Responses of Three Natural Enemy Species to Contact and Systemic Insecticide Exposures in Confined Assays[1]

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Abstract Chemical pesticides can efficiently control insect pests and are often relied upon by nursery producers. With increased consumer concerns regarding insecticides, growers may choose to limit insecticide applications by incorporating natural enemies into their pest management program. This study assessed the effects of commonly used contact (bifenthrin and carbaryl) and systemic (imidacloprid and dinotefuran) insecticides on adult *Chrysoperla rufilabris* (Burmeister), adult *Hippodamia convergens* (Guérin-Méneville), and adult *Orius insidiosus* (Say) to evaluate their safety for use with natural enemies. Insects were confined in experimental arenas either with leaves sprayed to provide insecticide residues or leaves treated with only water and then air-dried prior to use. Both systemic and contact insecticides caused mortality in all three insect species. The contact insecticide bifenthrin was the least toxic to *C. rufilabris,* and the systemic insecticide, dinotefuran, was not toxic to *H. convergens*. The broad-spectrum contact insecticide carbaryl was the most toxic insecticide to both *C. rufilabris* and *H. convergens*. All insecticides caused mortality to *O. insidiosus* with bifenthrin being the most toxic. None of the insecticides chosen in this study were “safe” for all three natural enemy species.

Key Words bifenthrin, biological control, carbaryl, dinotefuran, imidacloprid

Pressure to produce new, unique, or easy-to-grow ornamental plant cultivars has led to breeding and selection largely focused on attractive flowers and foliage. When plants are bred for these specific aesthetic traits, general pest-resistance genes can be inadvertently lost, leaving plants more susceptible to a range of pests (Tripp and van der Heide 1996). For ornamental crops, which are valued solely for their aesthetics, the threshold for pest damage is often zero because a single pest can render a plant unmarketable (Klingeman et al. 2000). One pest can be too many, not only because of feeding damage, but also because of reproductive potential. For example, one female bagworm, *Thyridopteryx ephemeraeformis* (Haworth), can produce enough offspring to cause a major infestation on American arborvitae (*Thuja occidentalis* L.) (Horn and Sheppard 1979, Raupp et al. 1989). However, achieving a pest level of zero is difficult, and thus protecting nursery crop aesthetics can be challenging. Chemical insect control has traditionally been an important part of nursery crop production, in part because insecticides work quickly and help maintain pest populations at acceptable levels with minimal effort

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expended by the grower (Bethke and Cloyd 2009). However, as consumer perceptions of pesticides become increasingly negative due to concerns for environmental impacts (Falconer 1998, Kher et al. 2013, Montella et al. 2012), worker safety (Kher et al. 2013), and the ability of insects to develop resistance to chemicals (Falconer 1998, Montella et al. 2012), it is important that nurseries consider more sustainable pest management options.

Systemic insecticides are often believed to be safer for biological control organisms because they are taken up by the plant and are injested by only phytophagous arthropods (Bellows et al. 1988, Cloyd 2010, Jeppson 1953, Mizell and Sconyers 1992, Rudinsky 1959, Stapel et al. 2000). However, research suggests that systemic insecticides can limit functionality and even cause death to natural enemy arthropods used for biological control of pests when these organisms either come in direct contact with the insecticide or feed on prey that has ingested the pesticide (Koppert Biological Systems 2005, Szczepaniec et al. 2011). For example, the systemic insecticide imidacloprid is toxic to insects used for biological control, including *Chrysoperla rufilabris* (Burmeister) larvae when used as a foliar spray, but not as a drench, and to *Orius insidiosus* (Say) as both a foliar spray (Studebaker and Kring 2003) and a drench (Koppert Biological Systems 2005). Dinotefuran, another common systemic neonicotinoid insecticide, was established as an alternative to imidacloprid and is labeled as a reduced-risk pesticide by the U.S. Environmental Protection Agency. However, dinotefuran is highly toxic to beneficial insects not used for pest control, such as honey bees (*Apis mellifera* L.) and silkworms (*Bombyx mori* L.) (Mitsui Chemicals America, Inc. 2013), and has not been tested on natural enemies.

Several studies have evaluated the effectiveness of contact and systemic insecticides for controlling target pests of ornamental crops (IR-4 Project 2014), yet limited independent research has been conducted on the effects of insecticides on natural enemies (Colin et al. 2004, Lucas et al. 2004, Szczepaniec et al. 2011, 2013b). Similarly, relatively limited research has been undertaken to examine compatibility of a range of insecticides against specific natural enemies that are available to the U.S. nursery industry for commercial biological control. The objective of this study was to investigate the effects of commonly used contact and systemic insecticides on selected natural enemies *C. rufilabris*, *Hippodamia convergens* (Guérin-Méneville), and *O. insidiosus* when subjected to direct contact with insecticide residue in a confinement scenario. With this information we hope to gain insight on which insecticides, if any, can be used cohesively with these natural enemies so ornamental growers can sustainably incorporate both forms of pest control into their integrated pest management programs.

Materials and Methods

Chrysoperla rufilabris, *H. convergens*, and *O. insidiosus* were ordered from Rincon-Vintova (Ventura, CA) in 2011 and from Beneficial Insectaries (Redding, CA) in 2012. Insects, which arrived 4 May 2011 and 11 October 2012, were held in a cooler overnight and then used in assays once trees were treated the following morning. For *C. rufilabris* and *H. convergens*, experimental arenas were built from 90-mm petri dishes (Fisher Scientific, Pittsburgh, PA) by removing a 7.6-cm diameter opening in the lid and covering the opening with organdy fabric to allow for gas exchange. A single 90-mm filter paper was placed in each arena to absorb excess moisture. Arenas for *O. insidiosus* were 76 mm (Gelman, Ann Arbor, MI) in diameter and were left intact as the *O. insidiosus* were small enough to climb through the organdy. For each arena, a hole was drilled in the lid of a 0.65-mL microcentrifuge tube (Costar®, Corning, Corning, NY), plugged with cotton, and filled with a honey–water solution (5% v/v) to serve as a food source. On the morning of treatment, 10 insects were placed in their respective arenas. Treated and air-dried leaves had petioles inserted in a 5-mL centrifuge tube water source and then placed in arenas.

Forty tulip poplar (*Liriodendron tulipifera* L.) trees grown in the field at the University of Tennessee Forest Resources Center, Cumberland Forest Unit, in Oliver Springs, TN, were placed into insecticide treatment groups, eight trees per treatment. A different group of trees was used each year; that is, trees treated in 2011 were not used in 2012. Trees were 2 yr old and 1.22–1.68 m tall with a 2.54-cm caliper in 2011 and 3 yr old, 1.83–2.74 m tall with a 10.16-cm caliper in 2012. In 2011, the whole tree canopy was treated. In 2012, due to a much larger tree size, a single branch on each tree was treated. In both years, foliage was covered with insecticide until runoff, and then leaves were allowed to air-dry on the tree before collection. Although foliage is not always thoroughly covered during a pesticide application, in this study we were interested in a scenario in which the natural enemies were forced into contact with air-dried pesticide residues. Trees were sprayed using a CO_2 sprayer at 0.21 MPa (Teejet® Even Flat Spray Tip, Springfield, IL, 0.6435 liters per min). Treatments chosen are widely used in commercial nursery operations and included bifenthrin (Talstar® Select, FMC Corporation, Philadelphia, PA, mode of action Group 3) at 2.9 $\mu L/m^2$, carbaryl (Sevin® SL, Bayer CropScience, Durham, NC, mode of action Group 1) at 2.5 mL/L, imidacloprid (Marathon® II, OHP, Inc., Mainland, PA, mode of action Group 4a) at 6 ml per inch diameter at breast height (dbh), and dinotefuran (Safari® 20 SG, Valent Professional Products, Walnut Creek, CA, mode of action Group 4a) at 0.126 g/dbh. Treatments were compared to a water-spray control. Carbaryl (carbamate) and bifenthrin (pyrethroid) are both broad-spectrum contact insecticides. Imidacloprid and dinotefuran are systemic neonicotinoid insecticides. Dinotefuran is labeled as a drench-only, but in a drench application, the pesticide solution may splash on the lower leaves of the treated plant or surrounding vegetation that natural enemies encounter while foraging for prey.

Once air-dried, three leaves (one for each insect species) were collected from each tree and placed in labeled, resealable bags in a cooler for transport to campus. Leaf petioles were placed in water picks and placed in their respective arenas. Arenas were placed in a laboratory at the University of Tennessee in Knoxville, TN, and maintained at 20°C with 8 h of light. Survival was assessed every 24 h over the course of 4 d. Insects that were not moving were recorded as dead and removed, and those that were moving were recorded as alive.

Each arena was an experimental unit with eight replicates per insecticide treatment. Data were analyzed as a completely randomized design with repeated measures using the GLM procedure of SAS (9.3S; SAS Institute, Cary, NC). Means were separated using Tukey's least significant difference, $\alpha = 0.05$. Data were not

Table 1. Survival of adult *Chrysoperla rufilabris* when exposed to contact and systemic insecticides in May 2011.*

	Survival (%)			
Treatment	**24 HOE****	**48 HOE**	**72 HOE**	**96 HOE**
Water	100 a	100 a	96 a	83 a
Bifenthrin	99 a	88 a	65 ab	64 ab
Carbaryl	49 b	25 b	20 c	21 c
Dinotefuran	63 b	48 b	39 bc	35 bc
Imidacloprid	56 b	45 b	33 bc	25 bc

* Means followed by the same letter within a column were not significantly different (Tukey $\alpha = 0.05$).
** HOE, hours of exposure.

pooled because results varied between years. Each insect species was analyzed separately.

Results and Discussion

***Chrysoperla rufilabris*.** More than 80% of adult *C. rufilabris* in arenas containing water-treated control foliage survived for the duration of the 2011 trial, but adult survival decreased below 60% in 2012 (Tables 1, 2). This decrease in survival may be attributed to the seasonal differences in the two experiments. Bifenthrin exposure, when compared with water exposure, caused no greater *C. rufilabris* mortality at any time point except at 96 h of exposure in 2012 ($F = 9.01$; df = 4, 35; $P < 0.0001$), even in this confinement situation. Schuster and Stansly (2000) also found bifenthrin to be nontoxic to C. rufilabris and Ceraeochrysa cubana (Hagen),

Table 2. Survival of adult *Chrysoperla rufilabris* when exposed to contact and systemic insecticides in October 2012.*

	Survival (%)			
Treatment	**24 HOE****	**48 HOE**	**72 HOE**	**96 HOE**
Water	93 a	83 a	66 a	59 a
Bifenthrin	91 a	54 a	40 ab	24 bc
Carbaryl	59 b	15 b	9 b	6 c
Dinotefuran	83 a	74 a	65 a	61 a
Imidacloprid	84 a	64 a	48 a	43 ab

* Means followed by the same letter within a column were not significantly different (Tukey $\alpha = 0.05$).
** HOE, hours of exposure.

Table 3. Survival of adult *Hippodamia convergens* exposed to contact and systemic insecticides in May 2011.*

	Survival (%)			
Treatment	**24 HOE****	**48 HOE**	**72 HOE**	**96 HOE**
Water	95 a	85 a	83 a	80 a
Bifenthrin	84 b	39 b	31 c	26 b
Carbaryl	43 b	10 c	1 c	1 b
Dinotefuran	93 a	80 a	73 ab	62 a
Imidacloprid	84 a	69 a	48 bc	21 b

* Means followed by the same letter within a column were not significantly different (Tukey $\alpha = 0.05$).
** HOE, hours of exposure.

yet Koppert Biological Systems (2005) reported mortality in Chrysoperla carnea (Stephens). Carbaryl was 51%, 72%, 69%, and 67% more lethal than bifenthrin in 2011 at 24 ($F = 7.67$; df = 4, 35; $P = 0.0002$), 48 ($F = 13.20$; df = 4, 35; $P < 0.0001$), 72 ($F = 11.51$; df = 4, 35; $P < 0.0001$), and 96 h of exposure ($F = 7.73$; df = 4, 35; $P = 0.0002$), respectively. In 2012, carbaryl was more lethal than bifenthrin by 35% and 72% at 24 ($F = 6.26$; df = 4, 35; $P = 0.0007$) and 48 h of exposure ($F = 12.09$; df = 4, 35; $P < 0.0001$). *Chrysoperla rufilabris* exposed to carbaryl had less than 50% survival compared to water exposure, which is consistent with the Side Effects Database, which shows that carbaryl is lethal to larval and adult stages of the same green lacewing species used in this study (Koppert Biological Systems 2005). While survival was generally lower in 2012, neither systemic insecticide caused greater mortality than water exposure. In 2011, however, the systemic insecticides reduced survival of adult *C. rufilabris* by 37%, 52%, 59%, and 58% for dinotefuran, and 44%, 55%, 66%, and 70% for imidacloprid, at 24 ($F = 7.67$; df = 4, 35; $P = 0.0002$), 48 ($F = 13.20$; df = 4, 35; $P < 0.0001$), 72 ($F = 11.51$; df = 4, 35; $P < 0.0001$), and 96 h of exposure ($F = 7.73$; df = 4, 35; $P = 0.0002$), respectively. Harm to *C. rufilabris* larvae can occur following exposure to imidacloprid when used as a foliar spray; however, foliar spray effects on *C. rufilabris* adults have not been reported (Koppert Biological Systems 2005).

***Hippodamia convergens*.** As with *C. rufilabris* adults, *H. convergens* adult survival on water-treated foliage was higher in 2011 than in 2012 by 9%, 8%, 20%, and 24% at 24, 48, 72, and 96 h of exposure, respectively (Tables 3, 4). Greater survival could be explained, in part, by the time of year when *H. convergens* were collected for commercial distribution (May in 2011 versus October in 2012). In the fall, *H. convergens* begin accumulating metabolic reserves needed to survive overwintering (Hamedi et al. 2013). Hamedi et al. (2013) found that when storing *H. variegata* (Goeze) at 10°C between November and February, the population declined; the decline was directly related to the increased metabolic compounds and the suddenly warmer temperatures.

Table 4. Survival of adult *Hippodamia convergens* exposed to contact and systemic insecticides in October 2012.*

	Survival (%)			
Treatment	**24 HOE****	**48 HOE**	**72 HOE**	**96 HOE**
Water	86 ab	78 a	66 ab	61 ab
Bifenthrin	75 b	51 b	46 b	40 bc
Carbaryl	79 ab	61 ab	49 b	31 c
Dinotefuran	93 a	84 a	78 a	65 a
Imidacloprid	70 b	53 b	49 b	44 abc

* Means followed by the same letter within a column were not significantly different (Tukey $\alpha = 0.05$).
** HOE, hours of exposure.

In 2011, carbaryl exposure resulted in reduced *H. convergens* survival to below 50% at 24 h of exposure ($F = 19.36$; df $= 4, 35$; $P < 0.0001$), 10% at 48 h of exposure ($F = 30.73$; df $= 4, 35$; $P < 0.0001$), and 1% at 72 ($F = 26.17$; df $= 4, 35$; $P < 0.0001$) through 96 h of exposure ($F = 22.95$; df $= 4, 35$; $P < 0.0001$) (Table 3). By contrast, in 2012, carbaryl did not decrease survival until 96 h of exposure, when *H. convergens* survival decreased 49% compared to those exposed to water-treated foliage ($F = 5.93$; df $= 4, 35$; $P = 0.0009$) (Table 4). Despite lower *H. convergens* survival in 2012 than in 2011, by the end of the experiment, carbaryl-exposed *H. convergens* had 1% survival in 2011 ($F = 22.95$; df $= 4, 35$; $P < 0.0001$) and 31% in 2012 ($F = 5.93$; df $= 4, 35$; $P = 0.0009$).

Like carbaryl, bifenthrin caused greater *H. convergens* mortality in 2011 than in 2012 (Tables 3, 4). In 2011, survival of adults exposed to bifenthrin was reduced by 12%, 54%, 63%, and 68% compared to water controls at 24 ($F = 19.36$; df $= 4, 35$; $P < 0.0001$), 48 ($F = 30.73$; df $= 4, 35$; $P < 0.0001$), 72 ($F = 26.17$; df $= 4, 35$; $P < 0.0001$), and 96 h of exposure ($F = 22.95$; df $= 4, 35$; $P < 0.0001$), respectively. In 2012, however, survival was only negatively affected at 48 h of exposure ($F = 7.01$; df $= 4, 35$; $P = 0.0003$) (by 35%) when compared to water controls. A decrease in survival is consistent with observations of larval multicolored Asian lady beetle *(Harmonia axyridis* Pallas) in corn (*Zea mays* L.) fields treated with bifenthrin (0.045 kg active ingredient [AI]/ha), in which survival decreased below that observed among lady beetles in control fields (Galvan et al. 2005). In laboratory experiments conducted during the same study, bifenthrin also decreased survival of multicolored Asian lady beetle adults. Additionally, *Coccinella transversalis* (F.) and *Harmonia octomaculata* (F.) lady beetle populations declined following exposure to bifenthrin-treated cotton (*Gossypium hirstum* L.) leaves in comparison to water controls (Ma et al. 2000).

In both years of this study, *H. convergens* survival following exposure to dinotefuran was not different from exposure to water (Tables 3, 4). In field studies, Fulcher and Klingeman (2012) also found that dinotefuran exposure did not decrease *H. convergens* survival when compared with water exposure. Imidacloprid exposure yielded no observable negative effects at 24 and 48 h of exposure in

Table 5. Survival of adult *Orius insidiosus* exposed to contact and systemic insecticide in May 2011.*

	Survival (%)			
Treatment	**24 HOE****	**48 HOE**	**72 HOE**	**96 HOE**
Water	94 a	71 a	45 a	39 a
Bifenthrin	5 c	0 c	0 c	0 b
Carbaryl	66 a	38 b	19 b	14 b
Dinotefuran	15 bc	3 c	1 c	1 b
Imidacloprid	35 b	9 c	0 c	0 b

* Means followed by the same letter within a column were not significantly different (Tukey $\alpha = 0.05$).
** HOE, hours of exposure.

2011, but caused a 42% decline in survival at 72 h of exposure ($F = 26.17$; df = 4, 35; $P < 0.0001$) and a 74% decline by 96 h of exposure ($F = 22.95$; df = 4, 35; $P < 0.0001$). In 2012, imidacloprid caused a 32% decline in survival by 48 h of exposure ($F = 7.01$; df = 4, 35; $P = 0.0003$), yet survivorship was not different from water exposure at all other data collection points. In 2011, imidacloprid exposure caused survival rates to decline about 20% between each time point. In 2012, survival dropped quickly between 24 and 48 h of exposure and then decreased by less than 5% during each subsequent count. Toxicity of imidacloprid (240 g AI/L) to 12-spotted lady beetle larvae (*Coleomegilla maculata* DeGeer) has been demonstrated in laboratory tests during which 80% of larvae died within 48 h (Lucas et al. 2004). Eggs and first- and second-instar multicolored Asian lady beetle larvae also died following exposure to imidacloprid (50mg AI/L), yet imidacloprid did not kill adult beetles (Youn et al. 2003).

Although dinotefuran and imidacloprid are both neonicotinoid insecticides, their active ingredients differ in their physical chemistries (Toscano and Byrne 2005, Wakita et al. 2005). Dinotefuran has greater water solubility and does not bind as easily with organic matter as imidacloprid (Wakita et al. 2005). These characteristics could help explain why *H. convergens* reacted differently to the two systemic insecticides. Several studies using dinotefuran and imidacloprid have also reported different responses among spider mites to residues of these two insecticides (Gupta and Krischik 2007; Sclar et al. 1998; Szczepaniec et al. 2011, 2013a, 2013b; Szczepaniec and Raupp 2013).

***Orius insidiosus*.** When exposed to water-treated leaves, *O. insidiosus* populations decreased below 50% by 72 h of exposure ($F = 31.80$; df = 4, 35; $P < 0.0001$) in 2011 and by 96 h of exposure ($F = 12.21$; df = 4, 35; $P < 0.0001$) in 2012, suggesting that *O. insidiosus* may not be suited to the experimental arena environment to which they were confined (Tables 5, 6). Fulcher and Klingeman (2012) conducted a similar study using modified petri dishes attached to leaves of field-grown trees in which adult *O. insidiosus* survival did not decline as severely. The arena design was different for *O. insidiosus* than those used for *C. rufilabris*

Table 6. Survival of adult *Orius insidiosus* exposed to contact and systemic insecticides in October 2012.*

	Survival (%)			
Treatment	**24 HOE****	**48 HOE**	**72 HOE**	**96 HOE**
Water	100 a	71 a	54 a	36 a
Bifenthrin	9 c	0 c	0 c	0 b
Carbaryl	60 b	20 bc	20 b	10 b
Dinotefuran	43 b	25 b	23 b	8 b
Imidacloprid	48 b	26 b	21 b	6 b

* Means followed by the same letter within a column were not significantly different (Tukey $\alpha = 0.05$).
** HOE, hours of exposure.

and *H. convergens* because of their smaller size; air exchange was limited because the arena lid was solid. High mortality may also be partly explained by the small body size (1.6–2.2 mm length compared with 10–20 mm and 5.8–7.8 mm for *C. rufilabris* and *H. convergens,* respectively), which enabled proportionately greater exposure to residues than was received by the larger insects.

In both years, carbaryl was the least toxic contact insecticide, yet was still highly lethal to *O. insidiosus* (Tables 5, 6). Exposure effects were also seen quickly. *Orius insidiosus* survival when exposed to carbaryl did not differ compared to water control exposure at 24 h of exposure in 2011, yet was 46%, 58%, and 64% lower at 48 ($F = 31.18$; df = 4, 35; $P < 0.0001$), 72 ($F = 31.80$; df = 4, 35; $P < 0.0001$), and 96 h of exposure ($F = 19.69$; df = 4, 35; $P < 0.0001$), respectively. In 2012, *O. insidiosus* survival was lower following carbaryl exposures when assessed at every time point. More specifically, exposure to carbaryl decreased *O. insidiosus* survival by 40% ($F = 17.51$; df = 4, 35; $P < 0.0001$), 72% ($F = 18.96$; df = 4, 35; $P < 0.0001$), 63% ($F = 11.78$; df = 4, 35; $P < 0.0001$), and 72% ($F = 12.21$; df = 4, 35; $P < 0.0001$) across time compared with water controls. This result is consistent with laboratory studies demonstrating carbaryl toxicity to *O. insidiosus* larvae and adults (Koppert Biological Systems 2005).

In both years, bifenthrin was generally the most toxic pesticide to *O. insidiosus*, decreasing survival by greater than 90% in 24 h (Tables 5, 6). Bifenthrin exposures have also yielded high mortality to *O. insidiosus* larva and adults in laboratory studies (Koppert Biological Systems 2005) and to adults on corn (Al-Deeb et al. 2001).

Both systemic insecticides were consistently toxic to *O. insidiosus* (Tables 5, 6). Dinotefuran decreased *O. insidiosus* populations by 84% ($F = 27.56$; df = 4, 35; $P < 0.0001$), 96% ($F = 31.18$; df = 4, 35; $P < 0.0001$), 97% ($F = 31.80$; df = 4, 35; $P < 0.0001$), and 98% ($F = 19.69$; df = 4, 35; $P < 0.0001$) in 2011 and by 57% ($F = 17.51$; df = 4, 35; $P < 0.0001$), 65% ($F = 18.96$; df = 4, 35; $P < 0.0001$), 57% ($F = 11.78$; df = 4, 35; $P < 0.0001$), and 78% ($F = 12.21$; df = 4, 35; $P < 0.0001$) in 2012 at 24, 48, 72, and 96 h of exposure, respectively. Imidacloprid decreased *O.*

insidiosus populations by 63% ($F = 27.56$; df $= 4, 35$; $P < 0.0001$), 87% ($F = 31.18$; df $= 4, 35$; $P < 0.0001$), 100% ($F = 31.80$; df $= 4, 35$; $P < 0.0001$), and 100% ($F = 19.69$; df $= 4, 35$; $P < 0.0001$) in 2011 and by 52% ($F = 17.51$; df $= 4, 35$; $P < 0.0001$), 63% ($F = 18.96$; df $= 4, 35$; $P < 0.0001$), 61% ($F = 11.78$; df $= 4, 35$; $P < 0.0001$), and 83% ($F = 12.21$; df $= 4, 35$; $P < 0.0001$) in 2012 at 42, 48, 72, and 96 h of exposure, respectively. In laboratory tests, imidacloprid caused *O. insidiosus* mortality as both a foliar spray and a drench (Funderburk et al. 2013, Koppert Biological Systems 2005). Imidacloprid applied to sorghum [*Sorghum bicolor* (L.) Moench] and corn seeds then grown into mature plants decreased *O. insidiosus* survival even on plants that did not contain prey (Al-Deeb et al 2001). This decrease in survival may be due to the omnivorous nature of *O. insidiosus* to feed not only on other insects, but also on plant material (Coll 1996).

In this study, both contact and systemic insecticides were toxic to natural enemies. However, this study was conducted in an unnatural confinement scenario in which insects were trapped with insecticide residue. In a dynamic nursery setting, systemic insecticides offer several potential advantages for conserving natural enemies and limiting pesticide exposure to the environment when compared with contact insecticides. For example, when systemic insecticides are applied as a drench, little to no residue may reach crop foliage for natural enemies to contact. Similarly, keeping production areas weed-free will limit the amount of foliar substrate available to intercept insecticide sprays and provide a source of exposure to residues. Systemic insecticides are also taken up by foliage and roots and translocated throughout a plant, thereby avoiding environmental breakdown and controlling foliage-feeding pests even in crop portions where spray does not penetrate, such as complex or dense canopies (Ripper et al. 1949), and also potentially reducing the number of insecticide applications needed to manage pests (Reynolds 1954).

Further studies are needed that expose natural enemies several days after various pesticides are applied to determine when natural enemy populations may be safely introduced, or reintroduced, within a managed nursery or landscape as part of an augmentative biological control program. Although in this study bifenthrin was compatible with *C. rufilabris* and dinotefuran with *H. convergens*, effects of insecticides vary among species (Koppert Biological Systems 2005; Szczepaniec et al. 2013a, 2013b). Bifenthrin should be tested with several species of lacewing, and dinotefuran with several species of lady beetle, to determine which natural enemies can be used concurrently with chemical control in an integrated pest management strategy.

Although exposure to systemic insecticide is perceived to be safer than contact insecticides for natural enemies, results of these research trials were mixed. Insecticides are essentially neurotoxins in which almost every chemical class can yield decreases in birth rate and mobility among different insect species, even when not ingested (Haynes 1988). In the studies reported here, at least one systemic insecticide was toxic to all three natural enemy species tested, yet results varied by year and with length of exposure. If using natural enemy–based biological control, the contact insecticide bifenthrin may be the best option to help control insect pests while conserving adult *C. rufilabris* populations. The systemic insecticide dinotefuran was safe for adult *H. convergens*. Therefore, if using *H. convergens* as a biological control, the best chemical option may be dinotefuran. *Orius* *insidiosus* survival was negatively affected by all tested insecticides; however, if chemical controls must be used, choosing carbaryl may help conserve some portion of the *O. insidiosus* population.

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References Cited

Al-Deeb, M.A., G.E. Wilde and K.Y. Zhu. 2001. Effect of insecticides used in corn, sorghum, and alfalfa on the predator *Orius insidiosus* (Hemiptera : Anthocoridae). J. Econ. Entomol. 94:1353–1360.

Bellows, T., Jr, J. Morse, L. Gaston and J. Bailey. 1988. The fate of two systemic insecticides and their impact on two phytophagous and a beneficial arthropod in a citrus agroecosystem. J. Econ. Entomol. 81:899–904.

Bethke, J.A. and R.A. Cloyd. 2009. Pesticide use in ornamental production: What are the benefits? Pest Manag. Sci. 65:345–350.

Cloyd, R. 2010. Systemic insecticides 101. Am. Nurseryman 210:18–21.

Colin, M.E., J.M. Bonmatin, I. Moineau, C. Gaimon, S. Brun and J.P. Vermandere. 2004. A method to quantify and analyze the foraging activity of honey bees: Relevance to the sublethal effects induced by systemic insecticides. Arch. Environ. Contam. Toxicol. 47: 387–395.

Coll, M. 1996. Feeding and ovipositing on plants by an omnivorous insect predator. Oecologia 105:214–220.

Falconer, K.E. 1998. Managing diffuse environmental contamination from agricultural pesticides: An economic perspective on issues and policy options, with particular reference to Europe. Agric. Ecosyst. Environ. 69:37–54.

Fulcher, A. and W.E. Klingeman. 2012. Effect of contact and systemic insecticides used for scale pests on beneficial insects. Southern Nurserymans Assoc. Res. Conf. 57:108–115.

Funderburk, J., M. Srivastava, C. Funderburk and S. McManus. 2013. Evaluation of imidacloprid and cyantraniliprole for suitability in conservation biological control program for *Orius insidiosus* (Hemiptera: Anthocoridae) in field pepper. Fla. Entomol. 96:229–231.

Galvan, T.L., R.L. Koch and W.D. Hutchison. 2005. Toxicity of commonly used insecticides in sweet corn and soybean to multicolored Asian lady beetle (Coleoptera : Coccinellidae). J. Econ. Entomol. 98:780–789.

Gupta, G. and V.A. Krischik. 2007. Professional and consumer insecticides for management of adult Japanese beetle on hybrid tea rose. J. Econ. Entomol. 100:830–837.

Hamedi, N., S. Moharramipour and M. Barzegar. 2013. Temperature-dependent chemical components accumulation in *Hippodamia variegata* (Coleoptera: Coccinellidae) during overwintering. Environ. Entomol. 42:375–380.

Haynes, K.F. 1988. Sublethal effects of neurotoxic insecticides of insect behavior. Annu. Rev. Entomol. 33:149–168.

Horn, D.J. and R.F. Sheppard. 1979. Sex-ratio, pupal parasitism, and predation in 2 declining populations of the bagworm, *Thyridopteryx ephemeraeformis* (Haworth) (Lepidoptera: Psychidae). Ecol. Entomol. 4:259–265.

IR-4 Project. **2014.** The IR-4 Ornamental Horticulture Program Database. 29 March 2014. (http://ir4.rutgers.edu/Ornamental/Ornamentals.cfm).

Jeppson, L.R. 1953. Systemic insecticides—Entomological aspects of systemic insecticides. J. Agric. Food Chem. 1:830–832.

Kher, S.V., J. De Jonge, M.T.A. Wentholt, R. Deliza, J.C. de Andrade, H.J. Cnossen, N.B.L. Luijckx and L.J. Frewer. 2013. Consumer perceptions of risks of chemical and microbiological contaminants associated with food chains: A cross-national study. Int. J. Consumer Stud. 37:73–83.

Klingeman, W.E., S.K. Braman and G.D. Buntin. 2000. Evaluating grower, landscape manager, and consumer perceptions of azalea lace bug (Heteroptera: Tingidae) feeding injury. J. Econ. Entomol. 93:141–48.

Koppert Biological Systems. 2005. Side effects database. 28 January 2015 (http://side-effects.koppert.nl) Koppert Biological Systems, Berkel en Rodenrijs, The Netherlands.

Lucas, E., S. Giroux, S. Demougeot, R.M. Duchesne and D. Coderre. 2004. Compatibility of a natural enemy, *Coleomegilla maculata* lengi (Col., Coccinellidae) and four insecticides used against the Colorado potato beetle (Col., Chrysomelidae). J. Appl. Entomol. 128: 233–239.

Ma, D.L., G. Gordh and M.P. Zalucki. 2000. Toxicity of biorational insecticides to *Helicoverpa* spp. (Lepidoptera: Noctuidae) and predators in cotton field. Int. J. Pest Manag. 46:237–240.

Mitsui Chemicals America, Inc. 2013. Dinotefuran. 16 April 2013. (http://www.mitsuichemicals.com).

Mizell, R.F. and M.C. Sconyers. 1992. Toxicity of imidacloprid to selected arthropod predators in the laboratory. Fla. Entomol. 75:277–280.

Montella, I.R., R. Schama and D. Valle. 2012. The classification of esterases: An important gene family involved in insecticide resistance—A review. Mem. Inst. Oswaldo Cruz 107: 437–449.

Raupp, M.J., J.A. Davidson, C.S. Koehler, C.S. Sadof and K. Reichelderfer. 1989. Economic and aesthetic injury levels and thresholds for insect pests of ornamental plants. Fla. Entomol. 72:403–407.

Reynolds, H. 1954. Entomological aspects of systemic pesticides. Agric. Chem. 1(13): 830–832.

Ripper, W.E., R.M. Greenslade and L.A. Lickerish. 1949. Combined chemical and biological control of insects by means of a systemic insecticide. Nature 163:787–789.

Rudinsky, J. 1959. Systemics in the control of forest insects. J. For. 57:284–286.

Schuster, D.J. and P.A. Stansly. 2000. Response of two lacewing species to biorational and broad-spectrum insecticides. Phytoparasitica 28:297–304.

Sclar, D.C., D. Gerace and W.S. Cranshaw. 1998. Observations of population increases and injury by spider mites (Acari: Tetranychidae) on ornamental plants treated with imidacloprid. J. Econ. Entomol. 91:250–255.

Stapel, J., A. Cortesero and W. Lewis. 2000. Disruptive sublethal effects of insecticides on biological control: Altered foraging ability and life span of a parasitoid after feeding on extrafloral nectar of cotton treated with systemic insecticides. Biol. Control 17:243–249.

Studebaker, G.E. and T.J. Kring. 2003. Effects of insecticides on *Orius insidiosus* (Hemiptera: Anthocoridae), measured by field, greenhouse and petri dish bioassays. Fla. Entomol. 86:178–185.

Szczepaniec, A., S.F. Creary, K.L. Laskowski, J.P. Nyrop and M.J. Raupp. 2011. Neonicotinoid insecticide imidacloprid causes outbreaks of spider mites on elm trees in urban landscapes. PLoS One 6:e20018.

Szczepaniec, A. and M.J. Raupp. 2013. Direct and indirect effects of imidacloprid on fecundity and abundance of *Eurytetranychus buxi* (Acari: Tetranychidae) on boxwoods. Exp. Appl. Acarol. 59:307–318.

Szczepaniec, A., M.J. Raupp, R.D. Parker, D. Kerns and M.D. Eubanks. 2013a. Neonicotinoid insecticides alter induced defenses and increase susceptibility to spider mites in distantly related crop plants. PLoS One 8:e62620.

Szczepaniec, A., B.B. Raupp and M.J. Raupp. 2013b. Effects of dinotefuran and imidacloprid on target and non-target arthropods on American elm. Arboric. Urban For. 39:231–235.

Toscano, N.C. and F.J. Byrne. 2005. Laboratory and field evaluations of neonicotinoid insecticides against the glassywinged sharpshooter. Pp. 380–383. *In* M.A. Tariq, P. Blincoe, M. Mochel, S. Oswalt and T. Esser (eds.), Pierce's Disease Research Symposium, San Diego, CA. Proceedings compiled by: M. Athar Tariq, Peggy Blincoe, Melinda Mochel, Stacie Oswalt, and Thomas Esser.

Tripp, R. and W. van der Heide. 1996. The erosion of crop genetic diversity: Challenges, strategies and uncertainties. Natural Resource Perspectives. Overseas Development Institute, London, U.K.

Wakita, T., N. Yasui, E. Yamada and D. Kishi. 2005. Development of a novel insecticide, dinotefuran. J. Pestic. Sci. 30:122–123.

Youn, Y.N., M.J Seo, J.G Shin, C. Jang and Y.M Yu. 2003. Toxicity of greenhouse pesticides to multicolored Asian lady beetles, *Harmonia axyridis* (Coleoptera : Coccinellidae). Biol. Control 28:164–170.