Reduced Risk Insecticides to Control Scale Insects and Protect Natural Enemies in the Production and Maintenance of Urban Landscape Plants

Author(s) :Steven D. Frank
Source: Environmental Entomology, 41(2):377-386. 2012.
Published By: Entomological Society of America
DOI: http://dx.doi.org/10.1603/EN11230
URL: http://www.bioone.org/doi/full/10.1603/EN11230

Reduced Risk Insecticides to Control Scale Insects and Protect Natural Enemies in the Production and Maintenance of Urban Landscape Plants

STEVEN D. FRANK[1]

North Carolina State University, Department of Entomology, Campus Box 7613, Raleigh, NC 27695

Environ. Entomol. 41(2): 377–386 (2012); DOI: http://dx.doi.org/10.1603/EN11230

ABSTRACT Armored scale insects are among the most difficult to manage and economically important arthropod pests in the production and maintenance of urban landscape plants. This is because of morphological traits that protect them from contact insecticides. I compared initial and season long control of euonymus scale, *Unaspis euonymi* Comstock (Hemiptera: Diaspidae), by reduced risk insecticides (insect growth regulators [IGRs], neonicotinoids, spirotetramat) to determine if they controlled scale as well as more toxic insecticides such as the organophosphate, acephate, and pyrethroid, bifenthrin. I also evaluated how these insecticides affected natural enemy abundance on experimental plants and survival when exposed to insecticide residue. All insecticides tested reduced first generation euonymus scale abundance. In 2009, reinfestation by second generation euonymus scale was highest on plants treated with acetamiprid and granular dinotefuran. In 2010, systemic neonicotinoids and spirotetramat prevented cottony cushion scale infestation 133 d after treatment whereas scale readily infested plants treated with bifenthrin and horticultural oil. *Encarsia* spp. and *Cybocephalus* spp. abundance was related to scale abundance. These natural enemies were generally less abundant than predicted by scale abundance on granular dinotefuran treated plants and more abundant on granular thiamethoxam treated plants. Bifenthrin residue killed 90–100% of *O. insidiosus* and *E. citrina* within 24 h. My results indicate that reduced risk insecticides can provide season long scale control with less impact on natural enemies than conventional insecticides. This could have economic and environmental benefits by reducing the number of applications necessary to protect nursery and landscape plants from scale.

KEY WORDS *Cybocephalus* spp., *Encarsia citrina*, euonymus scale (*Unaspis euonymi*), nontarget effects, nursery production

Armored scale insects (Hemiptera: Diaspidae) are among the most economically important pests of trees and shrubs in ornamental nurseries and landscapes because they cause severe plant damage and are difficult for growers and landscape professionals to manage effectively (IR 4 2007, Adkins et al. 2010). Armored scale hatch from eggs into crawlers which search the host plant for a feeding site. Crawlers settle at a suitable feeding site, become immobile first instars. and begin exuding a waxy cover, or test (Miller and Davidson 2005). The waxy test prevents insecticide from contacting the scale body beneath. Because armored scales are immobile for all but the crawler stage they do not come into contact with insecticide residue on leaves and branches (Raupp et al. 2001). Therefore, armored scale is most effectively managed by applying insecticides during the crawler stage, which may be killed by contact with or by traversing the toxic residue.

Monitoring scale populations and using pest forecasting tools, such as growing degree days or plant phenological indicators, help determine when scale crawlers are active and can be managed most effectively (Raupp 1985, Hodges and Braman 2004). However, these practices are implemented by a low percentage of nursery and landscape professionals because of the time involved and the diversity of plants and pests they have to manage (Sellmer et al. 2004, Hodges et al. 2008, Lebude et al., in press). Instead, they rely heavily on broad spectrum pyrethroid, carbamate, and organophosphate insecticides applied on a calendar basis or in response to plant damage (Hudson et al. 1996, Sellmer et al. 2004, Lebude et al. in press). However, because scales are protected from contact insecticides for most of their life cycle, such routine applications do not provide adequate control. Moreover, by drastically reducing natural enemy abundance and efficacy, these insecticide applications create enemy free space for scale and other pests, which can result in pest outbreaks

[1] Corresponding author, e mail: sdfrank@ncsu.edu.

Table 1. Insecticide treatments and rates applied to *Euonymus japonica* Microphylla in 11.4 liter pots and mean (± SEM) euonymus scales on 10 leaves on each sampling date in 2009

Insecticide class	Active ingredient	Trade name	Rate (per 3.79 liters)	0 DAT	7 DAT	14 DAT	28 DAT	42 DAT	90 DAT
Insect growth regulators	Buprofezin	Talus	6.10 g	102.17 ± 22.0	32.5 ± 6.6cd	2.33 ± 0.6c	1.33 ± 1.2c	0.08 ± 0.1b	0.4 ± 0.4c
	Pyriproxyfen	Distance	3.54 ml	51.17 ± 22.9	25.42 ± 14.6d	2.83 ± 0.9c	0.25 ± 0.2c	0.08 ± 0.1b	0 ± 0.0c
Neonicotinoids	Acetamiprid	TriStar 30SG	2.27 g	79.17 ± 19.5	55.75 ± 8.9bcd	8.67 ± 3.3bc	2.08 ± 1.2c	1.25 ± 0.7b	21.33 ± 9.8b
	Dinotefuran	Safari 20 SG	6.80 g	83.33 ± 15.8	83.5 ± 17.0ab	1.58 ± 0.6c	0.5 ± 0.3c	0.25 ± 0.2b	0.08 ± 0.1c
	Dinotefuran	Safari G	2.60 g[a]	106.5 ± 23.1	64.83 ± 11.3bc	19.83 ± 8.2a	2.5 ± 0.5c	0.58 ± 0.3b	5.33 ± 1.9c
	Thiamethoxam	Flagship 25WG	2.27 g	92.25 ± 25.1	51.5 ± 12.0bcd	6.17 ± 3.7bc	0.25 ± 0.1c	0.67 ± 0.3b	0.5 ± 0.5c
	Thiamethoxam	Flagship G	20.0 g[b]	101.83 ± 25.4	54 ± 13.3bcd	16 ± 5.0ab	9 ± 3.7b	1.83 ± 0.8b	3.5 ± 2.3c
Organophosphate	Acephate	Acephate 75WP	3.04 g	75.58 ± 23.7	34 ± 12.0cd	2.17 ± 0.7c	1.25 ± 1.1c	0.25 ± 0.1b	0.08 ± 0.1c
	Untreated	–	–	132.75 ± 32.0	109 ± 11.9a	20.75 ± 2.7a	14.67 ± 2.2a	6.58 ± 1.9a	65.83 ± 8.8a
	$F_{8,45}$			0.95	4.67	4.38	9.47	8.03	22.60[c]
	P			0.49	<0.001	<0.001	<0.001	<0.001	<0.001

[a] 2.6 g of granular product per gallon of container vol applied to media surface.
[b] 20 g of granular product per gallon of container vol applied to media surface.
[c] Degrees of freedom 8, 44 due to missing value.

(McClure 1977a, Raupp et al. 2001, Frank and Sadof 2011).

Neonicotinoid insecticides, IGRs, spirotetramat, and other insecticides are classified as reduced risk by the Environmental Protection Agency (EPA 2010). Reduced risk insecticides have lower vertebrate toxicity than conventional insecticides and provide alternatives to pyrethroids, carbamates, and organophosphates (EPA 2010). Reduced risk insecticides often pose less risk to natural enemies than conventional insecticides (Rebek et al. 2003; Prabhaker et al. 2007). Research has demonstrated reduced risk insecticides to provide effective control of some scale (Rebek et al. 2003, Grafton Cardwell et al. 2006) but not others (Grafton Cardwell et al. 2006; Raupp et al. 2008). It is important to determine scale suppresssion and risk to natural enemies of reduced risk insecticides because these effects are dependent on scale or natural enemy species.

Euonymus scale, *Unaspis euonymi* Comstock (Hemiptera: Diaspidae), is considered a key pest of ornamental landscapes because *Euonymus* is one of the most commonly planted shrub genera and surveys have found up to 68% of plants to be infested (Raupp and Noland 1984, Raupp 1985, Van Driesche et al. 1998a). Feeding by euonymus scale causes leaf discoloration and absicion, stunted growth, branch dieback, and plant death (Cockfield and Potter 1987, Cockfield and Potter 1990, Van Driesche et al. 1998a). The yearly replacement cost of plants that die from euonymus scale damage has been estimated as $355,568 in Massachusetts alone (Van Driesche et al. 1998a). Nurseries, landscapers, and homeowners also incur costs to treat infested plants with insecticides and reduce the need for replacement.

Euonymus scale has 2–4 generations per year in the United States (Hodges and Braman 2004). Female and male euonymus scales have three and five instars respectively and develop from egg hatch to adult in 4–6 wk (Gill et al. 1982). Armored scale crawlers spread from one plant to another by wind, birds, or locomotion (McClure 1977b; Greathead 1990; Magsig Castillo et al. 2010). Therefore, even if insecticides are applied to kill the first euonymus scale generation in spring, crawlers from subsequent generations can reinfest plants the same year. This life history and key pest status make euonymus scale a perfect system in which study efficacy of insecticides against first generation crawlers and whether insecticides provide protection from mid and late season infestation. Specifically my objectives were to determine 1) the efficacy of conventional and reduced risk insecticides against first generation euonymus scale crawlers; 2) if a single application protects plants from reinfestation by second generation euonymus scale or infestation by cottony cushion scale to provide season long scale suppression; and 3) the effect of conventional and reduced risk insecticides on natural enemy survival and abundance.

Methods

Effect of Insecticides on Euonymus Scale Abundance. Experiments were conducted at the Varsity Drive Greenhouse Complex at North Carolina State University, Raleigh, NC. Study plants were *Euonymus japonica* Microphylla and *Euonymus japonica* Silver Queen in 2009 and 2010, respectively. Plants were grown in 11.4 liter pots with pine bark substrate and slow release fertilizer. Plants were arranged 1.5 m apart in six rows that were also 1.5 m apart. Plants had not been treated with insecticide for at least 1 yr prior.

In 2009, we assigned 54 plants to one of nine treatments (Table 1). Plants were not infested with euonymus scale when purchased. We infested the study plants with branches from a heavily infested *Euonymus japonica* Thunberg plant in a residential landscape when first generation crawlers became active on 22 April 2009. We cut 108 40 cm branches from the infested plant and placed the bottom end of each in a oral pick with water to slow desiccation. Two branches were attached to each experimental plant with twist ties. On 29 April 2009, we removed the branches and repeated the infestation procedure with newly collected branches, which were removed 4 May 2009. The next day, two heavily infested branches (focal branches) on each experimental plant were selected for sampling. We counted the number of

Table 2. Insecticide treatments and rates applied to *Euonymus japonica* Silver Queen in 11.4 liter pots and mean (± SEM) euonymus scales on 10 leaves on each sampling date in 2010

Insecticide class	Active ingredient	Trade name	Rate (per 3.79 liters)	0 DAT	7 DAT	14 DAT	28 DAT	42 DAT	147 DAT
Insect growth regulator	Buprofezin	Talus	3.94 g	199.17 ± 91.5	55.67 ± 30.8	50.33 ± 38.2	2.67 ± 1.5c	0.83 ± 0.2b	0.33 ± 0.0
	Pyriproxyfen	Distance	3.54 ml	242.17 ± 152.1	122.67 ± 89.7	76.83 ± 51.0	33.5 ± 19.4ab	9 ± 2.3b	1.33 ± 0.8
Neonicotinoids	Acetamiprid	TriStar 30SG	2.27 g	184.33 ± 81.2	95.33 ± 41.3	32.33 ± 14.1	6.83 ± 3.9bc	1.83 ± 1.8b	0 ± 0.0
	Dinotefuran	Safari 20 SG	6.80 g	206.83 ± 98.1	109.33 ± 67.2	43.5 ± 26.8	7.17 ± 4.4bc	2.17 ± 0.3b	0 ± 0.0
	Dinotefuran	Safari G	2.60 g[a]	172.67 ± 65.1	86.67 ± 40.1	33.83 ± 13.1	7 ± 3.4bc	1 ± 0.0b	0 ± 0.0
	Thiamethoxam	Flagship 25WG	2.27 g	225.33 ± 109.6	102 ± 48.7	43.67 ± 20.3	22.5 ± 9.4ab	2.83 ± 0.3b	0 ± 0.0
	Thiamethoxam	Flagship G	20.0 g[b]	202.5 ± 110.8	64.17 ± 40.6	39.5 ± 32.2	14 ± 10.4bc	4.83 ± 0.5b	0 ± 0.0
Oils	Paraffinic Oil	Hort. Oil	47.3 ml	135 ± 49.3	48.33 ± 16.6	8.167 ± 3.2	3 ± 2.0c	1 ± 0.2b	0 ± 0.3
Pyrethroid	Bifenthrin	Talstar	6.41 ml	166.33 ± 83.9	122.33 ± 76.4	41.83 ± 18.0	4.67 ± 3.6bc	1 ± 1.0b	0.33 ± 0.7
Tetramic acid	Spirotetramat	Kontos	1.00 ml	234.67 ± 122.5	68.67 ± 38.4	24.33 ± 17.3	7.83 ± 4.6bc	0.5 ± 1.5b	0 ± 0.0
	Untreated	–	–	238 ± 101.3	181.33 ± 79.2	169.67 ± 90.6	261.83 ± 169.1a	127 ± 22.3a	32 ± 17.2
	$F_{10,50}$			0.34	1.29	1.95	2.33	7.48	35.63[c]
	P			0.967	0.264	0.06	0.024	<0.001	<0.001

[a] 2.6 g of granular product per gallon of container vol applied to media surface.
[b] 20 g of granular product per gallon of container vol applied to media surface.
[c] χ^2 value from Kruskal Wallis Test with 10 degrees of freedom.

crawlers and first instars on five randomly selected leaves from each focal branch. We arranged plants in a randomized complete block design using initial scale density.

We applied insecticide treatments on 6 May 2009. Plants that received foliar insecticide treatments were sprayed until wet with 150 ml of solution using a CO_2 powered backpack sprayer with a full cone nozzle. Granular applications were made by shaking the prod uct evenly around the base of each plant. Post appli cation counts were made 7, 14, 28, 42, and 90 d after treatment (DAT) by counting the number of live scales on five leaves per focal branch (10 leaves total). One plant in the buprofezin treatment died before the 90 DAT count.

In 2010, 66 plants were assigned to one of 11 treat ments (Table 2). These plants had euonymus scales when received from the nursery. We selected one heavily infested focal branch on each plant. We counted adult scales on 10 randomly selected leaves per focal branch and blocked plants by scale density. We counted the number of crawlers on ten randomly selected leaves per focal branch on12 May 2010. The next day we applied insecticide treatments as in 2009. Post counts were made 7, 14, 28, 42, 56, and 147 DAT.

We infested plants with crawlers over the course of two weeks in 2009 and crawler emergence from nat ural infestations (2010) lasts ≈4 wk (Gill et al. 1982). Thus, multiple scale life stages were present on each sample date. In both years crawlers and settled first instars were present at precount and application. On subsequent dates, we counted all live scales present on leaves regardless of sex or life stage. We also counted the number of adult female scale on 10 cm of each focal branch near the end of the first generation be cause female scale are more abundant on euonymus stems (Cockfield and Potter 1990) and have more affect on the number of parasitoids present and the number of crawlers in the next generation. This was done 42 and 90 DAT in 2009 and 42 and 147 DAT in 2010.

Statistics. The number of scale per five leaves (2009) or 10 leaves (2010) and number of female scale on 8 cm of stem (both years) was analyzed for each sample date with analysis of variance (ANOVA) followed by Fisher Protected least significant difference (LSD) if ANOVA results were significant (SAS Institute 2002). Data from 147 DAT on leaves and stems in 2010 were not normally distributed even after $\log(x + 1)$ trans formation and were analyzed using the Kruskal Wallis test in the NPARONEWAY procedure of SAS (SAS Institute 2002).

Effect of Insecticides on Scale Reinfestation. We reinfested study plants with euonymus scale to deter mine which insecticides could provide plant protec tion against more than one generation of scale. In 2009, we inspected a branch on each plant (not one of our original focal branches) to remove all scales. When second generation crawlers became active on our res idential source plant, we cut 54 20 cm branches, placed the ends in oral picks with water, and attached one to each clean branch with a twist tie. These branches were covered with bags for one week made of fine organdi fabric to protect crawlers. We counted scales on reinfested branches 45 d after reinfestation, which corresponded to 90 DAT.

In 2010, there were few second and third generation euonymus scales on our source plants. However, in September we found cottony cushion scale *Icerya pur chasi* Maskell (Hemiptera: Margarodidae) infesting *Euonymus fortunei* Turczaninow and *Nandina domes tica* Thunberg in a landscape planting on campus. Cottony cushion scale is biologically different than euonymus scale but it infests *Euonymus* plants and is susceptible to some of the insecticides used in this study. Therefore, cottony cushion scales were used these to assess late season toxicity of our experimental plants. Female cottony cushion scales produce large cottony ovisacs from which crawlers emerge. We col lected ovisacs before crawler emergence to use in field and laboratory experiments. On 23 September 2010, 133 DAT, we pinned two ovisacs to a randomly se

Table 3. Mean (± SEM) female euonymus scales on 10 cm of stem at the end of the r st (42 DAT) and second (90 DAT) generations in 2009

Insecticide class	Active ingredient	Trade name	42 DAT	90 DAT
Insect growth regulator	Buprofezin	Talus	0 ± 0.0b	0 ± 0.0c
	Pyriproxyfen	Distance	0 ± 0.0b	0 ± 0.0c
Neonicotinoid	Acetamiprid	TriStar 30SG	7.25 ± 2.5b	6.83 ± 1.5c
	Dinotefuran	Safari 20 SG	1.08 ± 0.9b	2.92 ± 1.5c
	Dinotefuran	Safari G	38.58 ± 12.5a	20.33 ± 2.7b
	Thiamethoxam	Flagship 25WG	3.83 ± 1.7b	0 ± 0.0c
	Thiamethoxam	Flagship G	8.67 ± 5.5b	1.58 ± 1.2c
Organophosphate	Acephate	Acephate 75WP	3.17 ± 1.8b	0.75 ± 0.5c
	Untreated	–	58.33 ± 15.7a	35.58 ± 6.6a
	$F_{8,45}$		8.62	11.33[a]
	P		<0.001	<0.001

[a] Degrees of freedom 8, 44 due to missing value.

lected nonfocal branch on each plant and covered the branch with an organdi bag. We counted live nymphs after 4 and 8 d.

To further assess plant resistance to infestation by cottony cushion scale we cut a 12 cm branch tip from each study plant, which were immediately placed in a orist pick of water. In the laboratory, cuttings in orist picks were held upright on the laboratory bench in a test tube holder. Two ovisacs were pinned to each cutting. Plants were monitored 4 and 8 d after ovisac placement to count the number of live nymphs.

Statistics. All data from reinfestation experiments were analyzed using Kruskal Wallis Test in the NPARONEWAY procedure of SAS (SAS Institute 2002).

Effect of Insecticides on Natural Enemy Survival and Abundance. We assessed natural enemy abun dance on the study plants was assessed on 22 June and 24 and on 24 August and 27 in 2009 just as second and third generation crawlers, respectively, began to emerge. At this time adult parasitoids are most abun dant (Rebek and Sadof 2003). To count natural ene mies, we grasped one quarter of a plant s foliage and beat it 10 times into an 8 by 10 in white plastic tray and repeated this with another quarter of the plant s foliage. Using a magnifying visor, we inspected the tray to count *Encarsia* spp. (Hymenoptera: Aphellinidae) and adult and larval *Cybocephalus* spp. (Coleoptera: Nitidulidae) which are the most commonly recorded natural enemies of euonymus scale (Matadha et al. 2003). In June we only counted parasitoids but in August we counted parasitoids and nitidulid adults and larvae. The contents of the tray were returned to each plant after counting.

We conducted laboratory bioassays in 2010 to de termine the toxicity of each insecticide to natural enemies. Natural enemies were purchased from Syn genta Bioline (Oxnard, CA). On 21 May, 10 d after insecticide application, two randomly selected leaves were removed from each of the 66 experimental plants. One leaf was placed in one of 132 test tubes (85 by 21 mm). We placed 10 *Encarsia citrina* in 66 of the test tubes (one from each plant) and counted the number that were alive or dead after 24 h. Ten *Orius insidiosus* were placed in the other 66 test tubes. These were inspected after 1 and 24 h to count the number alive or dead.

Statistics. Differences in the mean number of para sitoids captured from first generation scales (22 June and 24 pooled) and parasitoids and nitidulid larvae and adults captured from second generation scale and (24 August and 27 pooled) was analyzed with ANOVA followed by Fisher Protected LSD (SAS Institute 2002). Linear regression was used to examine the relationship between female scale abundance on stems and 1) *Encarsia* spp. parasitoids 42 DAT; 2) *Encarsia* spp. parasitoids 90 DAT; and 3) *Cybocephalus* spp. beetles (adults and larvae combined) captured by beat sampling. Differences in the mean number of *E. citrina* or *O. insidiosus* alive after 1 or 24 h on treated leaves was analyzed using ANOVA followed by Fisher Protected LSD means separation if ANOVA results were significant (SAS Institute 2002).

Results

Effect of Insecticides on Euonymus Scale Abun dance. In 2009, scale abundance on leaves was signif icantly less than on control plants in all treatments except plants treated with foliar dinotefuran by seven DAT. Foliar dinotefuran had the least scale by 14 DAT (Table 1). Granular dinotefuran and granular thiame thoxam did not significantly reduce scale abundance compared with controls until 28 DAT because these products have to be taken up from the soil. All treat ments significantly reduced scale abundance on leaves compared with untreated leaves by 42 DAT, which corresponded to the end of the first scale generation. By the end of the second generation at 90 DAT, scales were significantly more abundant on leaves of acet amiprid treated plants than on leaves of other treat ments, but still three times less than on leaves un treated plants (Table 1).

Female scales on plant stems were less abundant than on stems of control plants in all treatments accept those treated with granular dinotefuran 42 DAT (Ta ble 3). 90 DAT granular dinotefuran had significantly less female scale on plant stems than control plant but more than all other treatments.

Table 4. Mean (± SEM) female euonymus scale on 10 cm of stem at the end of the rst (42 DAT) and third (147 DAT) generations in 2010

Insecticide class	Active ingredient	Trade name	42 DAT	147 DAT
Insect growth regulators	Buprofezin	Talus	0.83 ± 0.2b	0 ± 0.3
	Pyriproxyfen	Distance	9 ± 2.3b	0.83 ± 1.0
Neonicotinoids	Acetamiprid	TriStar 30SG	1.83 ± 1.8b	0 ± 0.0
	Dinotefuran	Safari 20 SG	2.17 ± 0.3b	0 ± 0.0
	Dinotefuran	Safari G	1 ± 0.0b	0 ± 0.0
	Thiamethoxam	Flagship 25WG	2.83 ± 0.3b	0 ± 0.0
	Thiamethoxam	Flagship G	4.83 ± 0.5b	0 ± 0.0
Oils	Paraffinic Oil	Hort. Oil	1 ± 0.2b	0.33 ± 0.0
Pyrethroid	Bifenthrin	Talstar	1 ± 1.0b	0.67 ± 0.3
Tetramic acids	Spirotetramat	Kontos	0.5 ± 1.5b	0 ± 0.0
	Untreated	–	127 ± 22.3a	17.17 ± 6.4
	$F_{10,50}$		5.92	17.42[a]
	P		<0.001	0.066

[a] χ^2 value from Kruskal–Wallis Test with 10 degrees of freedom.

In 2010, all treatments took longer to reduce scale abundance on leaves than in 2009. At 28 DAT the insect growth regulator (IGR) pyriproxyfen and neo nicotinoid thiamethoxam had not significantly re duced scale abundance compared with untreated plants. Plants treated with horticultural oil and the other IGR, Buprofezin, had the lowest scale abun dance 28 DAT. By 42 DAT plants in all treatments had significantly less scales on their leaves than on leaves of untreated plants (Table 2). Scales were counted again 147 DAT (6 October) when plants in most treat ments had almost no scales on leaves (Table 2). Sim ilarly, female scales on plant stems were significantly less abundant in all treatments than on stems of con trol plants by 42 DAT and approached 0 by 147 DAT (Table 4).

Effect of Insecticides on Scale Reinfestation. When a branch on each plant was reinfested with second generation crawlers in 2009, untreated plants had over three times as many scales on leaves than foliar thia methoxam treated plants which had the most scales among insecticide treated plants (Table 5). More scale reinfested stems of plants treated with acetamiprid and granular dinotefuran than other treatments but less than half as many as untreated plants.

In 2010, cottony cushion scale did not infest plants treated with neonicotinoids in the laboratory or out door experiment (Table 6). Infestation was also very low on plants treated with systemic spirotetramat. In both experiments, more cottony cushion scale crawl ers settled on untreated plants than on plants treated with horticultural oil or bifenthrin (Table 6).

Effect of Insecticides on Natural Enemy Survival and Abundance. In 2009, significantly more *Encarsia* spp. parasitoids were captured from beat sampling untreated, acetamiprid, and buprofezin treated plants than plants in other treatments 42 DAT ($F_{8,45} = 10.17$; $P < 0.001$; Fig. 1). Similarly, the number of parasitoids captured on acetamiprid, buprofezin, and granular dinotefuran treated plants were not significantly dif ferent from untreated plants 90 DAT ($F_{8,45} = 4.72$; $P < 0.001$; Fig. 1). The number of *Cybocephalus* spp. bee tles and larvae captured was significantly greater on untreated plants than on all other treatments ($F_{8,45} = 8.52$; $P < 0.001$; Fig. 1).

Female scale abundance on focal stems predicted a significant amount of variation in *Encarsia* spp. para sitoid capture 42 DAT ($r^2 = 0.168$; df = 54; $P < 0.001$) and 90 DAT ($r^2 = 0.184$; df = 54; $P = 0.001$) and *Cybocephalus* spp. capture 90 DAT ($r^2 = 0.292$; df = 54; $P < 0.001$) when data from all treatments were combined (Fig. 2). Untreated plants and those treated with granular thiamethoxam or acephate had more *Encarsia* spp. parasitoids per scale than predicted by all treatments combined 42 DAT whereas granular dinotefuran and acetamiprid treated plants had fewer (Fig. 2). Likewise, granular thiamethoxam treated plants had more *Encarsia* spp. parasitoids relative to

Table 5. Mean (± SEM) euonymus scales on leaves (84 DAT) and female euonymus scale on stems (90 DAT) of branches that were infested with second generation crawlers 45 DAT in 2009

Insecticide class	Active ingredient	Trade name	Leaves	Stems
Insect growth regulator	Buprofezin	Talus	0.2 ± 0.2	0 ± 0.0
	Pyriproxyfen	Distance	0 ± 0.0	0 ± 0.0
Neonicotinoid	Acetamiprid	TriStar 30SG	3.17 ± 3.2	9.33 ± 5.2
	Dinotefuran	Safari 20 SG	0 ± 0.0	0.17 ± 0.2
	Dinotefuran	Safari G	3 ± 1.6	7 ± 5.1
	Thiamethoxam	Flagship 25WG	6.17 ± 4.6	0 ± 0.0
	Thiamethoxam	Flagship G	2.17 ± 0.8	0.17 ± 0.2
Organophosphate	Acephate	Acephate 75WP	0 ± 0.0	0.17 ± 0.2
	Untreated	–	22.33 ± 6.8	17.33 ± 5.3
	χ^2_8		29.81	39.7
	P		<0.001	<0.001

Table 6. Cottony cushion scale nymphs present 4 and 8 d after infestation on branches that were cut and held in flr al picks in the laboratory and on an intact branch of experimental plants outdoors 130 DAT in 2010

Insecticide class	Active ingredient	Trade name	Laboratory exp		Outdoor exp	
			Day 4	Day 8	Day 4	Day 8
Insect growth regulators	Buprofezin	Talus	3 ± 0.4	2.67 ± 0.3	3.67 ± 0.4	2.17 ± 0.3
	Pyriproxyfen	Distance	3 ± 0.6	2.33 ± 0.3	3 ± 0.7	1.83 ± 0.6
Neonicotinoids	Acetamiprid	TriStar 30SG	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0
	Dinotefuran	Safari 20 SG	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0
	Dinotefuran	Safari G	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0
	Thiamethoxam	Flagship 25WG	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0
	Thiamethoxam	Flagship G	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0
Oils	Paraffinic Oil	Hort. Oil	5.5 ± 0.9	8.83 ± 1.7	9.83 ± 1.7	9 ± 2.1
Pyrethroid	Bifenthrin	Talstar	4.17 ± 0.5	3.33 ± 0.5	5.17 ± 0.5	3.17 ± 0.3
Tetramic acids	Spirotetramat	Kontos	0.33 ± 0.2	0 ± 0.0	0.5 ± 0.2	0.17 ± 0.2
	Untreated	Untreated	12.6 ± 1.9	18.6 ± 3.2	14.2 ± 1.4	12 ± 1.1
	χ^2_{10}		60.14	62.69	59.17	57.23
	P		<0.001	<0.001	<0.001	<0.001

the number of scale 90 DAT whereas granular dinote furan treated plants had fewer parasitoids and *Cybo cephalus* spp. relative to scale abundance than other treatments (Fig. 2).

In 2010 laboratory toxicity experiments, 40% of *O. insidiosus* survived less than one hour on leaves from plants treated with bifenthrin ($F_{10,55}$ = 3.70; $P <$ 0.001) (Fig. 3). After 24 h over 40% of *O. insidiosus* had died on untreated leaves, but 90% had died on leaves from plants treated with bifenthrin and 70% had died on leaves from plants treated with pyriproxyfen ($F_{10,55}$ = 3.55; P = 0.001; Fig. 3). Similarly, no *E. citrina* survived 24 h on leaves from plants treated with bifen thrin and less than half as many survived on leaves from plants treated with pyriproxyfen than on un treated plants ($F_{10,55}$ = 3.80; $P <$ 0.001; Fig. 3).

Discussion

Landscape and nursery pest managers rely on re peated applications of pyrethroid and organophos phate insecticides to manage scale and other arthro pod pests (Hudson et al. 1996, Sellmer et al. 2004). In two years of research, I identified insecticides that provide season long suppression of euonymus scale with a single application. In addition, some of the insecticides I tested were more compatible with scale natural enemies than the organophosphate and pyre throid insecticides tested. This research builds on pre vious work documenting the efficacy of reduced risk insecticides for euonymus scale control and their ef fect on parasitism rate (Rebek and Sadof 2003). I extend the scope and applicability of this previous work by employing realistic nursery production prac tices, evaluating the efficacy of insecticides against multiple scale generations, and testing the direct tox icity of insecticides to natural enemy taxa.

All of the reduced risk insecticides I tested reduced scale abundance as effectively as acephate and bifen thrin, by the end of the first euonymus scale gen eration. Most products also kept scale abundance low through the second (2009) and third (2010) genera tions. Without infested *Euonymus* plants nearby, scale abundance would remain low on plants where scale was nearly eliminated by insecticides. Therefore, de liberate reinfestation is a better test of the residual efficacy of products against scale. In 2009, scale re colonized stems of acetamiprid and granular dinote furan treated plants in much greater numbers than other treatments corroborating observations on focal branches that were not reinfested. Acephate, a sys temic insecticide, also prevented infestation by sec ond generation scales. Acephate is toxic to many nat ural enemies (Reitz et al. 2003, Bacci et al. 2007, Chapman et al. 2009). However, it remains one of the most frequently used insecticides in the nursery and landscape industries (Hudson et al. 1996, Sellmer et al. 2004, S.D.F., unpublished data). Pest managers could reduce the negative impact of acephate by taking advantage of its long efficacy to reduce application frequency and use it in rotation with other insecticides that are less toxic.

In 2010, I tested two contact insecticides that are widely used for scale control: horticultural oil and the pyrethroid bifenthrin. These contact insecticides re duced first generation scale abundance as well as re duced risk systemic insecticides. However, they did not prevent infestation by cottony cushion scale. Al though bifenthrin and horticultural oil had similar efficacy in this experiment they have very different effects on nontarget organisms. Bifenthrin residue on euonymus leaves killed 90% of *O. insidiosus* and 100% of *E. citrina* in laboratory experiments whereas hor ticultural oil had no effect. Based on my results and that of others, a horticultural oil application targeting crawlers can control armored scale as well as or better than more toxic products such as pyrethroids, aceph ate (Sadof and Sclar 2000, Raupp et al. 2008) and chlorpyrifos (Fondren and McCullough 2005) with less negative impact on natural enemy communities (Raupp et al. 2001).

Natural enemies can help reduce scale populations in natural and managed ecosystems (Hanks and Denno 1993, Tooker and Hanks 2000). Euonymus scale is attacked by *Cybocephalus nipponicus* Enrody Younga, *Chilocorus kuwanae* Silvestri, *Encarsia citrina* and other natural enemies (Matadha et al. 2003) but control is consistently below esthetic thresholds (Van

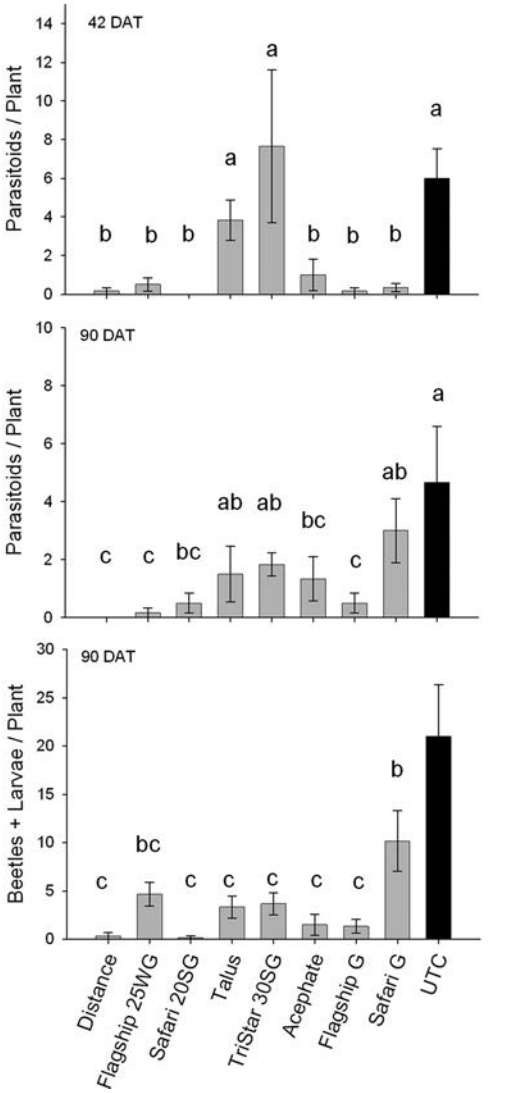

Fig. 1. *Encarsia* spp. parasitoids and *Cybocephalus* spp. beetles and larvae captured by beat sampling plants 42 and 90 DAT in 2009. Bars with the same letter are not significantly different ($P > 0.05$) based on Fisher Protected LSD means comparisons.

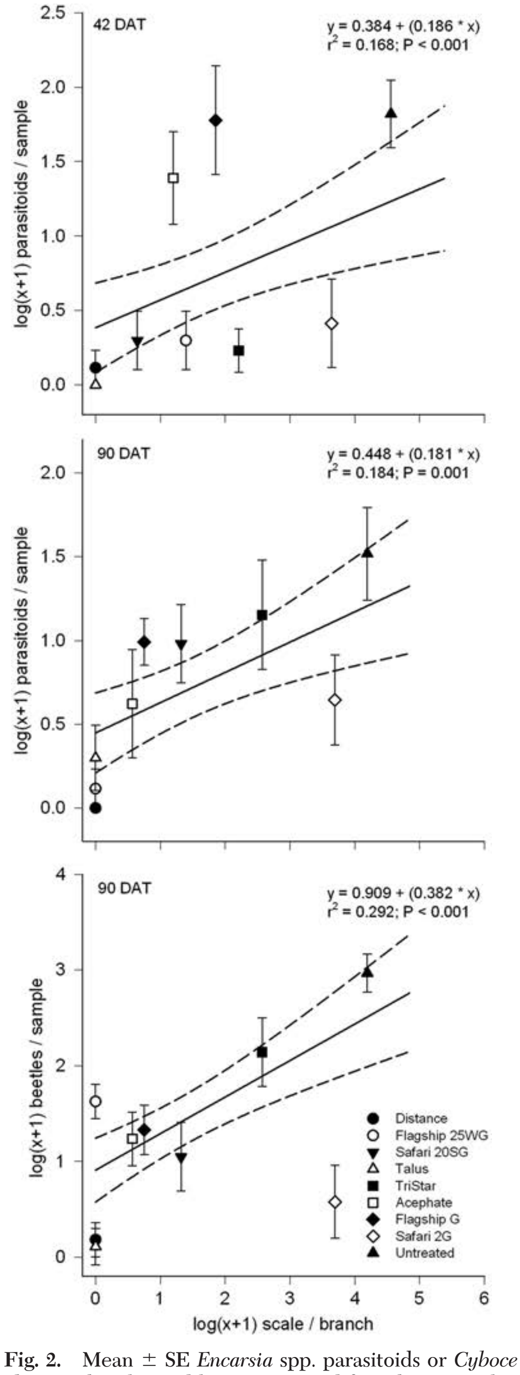

Fig. 2. Mean ± SE *Encarsia* spp. parasitoids or *Cyboce phalus* spp. beetles and larvae captured from beat sampling euonymus plants in each treatment 42 or 90 DAT plotted over the regression line with 95% confidence intervals of female scale abundance versus the number of parasitoids or cap tured when data from all treatments was combined.

Driesche et al. 1998a,b). Thus, the majority of euony mus landscape plants are infested with euonymus scale (Van Driesche et al. 1998a) and insecticides remain an essential aspect of control for this pest. I found bifenthrin treated leaves to be highly toxic to *Encarsia* spp. parasitoids and *O. insidiosus* corroborat ing the negative effect of pyrethroids on natural en emies found in other studies (Penman and Chapman 1988, Ohnesorg et al. 2009, Frank and Sadof 2011). All other insecticides except pyriproxyfen did not reduce *O. insidiosus* survival after 24 h. Pyriproxyfen, thiame thoxam (WG), and acetamiprid reduced *E. citrina* survival after 24 h.

The acute toxicity of IGRs and neonicotinoids was less than bifenthrin in this study and others (Prab haker et al. 2007). However, our methods could not assess the sub lethal or long term effects of these in secticides on *E. citrina* or *O. insidiosus.* Effects of neonicotinoids and IGRs on natural enemies can in

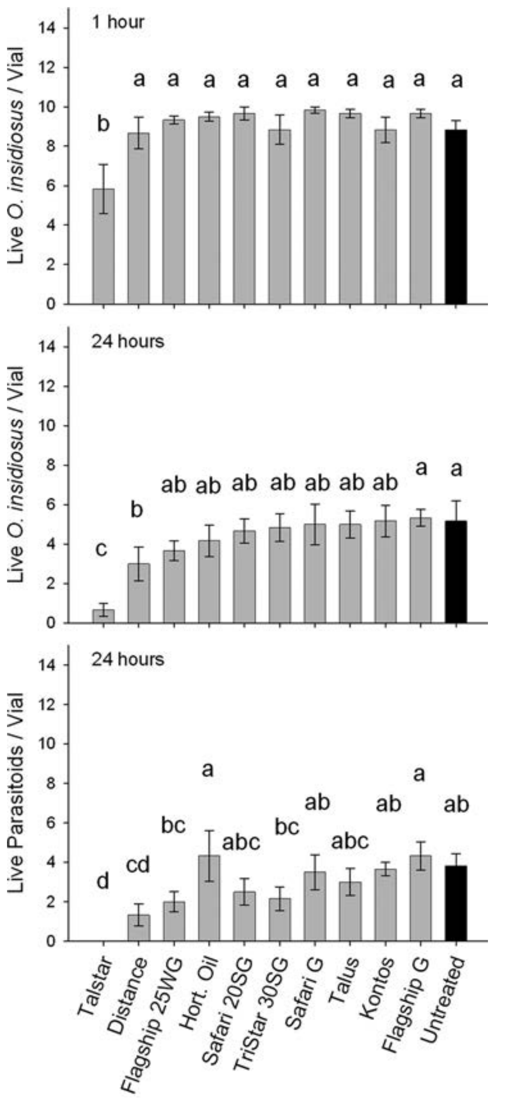

Fig. 3. *Orius insidiosus* and *Encarsia citrina* survival after one and 24 h in vials with leaves collected from experimental plants 10 DAT. Bars with the same letter are not significantly different ($P > 0.05$) based on Fisher Protected LSD means comparisons.

clude reduced mobility, prey consumption, fecundity, and longevity (Liu and Stansly 1997, Grafton Cardwell and Gu 2003, Poletti et al. 2007, Cloyd and Bethke 2010, Szczepaniec et al. 2011). Routes of ex posure include direct spray, consumption or parasit ism of tainted herbivores, or consumption of plant uids (Grafton Cardwell and Gu 2003, Cloyd and Bethke 2010, Szczepaniec et al. 2011). Moreover, these effects can occur even if contact with insecticide residue poses little threat (Lui and Stansly 1997; Graf ton Cardwell and Gu 2003; Poletti et al. 2007; Szcz epaniec et al. 2011). In scale management, pyriproxy fen and buprofezin, applied to California red scales reduced parasitoid emergence by 33% and 7% respec tively compared with untreated scales (Grafton Cardwell et al. 2006). These IGRs and the neonicoti noid imidacloprid can negatively affect development and survival of the cottony cushion scale predator *Rodolia cardinalis* Mulsant (Coleoptera: Coccinelli dae) and result in cottony cushion scale outbreaks in citrus orchards (Mendel and Blumberg 1991; Grafton Cardwell 1999).

Lethal and sublethal effects of insecticides combine with their effects on prey or host abundance to affect natural enemy abundance in a habitat (Grafton Cardwell et al. 2006; Cloyd and Bethke 2010). In this study, even though thiamethoxam residue on leaves was toxic to parasitoids, more parasitoids and *Cybo cephalus* spp. were captured per scale during beat samples than other treatments. In contrast, acet amiprid treated plants had fewer parasitoids than would be expect based on scale abundance and di notefuran (granular) treated plants had fewer para sitoids and beetles. Thus, products applied to soil that leave no residue on plants can still have effects on natural enemy fitness, abundance, and efficacy (Re bek and Sadof 2003, Cloyd and Bethke 2010, Szcz epaniec et al. 2011).

Despite the availability of reduced risk insecticides, many landscape and nursery pest management pro fessionals continue to rely on pyrethroids and organo phosphates because of their broad spectrum activity and lower initial cost. I have demonstrated that several reduced risk insecticides control scale for multiple generations. Though not evaluated in this study, re ducing the number of insecticide applications per year could reduce product and labor costs. In addition, future pesticide applications to correct secondary pest outbreaks dramatically increases the season long cost of pyrethroid applications (Frank and Sadof 2011). Therefore, based on their efficacy and potential to conserve natural enemies, reduced risk insecticides are an important component of armored scale man agement in the production and maintenance of orna mental plants.

Acknowledgments

I would like to thank two anonymous reviewers for pro viding valuable input on this manuscript. Swift Creek Nurs ery donated plants in 2010. Funding was provided, in part, by USDA IR 4. Syngenta, OHP Inc, Valent, SePro, Cleary Chem ical, and Nufarm provided insecticides. Alan Stephenson, Adam Dale, Katie Youngs, Sally Taylor, and Matt Cochran assisted with plant maintenance and data collection.

References Cited

Adkins, C., G. Armel, M. Chappell, J. C. Chong, S. D. Frank, A. Fulcher, F. Hale, W. Klingeman, K. Ivors, A. Lebude, et al. 2010. Pest management strategic plan for container and field produced nursery crops. (http://www.ipmcenters.org/pmsp/pdf/GA KY NC SC TNnurserycropsPMSP.pdf).

Bacci, L., A.L.B. Crespo, T. L. Galvan, E.J.G. Pereira, M. C. Picanco, G. A. Silva, and M. Chediak. 2007. Toxicity of insecticides to the sweetpotato white y (Hemiptera:

Aleyrodidae) and its natural enemies. Pest Manag. Sci. 63: 699–706.

Chapman, A. V., T. P. Kuhar, P. B. Schultz, T. W. Leslie, S. J. Fleischer, G. P. Dively, and J. Whalen. 2009. Integrating chemical and biological control of European corn borer in bell pepper. J. Econ. Entomol. 102: 287–295.

Cloyd, R. A., and J. A. Bethke. 2010. Impact of neonicotinoid insecticides on natural enemies in greenhouse and interiorscape environments. Pest Manag. Sci. 67: 3–9.

Cockfield, S. D., and D. A. Potter. 1987. Distribution, development, and feeding impact of euonymus scales (Homoptera: Diaspididae) on *Euonymus fortunei* under greenhouse conditions. Environ. Entomol. 16: 917–921.

Cockfield, S. D., and D. A. Potter. 1990. Euonymus scale (Homoptera: Diaspididae) effects on plant growth and leaf abscission and implications for differential site selection by male and female scales. J. Econ. Entomol. 83: 995–1001.

[EPA] Environmental Protection Agency. 2010. Reduced risk/organophosphate alternative1 decisions for conventional pesticides: updated 9/7/10. (http://www.epa.gov/opprd001/workplan/completionsportrait.pdf).

Fondren, K. M., and D. G. McCullough. 2005. Phenology, natural enemies, and efficacy of horticultural oil for control of *Chionaspis heterophyllae* (Homoptera: Diaspididae) on Christmas tree plantations. J. Econ. Entomol. 98: 1603–1613.

Frank, S. D., and C. S. Sadof. 2011. Reducing insecticide volume and non target effects of ambrosia beetle management in nurseries. J. Econ. Entomol. 104: 1960–1968.

Gill, S. A., D. R. Miller, and J. A. Davidson. 1982. Bionomics and taxonomy of the euonymus scale, *Unaspis euonymi* (Comstock), and detailed biological information on the scale in Maryland (Homoptera; Diaspididae). Misc. Publ. Md. Agric. Exp. Stn. 969.

Grafton Cardwell, E. E. 1999. Pesticide disruption of vedalia beetle results in cottony cushion scale outbreaks. KAC Plant Prot. Q. 9: 9–10.

Grafton Cardwell, E. E., and P. Gu. 2003. Conserving vedalia beetle, *Rodolia cardinalis* (Mulsant) (Coleoptera: Coccinellidae), in citrus: a continuing challenge as new insecticides gain registration. J. Econ. Entomol. 96: 1388–1398.

Grafton Cardwell, E. E., J. E. Lee, J. R. Stewart, and K. D. Olsen. 2006. Role of two insect growth regulators in integrated pest management of citrus scales. J. Econ. Entomol. 99: 733–744.

Greathead, D. J. 1990. Crawler behavior and dispersal, pp. 305–308. *In* D. Rosen (ed.), World crop pests, vol. 4A. Armored scale insects: their biology, natural enemies and control. Elsevier, Amsterdam, The Netherlands.

Hanks, L. M., and R. F. Denno. 1993. Natural enemies and plant water relations in uence the distribution of an armored scale insect. Ecology 74.

Hodges, A. W., C. R. Hall, B. K. Behe, and J. H. Dennis. 2008. Regional analysis of production practices and technology use in the US nursery industry. HortScience 43: 1807–1812.

Hodges, G. S., and S. K. Braman. 2004. Seasonal occurrence, phenological indicators and mortality factors affecting five scale insect species (Hemiptera: Diaspididae, Coccidae) in the urban landscape setting. J. Entomol. Sci. 39: 611–622.

Hudson, W. G., M. P. Garber, R. D. Oetting, R. F. Mizel, A. R. Chase, and K. Bondari. 1996. Pest management in the United States greenhouse and nursery industry: V. Insect and mite control. Hortic. Technol. 6: 216–221.

IR 4. 2007. Ornamental Horticulture Survey. (http://ir4.rutgers.edu/ornamental/SummaryReports/2007OrnamentalHorticultureSurvey.pdf).

LeBude, A., S. White, A. Fulcher, S. Frank, J. H. Chong, M. Chappell, W. Klingeman, III, A. Windham, K. Braman, F. Hale, et al. Assessing the integrated pest management practices of southeastern U.S. ornamental nursery operations. Pest Manag. Sci. (in press).

Liu, T. X., and P. A. Stansly. 1997. Effects of pyriproxyfen on three species of Encarsia (Hymenoptera: Aphelinidae), endoparasitoids of *Bemisia argentifiolii* (Homoptera: Aleyrodidae). J. Econ. Entomol. 90: 404–411.

Magsig Castillo, J., J. G. Morse, G. P. Walker, J. L. Bi, P. F. Rugman Jones, and R. Stouthamer. 2010. Phoretic dispersal of armored scale crawlers (Hemiptera: Diaspididae). J. Econ. Entomol. 103: 1172–1179.

Matadha, D., G. C. Hamilton, M. G. Hughes, and J. H. Lashomb. 2003. Distribution of natural enemies of euonymus scale, *Unaspis euonymi* (Comstock) (Homoptera: Diaspididae), in New Jersey. Environ. Entomol. 32: 602–607.

McClure, M. S. 1977a. Resurgence of scale, *Fiorinia externa* (Homoptera: Diaspididae), on hemlock following insecticide application. Environ. Entomol. 6: 480–484.

McClure, M. S. 1977b. Dispersal of scale *Fiorinia externa* (Homoptera: Diaspididae) and effects of edaphic factors on its establishment on hemlock. Environ. Entomol. 6: 539–544.

Mendel, Z., and D. Blumberg. 1991. Colonization trials with *Cryptochetum iceryae* and *Rodolia iceryae* for improved biological control of *Icerya purchasi* in Israel. Biol. Control 1: 68–74.

Miller, D. R., and J. A. Davidson. 2005. Armored scale insect pests of trees and shrubs. Cornell University Press, Ithaca, New York.

Ohnesorg, W. J., K. D. Johnson, and M. E. O Neal. 2009. Impact of reduced risk insecticides on soybean aphid and associated natural enemies. J. Econ. Entomol. 102: 1816–1826.

Penman, D. R., and R. B. Chapman. 1988. Pesticide induced mite outbreaks: pyrethroids and spider mites. Exp. Appl. Acarol. 4: 265–276.

Poletti, M., A.H.N. Maia, and C. Omoto. 2007. Toxicity of neonicotinoid insecticides to *Neoseiulus californicus* and *Phytoseiulus macropilis* (Acari: Phytoseiidae) and their impact on functional response to *Tetranychus urticae* (Acari: Tetranychidae). Biol. Control 40: 30–36.

Prabhaker, N., J. G. Morse, S. J. Castle, S. E. Naranjo, T. J. Henneberry, and N. C. Toscano. 2007. Toxicity of seven foliar insecticides to four insect parasitoids attacking citrus and cotton pests. J. Econ. Entomol. 100: 1053–1061.

Raupp, M. J. 1985. Monitoring: An essential factor to managing pests of landscape trees and shrubs. J. Arboric. 11: 349–355.

Raupp, M. J., J. J. Holmes, C. Sadof, P. Shrewsbury, and A. Davidson. 2001. Effects of cover sprays and residual pesticides on scale insects and natural enemies in urban forests. J. Arboric. 27: 203–214.

Raupp, M. J., and R. M. Noland. 1984. Implementing landscape plant management programs in institutional and residential settings. J. Arboric. 10: 161–169.

Raupp, M. J., R. Ahern, B. Onken, R. Reardon, S. Bealmear, J. Doccola, P. Wolf, P. Becker, T. Mcintyre, K. Laskowski, et al. 2008. Comparing hemlock woolly adelgid and elongate hemlock scale control in ornamental and forest hemlocks. *In* B. Onken and R. Reardon, compilers. Fourth symposium on Hemlock Woolly Adelgid in the Eastern United States. FHTET 2008 01.

Rebek, E. J., and C. S. Sadof. 2003. Effects of pesticide ap plications on the euonymus scale (Homoptera: Diaspidi dae) and its parasitoid, *Encarsia citrina* (Hymenoptera: Aphelinidae). J. Econ. Entomol. 96: 446–452.

Reitz, S. R., E. L. Yearby, J. E. Funderburk, J. Stavisky, M. T. Momol, and S. M. Olson. 2003. Integrated management tactics for *Frankliniella thrips* (Thysanoptera: Thripidae) in field grown pepper. J. Econ. Entomol. 96: 1201–1214.

SAS Institute. 2002. SAS version 9.1. SAS Institute, Cary, NC.

Sadof, C. S., and D. C. Sclar. 2000. Effects of horticultural oil and foliar or soil applied systemic insecticides on Euony mus scale in pachysandra. J. Arboric. 26: 120–125.

Sellmer, J. C., N. Ostiguy, K. Hoover, and K. M. Kelley. 2004. Assessing the integrated pest management practices of Pennsylvania nursery operations. HortScience 39: 297–302.

Szczepaniec A., S. F. Creary, K. L. Laskowski, J. P. Nyrop, and M. J.Raupp. 2011. Neonicotinoid insecticide imidaclo prid causes outbreaks of spider mites on elm trees in urban landscapes. PLoS ONE 6: e20018. doi:10.1371/journal.pone.0020018.

Tooker, J. F., and L. M. Hanks. 2000. In uence of plant community structure on natural enemies of pine needle scale (Homoptera: Diaspididae) in urban landscapes. En viron. Entomol. 29: 1305–1311.

Van Driesche, R., P. Kingsley, M. Rose, and M. Bryan. 1998a. Effect of euonymus scale (Homoptera: Diaspididae) on *Euonymus* spp. survival in southern New England, with estimates of economic costs of pest damage. Environ. Entomol. 27: 217–220.

Van Driesche, R., K. Idoine, M. Rose, and M. Bryan. 1998b. Evaluation of the effectiveness of *Chilocorus kuwanae* (Coleoptera: Coccinellidae) in suppressing euonymus scale (Homoptera: Diaspididae). Biol. Control 12: 56–65.

Received 15 September 2011; accepted 9 February 2012.