Toxicity of Pesticides Registered for Use in Landscape Nurseries to the Acarine Biological Control Agent, *Neoseiulus fallacis*[1]

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Abstract

The predatory mite *Neoseiulus fallacis* (Garman) is an important biological control agent of spider mites in landscape plants produced in the Pacific Northwest. Using pesticide toxicity information from the SELCTV database and recent literature reports, we estimated toxicity of several general pesticide classes to *N. fallacis*, compared susceptibility of *N. fallacis* to 3 other predatory mites and developed summary tables of pesticide toxicity to *N. fallacis*. Pesticide classes ranged from low or non-toxic to *N. fallacis* (i.e., organosulfur) to highly toxic (i.e., oxime carbamate). Pesticide susceptibility data for *N. fallacis* within or between chemical classes was similar to data for either of *Typhlodromus pyri* Scheuten, *Galendromus occidentalis* Nesbitt, or *Phytoseiulus persimilis* Athias-Henriot. While all pesticide types (i.e., insecticides, fungicides, herbicides, etc.) contained representatives that were highly toxic to *N. fallacis*, various compounds were rated low or non-toxic. On average, insecticides were most toxic to *N. fallacis*, fungicides least toxic and herbicides intermediate. Probability of exposure and integration of *N. fallacis* into current control practices are discussed.

Index words: integrated pest management, Tetranychidae, Phytoseiidae, pesticide selectivity, predatory mite.

Species used in this study: *Neoseiulus fallacis* (Garman).

Significance to the Nursery Industry

A major obstacle impeding integration of the biological control agent *N. fallacis* into spider mite control programs is the use of disruptive pesticides. Selecting pesticides that are least toxic to *N. fallacis* may aid in conserving this predator. Herein we present toxicity values for various insecticides, miticides, fungicides and herbicides that are registered for use in landscape systems. Although each chemical class has pesticides that are highly toxic to *N. fallacis*, average toxicity ratings are highest for insecticides (pooled with miticides), intermediate for herbicides and lowest for fungicides. The toxicity tables presented herein will facilitate the integration of *N. fallacis* into control programs of landscape nursery systems. Further evaluations of pesticides are needed to improve development of integrated pest management (IPM) programs on landscape plants.

Introduction

Spider mites (Tetranychidae) are major pests of landscape nursery systems. Although the most common method of suppressing spider mites in nurseries is the application of pesticides, biological control programs are currently under development (8). The agents most commonly selected for biological control of spider mites are predatory mites in the family Phytoseiidae (3, 5). Preliminary tests in the Pacific Northwest suggest that inoculative releases of the predatory mite *Neoseiulus fallacis* (Garman) can control spider mite populations in landscape plants, and render miticide applications unnecessary in many cases (8, 9, 10).

One major obstacle that impedes integration of predatory mites into nursery control practices is the use of potentially disruptive herbicides, fungicides, insecticides, and miticides. Applications of these pesticides may be needed to control pests, and some applications are mandated by export regulations (i.e., Oregon State Law 571.200). Exposure to pesticides causes a range of direct and indirect effects on phytoseiid mites and often results in resurgence or secondary outbreaks of the pest (1, 13). Ruberson et al. (13) suggested that selective pesticides were the most useful method of integrating biological control agents into pest control programs. Therefore, we sought to evaluate toxicity of pesticides registered for use in nurseries to the biological control agent *N. fallacis*. We gathered pesticide toxicity information from the SELCTV database (1, 14) and recent literature. From these data we estimated general toxicity of pesticide classes (organophosphates, pyrethroids, etc.) to *N. fallacis* and developed a summary table of pesticide selectivity to *N. fallacis*.

Materials and Methods

Toxicity of general classes of pesticides to N. fallacis. Extensive pesticide toxicity data exists for natural enemies on SELCTV database housed in the Department of Entomology at Oregon State University (OSU) (14). To measure toxicity of major chemical classes we searched SELCTV for entries containing *Neoseiulus* (= *Amblyseius*) *fallacis*. Within this criterion, 3 strains were represented (total entries 531): resistant, tolerant and susceptible. Resistant strains refer to populations of *N. fallacis* that have developed resistance to organophosphate pesticides (1). For the purposes of this study, we used only the resistant and susceptible strains for evaluation. We identified the chemical classes that contained 4 or more data entries and assessed percent effect (mortality and repellency) for a single strain. We also included the alternative strain (resistant or susceptible) regardless of number of

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tests preformed. From these data we calculated a mean toxicity rating (with standard deviation) across all entries within the chemical class (Toxicity rating: 1 = 0% effect, 2 = < 10%, 3 = ≥ 10 but < 30%, 4 = ≥ 30 but < 90%, 5 = > 90%; see 14).

To determine the relative susceptibility of the resistant strain of *N. fallacis* to agricultural chemicals as compared to other phytoseiid mites, we followed the same procedure as described above for *Typhlodromus pyri* Scheuten, *Galendromus occidentalis* Nesbitt, and *Phytoseiulus persimilis* Athias-Henriot. We narrowed our analysis to the common chemical classes: carbamate, organochlorine, organophosphate, organotin and pyrethroid. We used a Kruskal-Wallis statistical test to compare the mean pesticide susceptibility ratings among species (12).

Caution should be taken when interpreting toxicity of chemical classes in these analyses. SELCTV does not include many toxicity testing that were performed after 1986. Thus, there undoubtedly are more extensive data sets for older testing methods, active ingredients and formulations than for newer ones. The toxicity ratings presented herein are derived from SELCTV records that include different testing methods, treated substrates and routes of exposure. This array of sources increases the number of records that are in the analysis, but also adds to the variability in results (6). Finally, averaging over different testing methods and active ingredients assumes that all methods and ingredients are equally represented, which we acknowledge that they are not. To determine if the variability of test methods affected average toxicity rating for pooled strains of *N. fallacis,* we compared dip, field and residual test methods for organophosphate, carbamate and organochlorine chemical classes (1). Statistical comparisons were preformed with the general linear model (12).

Development of the selectivity table. A list of pesticides (different chemical compounds) registered for use on ornamentals in Oregon was obtained from extension publications at Oregon State University (2, 11, 15). Using this list, we then scanned SELCTV for selected compounds. Next, we calculated average toxicity (with SD) for either resistant or susceptible strains for all compounds with 1) three or more entries, 2) the same formulation, 3) the same rate applied and 4) measured % effect. We also reviewed more recent literature that was not entered in SELCTV (post-1986, 7, 8) and calculated the toxicity rating with the same criteria as above (5). Finally, we averaged both the toxicity ratings from SELCTV and recent literature to produce a summary toxicity rating. We compared summary toxicity ratings among pesticide types with the Mann-Whitney U test (12). We used the Sidak inequality formula to maintain a 0.05 experimentwise a level among comparisons (4).

As described above, caution should be taken when interpreting the averaged toxicity summaries. These values are used to estimate the toxicity of pesticides to *N. fallacis* but may not be appropriate in all environmental conditions. Extrapolation from these data to field systems ignores direct and indirect effects mitigated by ecological (life history) and toxicological (exposure) parameters (1).

Table 1. Toxicity of chemical classes to resistant and susceptible strains of *N. fallacis.*

Chemical class	Strain[z]	N[y]	Avg. tox.[x]	SD[w]
organosulfur	R	3	1.43	0.53
organosulfur	S	4	1.75	0.96
benzimidazole	R	4	2.20	0.79
organotin	R	3	2.20	0.94
organotin	S	12	2.42	1.24
N-trihalomethylthio	R	1	2.57	1.40
N-trihalomethylthio	S	4	3.00	1.83
organochlorine	R	2	3.00	1.15
organochlorine	S	23	3.17	1.23
organophosphate	R	38	3.46	1.27
organophosphate	S	112	3.75	1.40
carbamate	S	17	3.88	1.22
benzimidazole	S	9	4.22	1.30
pyrethroid	R	11	4.39	0.72
pyrethroid	S	30	4.40	0.67
carbamate	R	7	4.50	0.76
oxime carbamate	R	2	4.75	0.50
oxime carbamate	S	9	4.78	0.44

[z]Strains of *N. fallacis* categorized as resistant (R) or susceptible (S) to organophosphates.

[y]Number of tests reported in SELCTV database (14).

[x]Toxicity rating: 1 = 0% effect, 2 = < 10%, 3 = ≥ 10 but < 30%, 4 = ≥ 30 but < 90%, 5 = > 90%.

[w]Standard deviation.

Results and Discussion

Selectivity of general classes of pesticides to N. fallacis. Average toxicity ratings for susceptible and resistant strains of *N. fallacis* ranged from < 10% effect (i.e., organosulfurs) to > 90% effect (i.e., oxime carbamates) (Table 1). The fun-

Table 2. Relative susceptibility of phytoseiid biological control agents to pesticides.

	Typhlodromus pyri			*Galendromus occidentalis*			*Phytoseiulus persimilis*			*Neoseiulus fallacis*		
Chemical class	N[z]	Avg. tox.[y]	SD[x]	N	Avg. tox.	SD	N	Avg. tox.	SD	N	Avg. tox.	SD
carbamate	25	2.92	1.32	16	4.00	1.31	19	2.84	1.26	7	4.50	0.76
organochlorine	18	3.06	1.21	5	4.33	0.52	22	3.26	1.29	2	3.00	1.15
organophosphate	73	3.70	1.28	56	3.26	1.20	65	4.12	1.14	38	3.46	1.27
organotin	14	3.00	0.88	3	3.00	1.73	11	3.64	1.03	3	2.20	0.94
pyrethroid	18	4.67	0.69	32	4.27	0.72	20	3.72	1.49	11	4.39	0.72
Grand mean		3.47			3.77			3.52			3.51	

[z]Number of tests reported in SELCTV database.

[y]Toxicity rating: 1 = 0% effect, 2 = < 10%, 3 = ≥ 10 but < 30%, 4 = ≥ 30 but < 90%, 5 = > 90%.

[x]Standard deviation.

Table 3. Comparison of toxicity values among testing methods for three chemical classes to *N. fallacis*.

Chemical class	Dip[z] (N)	Field[y] (N)	Residue[x] (N)	F-value	df	P-value
Organophosphate	3.81[w] (57)	3.88 (16)	3.53 (30)	0.48	2,100	0.62
Carbamate	4.4 (5)	4.75 (4)	3.29 (7)	3.22	2,13	0.07
Organochlorine	2.65 (8)	4.0 (6)	3.0 (8)	2.47	2,19	0.11

[z]Slide dip method.

[y]Product application and evaluation under field conditions.

[x]Effect of residue (48 hours).

[w]Toxicity rating: 1 = 0% effect, 2 = < 10%, 3 = ≥ 10 but < 30%, 4 = ≥ 30 but < 90%, 5 = > 90%.

gicide benzimidazole was more toxic to susceptible strains (avg. toxicity = 4.22) than resistant strains (avg. toxicity = 2.20) (Table 1). The higher toxicity in the susceptible strain may be due to variability in the few tests used in the analysis as is seen in the standard deviation (SD = 1.3); also early tests for benomyl toxicity did not assess egg hatch reduction that usually results from exposure to this compound (1). Surprisingly, toxicity of organophosphates to the resistant strain had a value only slightly lower than that of the susceptible strain. Again, this may be due to variability of testing or inappropriate classification of susceptible strains that are actually resistant. Croft (1) discussed the difficulty of finding susceptible strains of *N. fallacis* in many untreated agroecosystems and the likely mis-classification of the many strains of this predator that have been tested.

When comparing pesticide susceptibility of *N. fallacis* with similar ratings for other phytoseiids, no differences were found within or between chemical classes (P > 0.05; Table

Table 4. Toxicity ratings for insecticide and miticide compounds registered for use in ornamental nurseries of Oregon.

Insecticides and miticides				SELCTV[y] data base		Current tests[v]	
Active ingredient	Trade name	Chemical class	Strain[z]	Ave. tox. rating[x] (N)	SD[w]	Ave. tox. rating (N)	Summary[u] tox. rating
abamectin	Avid	acyclic lactone	R	4.0 (1)			4.0
acephate	Orthene	organophosphate	R	1.0 (1)		4.0 (1)	2.5
			S	5.0 (1)			5.0
azinphos-methyl	Guthion	organophosphate	R	2.6 (14)	1.3	3.0 (1)	2.7
			S	3.1 (27)	1.5		3.1
bifenthrin	Talstar	pyrethroid	R			5.0 (1)	5.0
carbaryl	Sevin	carbamate	R	4.8 (5)	0.4		4.8
			S	4.3 (11)	0.8		4.3
carbofuran	Furadan	carbamate	R	5.0 (2)	0.0	5.0 (1)	5.0
			S	5.0 (1)			5.0
chlorpyrifos	Dursban (Lorsban)	organophosphate	R			5.0 (2)	5.0
			S	5.0 (1)		5.0 (1)	5.0
chlorotoluron	Alert		R			5.0 (1)	5.0
diazinon	Diazinon	organophosphate	R	3.0 (18)		5.0 (1)	3.2
			S	4.0 (8)	0.8		4.0
dicofol	Kelthane	organotin	R			5.0 (2)	5.0
			S	3.0 (9)	1.3	5.0 (1)	3.4
dimethoate	Dimethoate	organophosphate	R	4.0 (2)	1.4		4.0
dimethoate	Dimethoate	organophosphate	S	4.7 (6)	0.8		4.7
endosulfan	Endosulfan (Thiodan)	organosulfur	R			4.0 (2)	4.0
			S	2.9 (9)	1.1	5.0 (1)	3.4
fenbutatin oxide	Vendex	organotin	R			2.0 (1)	2.0
hexythiazox	Hexygon	organosulfur	R			2.0 (1)	2.0
lindane	Lindane	organochlorine	S	2.0 (1)			2.0
oxydemeton-methyl	Metasystox-R	organophosphate	R			5.0 (1)	5.0
oxythioquinox	Joust (Morestan	organosulfur	S	3.7 (3)	0.6		3.6
Mineral oil			R	4.0 (2)	0.0		4.0
permethrin	Ambush (Pounce)	pyrethroid	R	4.5 (6)	0.8		4.5
			S	4.5 (11)	0.8		4.5
phosmet	Imidan		R	3.0 (3)	1.7		3.0
			S	2.6 (15)	1.5		2.6
propargite	Omite (Ornamite)	organosulfur	R	1.0 (3)	0.0	1.0 (1)	1.0
			S	1.8 (4)	1.0		1.8
spinosad	Conserve	fungal metabolite	R			2.0 (1)	2.0

[z]R = resistant, S = susceptible to organophosphate insecticides.

[y]Database containing toxicity data of agrochemicals to beneficial organisms.

[x]Toxicity rating: 1 = 0% effect, 2 = < 10%, 3 = ≥ 10 but < 30%, 4 = ≥ 30 but < 90%, 5 = > 90%.

[w]Standard deviation.

[v]Toxicity data gathered from recent literature (post-1986).

[u]Average of all selective and current toxicity ratings.

Table 5. Selectivity of fungicides to the biological control agent *N. fallacis*.

Fungicides			SELCTV data base[y]		Current[v] tests		
Active ingredient	Trade name	Strain[z]	Ave. tox. rating[x] (N)	SD[w]	Ave. tox. rating (N)	SD	Summary[u] tox. rating
benomyl	Benlate	S	4.2 (9)	1.30			4.2
		R	2.0 (4)	0.0	2.0 (1)	0.0	2.0
captan	Captan	S	3.0 (4)	1.83			3.0
		R	1.0 (1)	0.0	2.0 (1)	0.0	1.5
dichlone	Diclone 50	S	2.3 (3)	0.58			2.3
dithianon	Dithionan	S	1.0 (2)	0.0			1.0
dodine	Syllit	S	2.3 (6)	1.03			2.3
fosetyl-aluminum	Aliette	R			2.0 (1)	0.0	2.0
glyodin	Glyodin	S	3.5 (2)	0.7			3.5
iprodione	Chipco 26019	R			2.0 (1)	0.0	2.0
metalaxyl	Subdue	R			5.0 (1)	0.0	5.0
metiram	Polyram	S	1.3 (3)	0.6			1.3
myclobutanil	Systhane/Eagle	R			2.0 (1)	0.0	2.0
propiconazole	Banner MAXX	R			1.0 (1)	0.0	1.0
sulfur	Kolo-100/Wetable S	S	3.0 (1)	0.0			3.0
		R			1.0 (1)	0.0	1.0
thiram	Thiram	S	2.5 (2)	0.0	2.0 (1)	0.0	2.3

[z]R = resistant, S = susceptible to organophosphate insecticides.
[y]Database containing toxicity data of agrochemicals to beneficial organisms.
[x]Average toxicity value calculated from reports (N) in SELCTV, see text for rating system.
[w]Standard deviation.
[v]Toxicity data gathered from recent literature (post-1986).
[u]Average of all selective and current toxicity ratings.

2). These findings suggest that *N. fallacis* exhibits similar levels of susceptibility to pesticides as other phytoseiids and common preservation strategies for multiple species of these mites may be used within agroecosystems.

When the toxicity ratings (% effect) among testing methods were compared for three chemical classes, data showed no differences among compounds ($P > 0.05$; Table 3). This pattern was surprising. Generally, laboratory tests show greater toxicity than field oriented testing (7). One explanation for this result may be the variability in the testing or the variable toxicity of different intert materials and active ingredients that are represented within a chemical class. In these analyses, the factors listed above were assumed to be alike among chemical groups.

Development of the selectivity table. The summary toxicity rating for the insecticides and miticides that are registered for use in Oregon landscape nurseries ranged from non-

Table 6. Selectivity of herbicides to the biological control agent *N. fallacis*.

Herbicides			SELCTV data base[y]		Current[v] tests		
Active ingredient	Trade name	Strain[z]	Ave. tox. rating[x] (N)	SD[w]	Ave. tox. rating (N)	SD	Summary[u] tox. rating
bentazon	Basagran	R			1.0 (1)	0.0	1.0
bromoxtnil	Buctril	R			5.0 (1)	0.0	5.0
clomazone	Command	R			2.0 (1)	0.0	2.0
dalapon	Dalapon	S	3.0 (1)	0.0			3.0
diuron	Karmex/Topsite	R	3.0 (1)	0.0	0.0 (1)	0.0	1.5
fluazipop-p-butyl	Fulislade	R			3.0 (1)	0.0	3.0
gramaxone	Paraquat/Cyclone	R			5.0 (1)	0.0	5.0
napropamide	Devrinol	R			2.0 (1)	0.0	2.0
oxyfluoren	Goal	R			3.5 (2)	0.7	3.5
pendimethylin	Prowl	R			5.0 (1)	0.0	5.0
pyridate	Tough	R			3.0 (1)	0.0	3.0
quizalofop-p-ethyl	Assure	R			3.0 (1)	0.0	3.0
sethoxydin	Poast	R			3.0 (2)	0.0	3.0
simazine	Simizine	R	2.0 (1)	0.0	2.0 (1)	0.0	2.0
sufentrazone	Authority	R			2.0 (1)	0.0	2.0
terbacil	Sinbar	R			2.5 (2)	0.7	2.5

[z]R = resistant, S = susceptible to organophosphate insecticides.
[y]Database containing toxicity data of agrochemicals to beneficial organisms.
[x]Average toxicity value calculated from reports (N) in SELCTV, see text for rating system.
[w]Standard deviation.
[v]Toxicity data gathered from recent literature (post-1986).
[u]Average of all selective and current toxicity ratings.

toxic to highly toxic (Table 4). The average toxicity rating among all compounds in Table 4 was 3.67 (SD = 1.19; N = 33). Among the least toxic chemicals to *N. fallacis* are two new products recently registered for ornamentals: hexythiazox and spinosad. Hexythiazox has been used extensively in the fruit industry and, as a spider mite ovicide, it may be very effective in IPM strategies. Spinosad is a fungal metabolite and is typically used for control of coleopteran and lepidopteran pests. Use of spinosad for root weevil control (*Otiorhynchus* spp.) may improve conservation of *N. fallacis* in landscape systems. In addition, acephate and lindane appear to be only mildly toxic to *N. fallacis* and may be candidates for IPM strategies. Consistent with field observations, carbaryl, carbofuran, chlorpyrifos, and permethrin are highly toxic to *N. fallacis* and should not be used with releases of the predatory mite.

The average toxicity rating among all fungicides was 2.28 (SD = 1.18; N = 10); this value was significantly lower than the values for insecticides and miticides ($P < 0.05$, Table 5). The systemic fungicide propiconazole had the lowest toxicity rating, followed by sulfur and captan for resistant strains of *N. fallacis*. Incorporation of these active ingredients into pathogen control programs may aid in conservation of *N. fallacis* on spider mite infested plants. In contrast, metalaxyl (Subdue®) had the highest toxicity and appears to be incompatible with introductions of *N. fallacis*.

The overall toxicity rating of herbicides in Table 6 was 3.06 (SD = 1.43; N = 8); this was intermediate to the other pesticide types ($P > 0.05$). The least toxic herbicide to *N. fallacis* was bentazon, followed by the moderately toxic napropamide and simazine. In contrast, gramaxone and pendimethylin were highly toxic to *N. fallacis*. As previously stated, these values should be used as coarse indicators of pesticides harmfulness.

The probability that *N. fallacis* could be exposed to the individual pesticides listed in Table 4–6 may differ spatially and temporally (13). For instance, insecticides, miticides and fungicides are applied directly to the foliage of landscape plants. This is in contrast to herbicides applications, which typically are not. However, systemic translocation of pesticides from plants to predaceous arthropods through their prey can occur. Little is known of this route of exposure to herebicides by predators (1). Assuming that *N. fallacis* is associated with spider mites on landscape plants, the probability for exposure to herbicides is probably less than to insecticides. Also, early season fungicides and pre-emergent herbicides may be applied prior to releases of *N. fallacis* and, assuming that residuals have no negative affects, these types of compounds will not interfere with biological control.

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