0.0038	4 ± 5.48a	70 ± 15.81b	100c	100c
	0.019	30 ± 7.07a	98 ± 4.47b	100b	100b
	0.038	34 ± 8.94a	98 ± 4.47b	100b	100b
	0.19	94 ± 5.48a	100b	100b	100b

Mean mortalities (%) followed by the same lowercase letter in the same row are not significantly different, based on analysis of transformed data, P > 0.05, LSD, Velleman (1997).

levels exceeded 90% after 72 hours and was 100% in all treatments, including distilled water controls, after 96 hours.

Based on results from residual toxicity experiments, a 24 hour post-exposure interval was determined the most appropriate for comparing insecticide susceptibility in the various aphid populations collected from Guam. The LD_{50} and LD_{90} with associated lethal dose ratios (LDR) are shown for each aphid species examined (Tables 2, 3, 4) as are 95% confidence levels.

The lethal dose response was similar for the two *A. gossypii* populations exposed to dimethoate and collected from the same taro field a week apart (Table 2). Differences were observed in *A. gossypii* survivorship in response to exposure to diazinon. *Aphis gossypii* collected from eggplant in Toto was significantly more susceptible than those collected from taro in Talofofo and from the exotic weed, eupatorium (*Chromolaena odorata*) in Yona. Similarly, *A. gossypii* collected from eupatorium in Yona were less susceptible to malathion than populations collected from taro in Barrigada. Analysis of the slopes of the probit regressions show that the regression lines were the same for the two *A. gossypii* collections from taro in Barrigada ($\chi^2 = 0.14$, df = 2, $P > 0.05$), while the regression lines computed for *A. gossypii* exposed to malathion were parallel ($\chi^2 = 4.45$, df = 3, $P > 0.05$). However, slopes of regression lines for *A. gossypii* populations exposed to diazinon were not parallel ($\chi^2 = 9.55$, df = 4, $P \leq 0.05$).

There were significant differences in susceptibility for *A. craccivora* collected from beans at various sites on Guam (Table 3). Aphid populations collected from University of Guam research plots in Mangilao were significantly less susceptible than aphid populations from Talofofo, Malojloj or Barrigada. There were also significant differences in susceptibility to diazinon between *A. craccivora* collected at Talofofo and Barrigada, and from two separate sites at Talofofo.

Table 2. Toxicity of dimethoate, diazinon and malathion to *Aphis gossypii*.

Collection Site	n	slope ± SE	Lethal Dose		95% CI	χ^2	Lethal Dose Ratio		95% CI
				Dimethoate					
Barrigada (taro) 1-Apr-99	30	1.041 ± 0.199	LD_{50}	0.076	0.044 - 0.140	8.937	–	–	–
			LD_{90}	1.286	0.495 – 9.116		–	–	–
Barrigada (taro) 7-Apr-99	30	1.012 ± 0.158	LD_{50}	0.069	0.043 – 0.125	7.419	LDR_{50}	1.094ns	0.516 – 2.321
			LD_{90}	1.277	0.508 – 6.608		LDR_{90}	1.007ns	0.173 – 5.855
				Diazinon					
Talofofo (taro) 15-Dec-98	30	1.025 ± 0.270	LD_{50}	0.157	0.084 – 0.510	20.620	–	–	–
			LD_{90}	2.584	0.693 – 112.289		–	–	–
Yona (*Chromolaena*) 16-Dec-98	30	1.699 ± 0.585	LD_{50}	0.145	0.086 – 0.375	17.048	LDR_{50}	1.076ns	0.426 - 2.713
			LD_{90}	0.826	0.339 – 55.944		LDR_{90}	3.123ns	0.271 – 36.026
Toto (eggplant) 26-Jan-99	30	0.960 ± 0.209	LD_{50}	0.129	0.070 – 0.356	11.436	LDR_{50}	1.218ns	0.426 – 3.481
			LD_{90}	2.783	0.761 – 60.013		LDR_{90}	0.929ns	0.063 - 13.701
Toto (eggplant) 11-Jan-99	30	1.421 ± 0.165	LD_{50}	0.045	0.022 – 0.073	10.167	LDR_{50}	3.511*	1.397 – 8.821
			LD_{90}	0.463	0.211 – 4.060		LDR_{90}	5.583ns	0.574 – 54.293
Toto (eggplant) 21-Jan-99	30	1.723 ± 0.227	LD_{50}	0.022	0.016 – 0.030	15.785	LDR_{50}	7.157*	3.155 – 16.233
			LD_{90}	0.121	0.080 – 0.228		LDR_{90}	21.275*	2.802 – 161.553
				Malathion					
Yona (*Chromolaena*) 23-Nov-98	30	1.539 ± 0.536	LD_{50}	0.313	–	31.888	–	–	–
			LD_{90}	2.126	–		–	–	–
Yona (*Chromolaena*) 18-Nov-98	30	0.987 ± 0.352	LD_{50}	0.192	0.102 – 1.326	20.509	LDR_{50}	1.630ns	0.526 – 5.049
			LD_{90}	3.811	0.780 – 21232.364		LDR_{90}	0.559ns	0.019 – 16.084
Barrigada (taro) 23-Nov-98	30	1.263 ± 0.402	LD_{50}	0.129	0.070 – 0.325	19.385	LDR_{50}	2.425ns	0.898 – 6.545
			LD_{90}	1.334	0.448 – 107.907		LDR_{90}	1.595ns	0.111 – 22.770
Barrigada (taro) 30-Nov-98	30	1.950 ± 0.509	LD_{50}	0.088	0.045 – 0.146	26.021	LDR_{50}	3.542*	1.435 – 8.745
			LD_{90}	0.401	0.215 – 2.790		LDR_{90}	5.303ns	0.607 – 46.303

Table 3. Toxicity of dimethoate, diazinon and malathion to *Aphis craccivora*.

Collection Site	n	slope ± SE	Lethal Dose		95% CI	χ^2	Lethal Dose Ratio		95% CI
				Dimethoate					
Mangilao (beans)	30	0.886 ± 0.144	LD_{50}	0.171	0.094 – 0.453	12.340	–	–	–
6-Apr-99			LD_{90}	4.794	1.330 – 53.472		–	–	–
Talofofo (beans)	30	1.184 ± 0.215	LD_{50}	0.077	0.048 – 0.130	7.966	LDR_{50}	2.235ns	0.934 – 5.347
5-Apr-99			LD_{90}	0.927	0.410 – 4.621		LDR_{90}	5.169ns	0.685 – 38.955
Malojloj (beans)	90	0.921 ± 0.078	LD_{50}	0.051	0.039 – 0.069	52.931	LDR_{50}	3.358*	1.522 – 7.412
6-Apr-99			LD_{90}	1.256	0.687 – 2.855		LDR_{90}	3.815ns	0.605 – 24.053
Barrigada (beans)	30	0.887 ± 0.126	LD_{50}	0.032	0.020 – 0.053	13.200	LDR_{50}	5.421*	2.272 – 12.936
31-Mar-99			LD_{90}	0.880	0.355 – 4.102		LDR_{90}	5.450ns	0.697 – 42.626
				Diazinon					
Talofofo (beans)	90	1.148 ± 0.090	LD_{50}	0.075	0.059 – 0.102	51.612	–	–	–
29-Dec-98			LD_{90}	0.986	0.584 – 1.983	–	–	–	
Barrigada (beans)	30	2.963 ± 0.660	LD_{50}	0.033	0.024 –0.044	20.120	LDR_{50}	2.269*	1.524 – 3.379
31-Mar-99			LD_{90}	0.090	0.063 – 0.194		LDR_{90}	10.944*	5.042 - 23.755
Talofofo (beans)	30	1.204 ± 0.146	LD_{50}	0.009	0.006 – 0.012	11.706	LDR_{50}	8.768*	5.595 – 13.742
10-Dec-98			LD_{90}	0.100	0.059 – 0.222		LDR90	9.886*	4.073 – 23.993
				Malathion					
Talofofo (beans)	30	0.845 ± 0.184	LD_{50}	0.069	0.034 – 0.161	15.942	–	–	–
12-Nov-98			LD_{90}	2.275	0.636 – 43.691		–	–	–
Toto (beans)	60	2.254 ± 0.270	LD_{50}	0.040	0.030 – 0.051	73.887	LDR_{50}	1.736ns	0.823 – 3.665
7-Dec-98			LD_{90}	0.147	0.104 – 0.262		LDR_{90}	15.388*	2.487 – 95.222
Yona (candlebush)	30	0.881 ± 0.142	LD_{50}	0.023	0.013 – 0.041	18.726	LDR_{50}	2.970*	1.209 – 7.296
18-Nov-98			LD_{90}	0.663	0.263 – 3.490		LDR_{90}	3.433ns	0.398 – 29.595
Toto (beans)	30	0.579 ± 0.131	LD_{50}	0.013	0.005 – 0.030	19.276	LDR_{50}	5.320*	1.757 – 16.105
30-Nov-98			LD_{90}	2.118	0.432 – 100.909		LDR_{90}	1.076ns	0.060 – 19.326

Table 4. Toxicity of dimethoate, diazinon and malathion to *Toxoptera citricida*.

Collection Site	n	slope ± SE	Lethal Dose		95% CI	χ^2	Lethal Dose Ratio		95% CI
Dimethoate									
Yona (citrus)	30	2.874 ± 0.639	LD_{50}	0.036	0.027 – 0.047	9.983	–	–	–
27-Jan-99			LD_{90}	0.102	0.072 – 0.223		–	–	–
Dededo (citrus)	30	1.402 ± 0.163	LD_{50}	0.015	0.010 – 0.021	21.655	LDR_{50}	2.470*	1.595 – 3.823
11-Jan-99			LD_{90}	0.121	0.076 – 0.236		LDR_{90}	0.842ns	0.405 – 1.751
Diazinon									
Dededo (citrus)	30	1.000 ± 0.355	LD_{50}	0.221	0.113 – 2.708	16.142	–	–	–
11-Dec-98			LD_{90}	4.234	0.784 – 35880.701		–	–	–
Toto (citrus)	30	1.245 ± 0.214	LD_{50}	0.075	0.049 – 0.130	17.851	LDR_{50}	2.939*	1.019 – 8.475
21-Dec-98			LD_{90}	0.806	0.358 – 3.797		LDR_{90}	5.252ns	0.247 – 111.730
Barrigada (citrus)	60	1.264 ± 0.109	LD_{50}	0.045	0.035 – 0.060	31.327	LDR_{50}	4.903*	1.821 – 13.206
4-Jan-99			LD_{90}	0.466	0.286 – 0.905		LDR_{90}	9.088ns	0.491 – 168.223
Dededo (citrus)	30	1.577 ± 0.242	LD_{50}	0.019	0.012 – 0.027	8.206	LDR_{50}	11.536*	4.116 – 32.330
4-Jan-99			LD_{90}	0.125	0.079 – 0.261		LDR_{90}	33.934*	1.836 – 627.325
Toto (citrus)	60	1.550 ± 0.152	LD_{50}	0.017	0.013 – 0.022	29.910	LDR_{50}	13.116*	4.877 – 35.274
14-Dec-98			LD_{90}	0.113	0.081 – 0.178		LDR_{90}	37.371*	2.081 – 671.226
Yona (citrus)	30	1.474 ± 0.214	LD_{50}	0.003	0.002 – 0.004	5.722	LDR_{50}	76.269*	26.775 – 217.250
16-Dec-98			LD_{90}	0.021	0.014 - 0.041		LDR_{90}	197.059*	10.759 – 3609.306
Malathion									
Dededo (citrus)	30	1.274 ± 0.317	LD_{50}	0.049	0.022 – 0.084	13.881	–	–	–
1-Dec-98			LD_{90}	0.497	0.229 – 3.547	–	–	–	
Dededo (citrus)	30	2.351 ± 0.389	LD_{50}	0.041	0.029 – 0.055	24.236	LDR_{50}	1.206ns	0.629 - 2.311
17-Nov-98			LD_{90}	0.143	0.096 – 0.292		LDR_{90}	3.478*	1.055 – 11.464
Yona (citrus)	30	2.941 ± 0.596	LD_{50}	0.035	0.026 – 0.047	16.196	LDR_{50}	1.387ns	0.726 – 2.646
2-Dec-98			LD_{90}	0.096	0.068 – 0.193		LDR_{90}	5.144*	1.566 – 16.898
Barrigada (citrus)	30	7.453 ± 1.293	LD_{50}	0.025	0.022 – 0.028	11.019	LDR_{50}	1.948*	1.071 – 3.544
10-Nov-98			LD_{90}	0.037	0.033 – 0.046		LDR_{90}	13.257*	4.376 – 40.163

Similarly, there were significant differences in susceptibility to malathion among populations of *A. craccivora* on beans and candlebush, *Senna alata*. Regression lines were parallel for *A. craccivora* exposed to diemthoate (χ^2 = 2.55, df = 3, P > 0.05), but not parallel for those exposed to diazinon (χ^2 = 13.81, df = 2, P ≤ 0.05) or to malathion (χ^2 = 51.30, df = 3, P ≤ 0.05).

Toxoptera citricida populations differed in susceptibility to dimethoate (Table 4), with aphids from Yona significantly less susceptible than aphids collected from Dededo. Populations of *T. citricida* also differed in susceptibility to diazinon with Dededo aphids being less susceptible than those collected from Toto, Barrigada, or Yona. Barrigada populations of *T. citricida* were significantly more susceptible to malathion than populations collcted from Dededo or Yona. Probit regression slopes were parallel only from *T. citricida* exposed to diazinon (χ^2 = 6.45, df = 5, P > 0.05), while regression line slopes were not parallel for *T. citricida* exposed to dimethoate (χ^2 = 8.74, df = 1, P ≤ 0.05) or to malathion (χ^2 = 32.37, df = 3, P ≤ 0.05).

Discussion

Hardman et al. (1959) and Kuperman et al. (1961) suggested that the slope of the probit regression reflects the quality of the enzyme systems that detoxify insecticides in an insect's body. Populations of insects having parallel probit regression slopes may have qualitatively similar detoxification systems, while those that do not may differ qualitatively as well as quantitatively. Populations of the same species of aphids collected from the same site at different dates would be expected to have equal regressions, as did *A. gossypii* collected from Barrigada and tested against dimethoate. Other aphid populations of the same aphid species collected from similar plants or in the same vicinity would be expected to show quantitative differences but have parallel probit regression lines, as did *A. gossypii* tested against malathion, *A. craccivora* tested against dimethoate, and *T. citricida* tested against diazinon.

However, localized insect populations may possess subtle and unique genetic and physiological characteristics that play a role in determining the slope of the probit regression line. These include such characteristics as the ability to absorb specific compounds through the gut wall, the ability to excrete those compounds, and the target specificity of a compound. This may explain in part why some of the probit regressions performed on the same species of aphids collected at different dates and sites in this study were neither equal nor their slopes parallel.

The results of this study suggest that resistance levels to dimethoate, diazinon, and malathion are generally low, although there are localized susceptibility differences among aphid populations on Guam that may be problematic in the future (Table 5). These differences in susceptibility may be due to variation in dosage rate and frequency of application of applied pesticides by different farmers.

Because most of Guam's farms are small, family-owned family operations, farm income is generally used to supplement retirement pensions, or other income

Table 5. Mean lethal doses of insecticides for aphids collected at various sites on Guam.

Collection Site	LD_{50}	(Range)	LD_{90}	(Range)
Aphis gossypii				
		Dimethoate		
Barrigada (taro)	0.073	(0.069 – 0.076)	1.282	(1.277 – 1.286)
		Diazinon		
Talofofo (taro)	0.157	–	2.584	–
Yona (*Chromolaena*)	0.145	–	0.826	–
Toto (eggplant)	0.065	(0.022 – 0.129)	1.122	(0.121 – 2.783)
		Malathion		
Yona (*Chromolaena*)	0.253	(0.192 – 0.313)	2.969	(2.126 – 3.811)
Barrigada (taro)	0.109	(0.088 – 0.129)	0.868	(0.401 – 1.334)
Aphis craccivora				
		Dimethoate		
Mangilao (beans)	0.171	–	4.794	–
Talofofo (beans)	0.077	–	0.927	–
Malojloj (beans)	0.051	–	1.256	–
Barrigada (beans)	0.032	–	0.88	–
		Diazinon		
Talofofo (beans)	0.042	(0.009 – 0.075)	0.543	(0.100 – 0.986)
Barrigada (beans)	0.033	–	0.09	–
		Malathion		
Talofofo (beans)	0.069	–	2.275	–
Toto (beans)	0.027	(0.013 – 0.040)	1.133	(0.663 – 2.118)
Yona (beans)	0.230	–	0.663	–
Toxoptera citricida				
		Dimethoate		
Yona (citrus)	0.036	–	0.102	–
Dededo (citrus)	0.015	–	0.121	–
		Diazinon		
Dededo (citrus)	0.120	(0.019 – 0.221)	2.18	(0.125 – 4.234)
Toto (citrus)	0.046	(0.017 – 0.075)	0.46	(0.113 – 0.806)
Barrigada (citrus)	0.045	–	0.466	–
Yona (citrus)	0.003	–	0.021	–
		Malathion		
Dededo (citrus)	0.045	(0.041 – 0.490)	0.32	(0.143 – 0.497)
Yona (citrus)	0.035	–	0.096	–
Barrigada (citrus)	0.025	–	0.037	–

from non-farm related employment. As a result there are few economic incentives for pesticide suppliers to provide local farmers with the wide range of products available to the agricultural community in the mainland United States. The relatively few agricultural pesticides available to Guam's farmers are determined by the market for such products to large-scale users such as golf courses or tourist hotels. Product availability may also be determined by the demand for over-the-counter home and garden products. Such limited access to new products, and limited pest management budgets of small-scale farm operations make it imperative that those products currently available to Guam's farmers not be lost due to loss of efficacy or use restrictions. Farmer education programs encouraging use of such integrated pest management strategies as pesticide rotation, biological control, and insect-resistant varieties may arrest the development of insecticide resistance before lack of efficacy among currently used insecticides becomes apparent.

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