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EFFICACY OF SOIL APPLIED NEONICOTINOID INSECTICIDES AGAINST THE AZALEA LACE BUG, *STEPHANITIS PYRIOIDES*, IN THE LANDSCAPE

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ABSTRACT

Azalea lace bugs (Heteroptera: Tingidae) are common pests of azaleas in the landscape and in plant production. Adults and nymphs feed on foliage causing stippling damage, which persists for multiple seasons. This study was conducted to determine the speed of translocation and residual longevity of various soil-applied neonicotinoid insecticides for control of azalea lace bugs in the landscape. Mass plantings of azaleas were treated with different formulations and application rates of clothianidin, dinotefuran, imidacloprid, and thiamethoxam. Treatments were evaluated at intervals of 3, 7, 14, 30 d, and 1 yr using a laboratory assay with excised shoots and field-collected adult lace bugs. A sample of field populations was taken 2 mo after the initial treatment. Plant health was determined by rating the severity of leaf injury and percent of damaged leaves per shoot. Dinotefuran and thiamethoxam provided the best control after 3 and 7 d in lab assays. A greater application rate improved efficacy of granular dinotefuran and thiamethoxam formulations in the 3-14 d evaluations. After 2 mo, azalea lace bug populations, primarily composed of nymphs, were lower than the controls. A laboratory choice test indicated that adult lace bugs do not avoid treated plants as has been shown for other sucking pests. After 12 mo, survival of lace bugs across all treatments averaged 61% and at least 1 product containing dinotefuran, thiamethoxam, and imidacloprid was significantly different from untreated controls. Plant appearance was also improved relative to untreated controls with fewer damaged leaves per plant on all treated plants after 1 yr.

Key Words: imidacloprid, thiamethoxam, dinotefuran, clothianidin

RESUMEN

Las chinches de encaje de azalea (Heteroptera: Tingidae) son plagas comunes de azaleas en el campo y en los lugares comerciales donde producen la planta. Los adultos y ninfas se alimentan en el follaje causando un daño punteado sobre las hojas, que persiste durante varias temporadas. Este estudio se realizó para determinar la velocidad de desplazamiento y la longevidad residual de diversos insecticidas neonicotinoides aplicados al suelo para el control de chinches de encaje de azalea en el campo. Azaleas cultivadas en masa fueron tratadas con diferentes formulaciones y dosis de aplicación de clotianidina, dinotefuran, imidacloprid y tiametoxam. Los tratamientos fueron evaluados en intervalos de 3, 7, 14, 30 dias, y de un año por medio de un ensayo de laboratorio con brotes extraídos y por adultos de las chinches de encaje de azalea recogidos en el campo. Una muestra de las poblaciones de campo fue tomada dos meses después del tratamiento inicial. La salud de las plantas fue determinada por la calificación de la gravedad de las lesiones de la hoja y porcentaje de hojas dañadas por retoño. Dinotefuran y tiametoxam proporcionó el mejor control a los 3 y 7 días en los ensayos de laboratorio. Una mayor tasa de aplicación mejoró la eficacia de formulaciones granulares de dinotefuran y de tiametoxam en la evaluación hecha a los 3-14 dias. Después de 2 meses, la supervivencia de las poblaciones de chinche de encaje de azalea, compuestas principalmente de ninfas, era más bajo que en el control. Un examen de opciónes hecho en el laboratorio indicó que los insectos adultos de chinches de encaje no evitan las plantas tratadas como ha sido demostrado por otras plagas chupadoras. Después de 12 meses, el promedio de la supervivencia de la chinche de encaje en todos los tratamientos fue del 61% y por lo menos un producto que contenga dinotefuran, tiametoxam e imidacloprid fue significativamente diferente de los controles no tratados. La apariencia de la planta también fue mejorado en relación con los controles no tratados, con menos hojas dañadas por planta en todas las plantas tratadas después de un año.

The azalea lace bug (ALB), *Stephanitis pyrioides* (Scott) (Heteroptera: Tingidae), is one of the most serious pests of azaleas (*Rhodendron* × spp.) in landscapes and production nurseries (Klingeman et al. 2000; Buss & Turner 2006). ALB develop through 5 nymphal instars in 22 d at 30°C (Braman et al. 1992) and all motile life stages feed on the host plants (Buntin et al. 1996). Adults and nymphs are found on the undersides of leaves where they feed through the stomates on the contents of upper palisade parenchyma cells which results in stippling damage as well as reduced leaf photosynthesis (Buntin et al. 1996). It is recommended to treat landscape azaleas when 15% or more of the foliage is damaged (Buss & Turner 2006). However, populations of ALB causing 14% canopy damaged for 20 wk had no significant affect on whole plant leaf and stem dry mass, and flower number (Klingeman et al. 2001). When surveyed, half of consumers and green-industry professionals would treat azaleas when >43% of foliage in the canopy had detectable damage (2% leaf injury) (Klingeman et al. 2000).

Systemic insecticides, specifically those in the neonicotinoid class, are widely used to control landscape pests including various lace bug species. Neonicotinoid insecticides currently labeled for use on ornamentals (e.g., thiamethoxam, dinotefuran, clothianidin, acetamiprid, and imidacloprid) can be applied to the root zone, except for acetamiprid. Soil-applied neonicotinoids vary in uptake, and speed and residual activity for each active ingredient (Byrne et al. 2007). Imidacloprid, for example, may have a slower uptake but typically has a longer post-treatment efficacy than other compounds (Sclar & Cranshaw 1996). A single application of imidacloprid provided >2 yr of residual control of hawthorn lace bug, *Corythuca cydoniae* Fitch, in containerized cotoneaster plants (Szczepaniec & Raupp 2007). Similarly, imidacloprid applied to field-grown hawthorn trees significantly reduced leaf damage and abundance of hawthorn lace bugs for 6 mo after treatment (Gill et al. 1999). Certain products containing imidacloprid claim to provide 12 mo of residual control of pests. However, few published evaluations have compared the initial control and the residual efficacy of neonicotinoids on pests in urban landscapes.

Neonicotinoid insecticides may also influence feeding and behaviors of herbivorous insects on treated plants. Imidacloprid applied systemically has antifeedant effects on the whitefly *Bemisia tabaci* Gennadius (Naeun et al. 1998) and the aphid *Myzus persicae* (Sulzer) (Naeun 1995). Japanese beetles that consume foliage from imidacloprid-treated plants are slower to turn over (i.e., right themselves) when placed on their backs (Gupta & Krischik 2007). It is possible, therefore, that the behavior of insect herbivores, not just mortality, may contribute to reductions in pest populations on treated plants.

Many plantings of azaleas on campus at Auburn University have severe damage from ALB. In 2009, the head of grounds maintenance approached the senior author about control options for ALB on campus. This study was in response to this request and conducted 1) to determine how rapidly soil-applications of dinotefuran, imidacloprid, thiamethoxam, and clothianidin become effective against ALB as influenced by application rate, 2) to determine the duration of residual efficacy of these insecticides against ALB through laboratory bioassays and sampling, 3) to determine if ALB avoid plants treated with neonicotinoid insecticides, and 4) to determine the impact of these applications on plant aesthetics after treatment. This study will provide data useful to landscape managers who must make an informed decision regarding ALB control.

Materials and Methods

Site and Insecticide Application

Mass plantings of azaleas (*Rhododendron* × 'George Tabor') on the Auburn University campus, established ≥2 yr at the time of the application, were used. Plants were ≥2 m apart on center and the soil was covered with ground bark mulch. Soil on sites was either sandy loam or clay with pH ranging from 6.1-7.0. Individual plant heights were measured and recorded to calculate application rates (Table 1), the amount of insecticide in solution, or the amount of post-treatment water applied to each plant.

Four neonicotinoid active ingredients, clothianidin, dinotefuran, imidacloprid, and thiamethoxam that can be applied to soil were used (Table 1). Treatments were applied on 6 VII 2009 when plants were not in bloom. The mulch under each plant was raked away approximately 30-45 cm from the base of each plant so that the treatments were applied to the soil where plant roots were exposed. Granular applications were preweighed and applied by gloved hand. CoreTect™ tablets were placed into a hole about 10 cm from the base of each plant, 6-10 cm deep, using a soil probe. The soil probe removed a plug of soil into which the tablet was placed then the soil plug was used to cover the treatment hole. Each tablet was installed about 10-15 cm apart around the base of each plant. All other applications were prepared on-site and applied in water at the rate of 1.5 L per m of shrub height. Untreated control plants and plants treated with granular products or CoreTect™ tablets also received water at 1.5 L per m of shrub height as previously described. Following application and\or watering, the mulch was replaced. There were 8 replicates for each treatment. Rain gauges were placed on each site at the time of application and checked daily for rain for 1 month after application.

Evaluation of Treatments

Pre-treatment assessments of lace bugs populations and plant injury were conducted in Jun 2009 by harvesting 4 terminal shoots from each plant from the cardinal directions on each plant. Shoots, about 10-15 cm long with 10 ± 0.2 leaves each, were placed into labeled bags then into a

TABLE 1. SURVIVAL OF ADULT AZALEA LACE BUGS CONFINED OVERNIGHT ON CUTTINGS FROM SYSTEMICALLY-TREATED AZALEAS IN A LABORATORY NO-CHOICE ASSAY.

Treatment\ Formulation	Application rates (amt. product/30.5 cm plant height)	Mean (±SEM) Percent Survival at				
		3 DAT	7 DAT	14 DAT	30 DAT	12 *MAT
UTC	NA	78.7 ± 4.5 a	70 ± 9.5 a	77.1 ± 5.4 a	65.6 ± 12.3 bc	85 ± 5 a
Safari® 20SG[a, d]	1.5 g	23.9 ± 7.6 de	36.1 ± 6.6 cd	32.7 ± 6.3 cd	55.2 ± 8.2 defg	71.3 ± 11.4 bcd
	3 g	22.2 ± 7.3 e	38.2 ± 8.2 cd	24.3 ± 5.8 d	35.5 ± 4.6 cdef	59.8 ± 8 abc
Safari® 2G[a, e]	47 g	38.4 ± 5.9 cd	33.8 ± 8.9 d	30.4 ± 5 cd	32.8 ± 4.4 efg	58.8 ± 8 bcd
	62 g	21.4 ± 7.2 e	37.7 ± 8.9 bcd	18.9 ± 3.1 c	37.7 ± 8.1 defg	49.1 ± 11.4 cd
Arena® 50WDG[a, f]	1.2 g	48.5 ± 7.3 bc	35.1 ± 9.7 cd	29.4 ± 4.8 cd	54.4 ± 5.1 cdef	80 ± 6.3 ab
Merit® 2F[b, g]	3 ml	62.4 ± 6.9 ab	73.6 ± 6.8 a	59.9 ± 7.5 b	64.6 ± 6.2 bc	64.6 ± 8.1 abcd
	6 ml	52.4 ± 8.6 bc	56.3 ± 6.8 abc	63.7 ± 2.1 ab	58.3 ± 12.5 bc	67.1 ± 8.2 abc
CoreTect™[b, h]	2 tablet	57.5 ± 10.5 bc	71.2 ± 8.9 a	62.6 ± 7.6 ab	93.6 ± 2.7 a	66.3 ± 7.1 abc
	3 tablet	56.5 ± 7.8 bc	63.3 ± 10.5 ab	64.1 ± 6.2 ab	78.7 ± 4.4 ab	56.3 ± 9.4 bcd
Meridian® 0.33G[c, i]	75 g	56.8 ± 4.5 bc	62.7 ± 6.5 ab	64.5 ± 6.2 ab	59.7 ± 12 bcd	79.4 ± 4.3 ab
	150 g	48 ± 4.6 bc	34.1 ± 7.5 cd	31 ± 8 cd	54.6 ± 9.6 bcde	57.1 ± 9.5 bcd
Meridian® 25WG[c, j]	1 g	37 ± 6.7 cde	43.4 ± 9.1 bcd	51.1 ± 11 bc	43.2 ± 3.7 cdefg	55 ± 9.8 cd
	2 g	45.9 ± 8.8 bc	22.9 ± 7.3 d	21.4 ± 6.4 d	30.6 ± 6.9 fg	50 ± 9.3 cd
	4 g	39.4 ± 7.1 cde	25 ± 5.7 d	33.2 ± 6.9 cd	24.7 ± 5.9 g	41.3 ± 12.7 d
ANOVA results		$F_{14,98} = 5.2, P < 0.001$	$F_{14,98} = 4.8, P < 0.001$	$F_{14,98} = 7.4, P < 0.001$	$F_{14,98} = 5.9, P < 0.001$	$F_{14,98} = 1.8, P = 0.05$
Precipitation[k]		5.1 cm	4.3 cm	0.25 cm	4.1 cm	

Means within a column followed by the same letter were not significantly different (LSD test, $P < 0.05$).
[a]Valent USA Corp., Walnut Creek, CA.
[b]Bayer Environmental Sciences, Research Triangle Park, NC.
[c]Syngenta Crop Protection, Inc., Greensboro, NC.
[d]20% dinotefuran.
[e]2% dinotefuran.
[f]50% clothianidin.
[g]21.4% imidacloprid or 0.9 kg active ingredient per 3.785 l.
[h]20% imidacloprid plus 12-9-4 fertilizer.
[i]0.33% thiamethoxam.
[j]25% thiamethoxam.
[k]Amount since previous reading. Measured on site using rain gauges.
*Mo after treatment.

cooler with ice packs for transport to the lab. In the lab, the number of ALB adults and nymphs per shoot was determined then the percent of damaged leaves per shoot was calculated as the number of leaves per shoot with visually detectable damage divided by the total number of leaves per shoot. In addition, injury was assessed visually using the modified tally threshold (0-100% ratings) for each leaf (Klingeman et al. 2000).

A laboratory assay was used to determine treatment efficacy. Four shoots from each plant were harvested as previously described. In the lab, the cut end of each cutting was placed through a hole in the lid of a 118 ml plastic cup. The cup was filled with water to keep cuttings turgid during the experiment. The cuttings were then placed in a 237 ml translucent drinking cup labeled with the site and plant number.

The insects for laboratory experiments were collected from untreated mass plantings of azaleas ('George Tabor') at other locations on campus by beat sampling infested bushes into a sweep net. In the lab, beat samples were dumped into trays and only active adult ALB were used in experiments. Ten, mixed sex ALB were placed onto the cuttings and a second drinking cup was inverted over the first cup. Cups were sealed together with parafilm then placed in a temperature controlled growth room at 28°C with a 14:10 (L:D) h photoperiod.

Insects were exposed to the treated cuttings for 24 h after which the cups were opened and ALB removed from the cup. Status (alive or dead) of each ALB in the cup was determined by the ability of the insects to move normally or right themselves when placed on their backs. Insects that were not observed actively moving on the cutting were placed on a sheet of paper for 3-5 minutes to determine status. Insects that could not move or not right themselves were classified as dead despite trivial twitching of antennae or legs. These methods were used to assess treatment efficacy (percent survival) at 3, 7, and 14 days after treatment, and 1 and 12 mo after treatment. Post-treatment plant injury assessments (percent of damaged leaves and percent injury rating per leaf) were conducted as previously described at 1, 2, and 12 mo after treatment. At 2 mo after treatment, shoot samples were collected to assess the in-field populations of ALB on treated plants. Four shoots per plant were collected and taken to the lab where all ALB nymphs and adults were counted.

For laboratory evaluations, data were analyzed within each post-treatment assessment using an ANOVA for each sample date. Before analysis, percentages, survival and injury measurements, were arcsin (square root) transformed before analysis to correct heterogeneity of variances (Analytical Software 2008). Means presented herein are actual means (±SEM). Total number of lace bugs at 2 mo after treatment were transformed [square root(x + 0.5)] before analysis with ANOVA followed by a Least Significant Difference (LSD; $P < 0.05$) for means separation (Analytical Software 2008). Plant injury ratings and percent of leaves damaged were analyzed with a repeated measures ANOVA followed by Least Significant Difference (LSD) test ($P < 0.05$).

Two-Choice Test

Behavioral responses of insects to treated plants may also contribute to population reductions on treated plants. Choice tests may provide insight into the behavioral responses of ALB to treated plants not evident in no-choice assays. The 4 previously-tested active ingredients and formulations; dinotefuran (Safari 20 SG applied at 1.5 g product per 30.5 cm of shrub height); clothianidin (Arena 50 WDG applied at 1.2 g product per 30.5 cm of shrub height); imidacloprid (Merit 2 F applied at 6 ml of product per 30.5 cm of shrub height); thiamethoxam (Meridian 25 WG applied at 2 g of product per 30.5 cm of shrub height) were evaluated. Azaleas ('George Tabor') in a mass planting on the Auburn University campus, established >2 yr and not previously treated in previous experiments, were measured and prepared for treatment as previously described. Products were prepared in water (1.5 liter per m of shrub height) and applied to the soil at the base of each plant on 1 IV 2010. Each treatment was replicated 4 times (4 separate plants) with 4 untreated plants used as controls.

On 6 V 2010, approximately 1 month after treatment (MAT), 2 cuttings were harvested from each of the treated plants. Cuttings were also harvested from an additional set of 4 control plants on each of the sites. In the lab, the cuttings were placed in cups as previously described. In this experiment, however, a mark was made on the cup to denote the location of the treated cuttings. The other 2 cuttings in each cup were from non-treated plants. The experimental control evaluated 4 cuttings from non-treated plants. Into each cup, 10 adult azalea lace bugs, collected from untreated azalea planting on campus as previously described, were placed on the plastic lid of the cup at the base of the cuttings. This avoided a possible bias of placing insects on a particular cutting. Lace bugs were exposed to the cuttings for 18-24 h in a growth room as before. The following day, the location and survival of the lace bugs were determined. The proportion of ALB on treated and untreated cuttings was compared by χ^2 analysis (Analytical Software 2008). Survival by treatment was analyzed using an analysis of variance followed by LSD test for means separation.

Results

Efficacy Against Azalea Lace Bug

At 3 DAT, survival of ALB on all treated plants, except with Merit 2F (3 ml rate), was significantly lower than the untreated control (Table 1). Also at 3 DAT, survival of ALB was lowest on plants treated with Safari 20SG treatments (<25%); while survival rates of ALB with Safari 2G (62 g rate), Meridian 25WG (1 and 4 g rates) were not significantly different from the best treatments (Safari 20 SG). At 7 DAT, the best treatment was Meridian 25WG at the 2 g application rate on which survival of ALB was 22.9%. Meridian 25WG (1 and 4 g rates), Meridian 0.33G (150 g rate), Arena, and all Safari treatments and rates were not significantly different from the best treatment. Merit 2F (both rates), CoreTect, and the low rate of Meridian 0.33G were not significantly different from the untreated control at 7 DAT. At 14 DAT, survival of ALB was 77% on untreated control and Merit 2F (6 ml rate), both application rates of Cortect, and the 75 g rate of Meridian 0.33 G were not significantly different from controls. The best treatment (survival 21%) was Meridian 25WG (2 g rate) and dinotefuran, clothianidin, and Meridian 25 WG (4 g rate) provided the same level of control (Table 1). After 30 d, the best treatment (survival 24.7%) was Meridian 25 WG (4g rate). Treatments comparable to this treatment were Meridian 25 WG (1 and 2g rate), Meridian 0.33 G, both rates of Safari 2G, and the low rate of Safari 20 SG. On untreated control cuttings, survival of ALB was 65%, which was not significantly different from imidacloprid products or Meridian 25 WG at the 1 g rate.

At 60 DAT, shoot samples, rather than lab bioassays, were used to assess treatments. The ALB population was primarily nymphs with few adults (Table 2). On average, control plants had 13.6 ALB, yet there was less than 1 ALB, on average, on all treated plants (Table 2). All treatments were significantly different from the untreated. After 1 year survival on shoots from control plants was 85% and the lowest survival was 41% on cuttings from plants treated with Meridian 25WG at the 4 g rate (Table 1). Eight treatments with 3 active ingredients were significantly different from the untreated control after 1 year. Of these, however, survival was ≤50% for Safari 2 G (62 g rate), Meridian 25WG (2 and 4 g rate) treatments. ALB in the other treatments significantly different from controls had an average survival of about 60%.

At all post-treatment samples, there were few differences in mortality or abundance of ALB (Tables 1 and 2) among application rates for the same formulation. These were mainly significant in early evaluations (3-14 DAT) but not thereafter. Specifically, the lower rates of Safari 2G (3 DAT) and Meridian 0.33 G (7 and 14 DAT) provided significantly greater survival of ALB than the higher rates of the same formulations.

Table 2. Number of azalea lace bugs on systemically-treated azaleas at 60 days after treatment.

Treatments/ Formulation	Application rates[a]	Mean (±SEM no. of ALB per sample[b])		
		Nymphs	Adults	Total
UTC	NA	13.4 ± 8.9 a	0.25 ± 0.2	13.6 ± 8.8 a
Safari 20SG	1.5 g	0.25 ± 0.2 b	0	0.25 ± 0.2 b
	3 g	0.38 ± 0.4 b	0.13 ± 0.1	0.5 ± 0.4 b
Safari 2 G	47 g	0.75 ± 0.5 b	0.13 ± 0.1	0.88 ± 0.6 b
	62 g	0.63 ± 0.4 b	0	0.63 ± 0.4 b
Arena 50WDG	1.2 g	0.88 ± 0.5 b	0	0.88 ± 0.5 b
Merit 2 F	3 ml	0.13 ± 0.1b	0.13 ± 0.1	0.25 ± 0.2 b
	6 ml	0.63 ± 0.5 b	0	0.63 ± 0.5 b
CoreTect	2 tablets	1.38 ± 0.8 b	0	1.38 ± 0.8 b
	3 tablets	2 ± 1.6 b	0.13 ± 0.1	2.13 ± 1.7 b
Meridian 0.33G	75 g	0.88 ± 0.7 b	0.5 ± 0.3	1.38 ± 0.9 b
	150 g	0.5 ± 0.3 b	0.25 ± 0.3	0.75 ± 0.4 b
Meridian 25WG	1 g	1.5 ± 1.4 b	0.38 ± 0.3	1.88 ± 1.6 b
	2 g	4.63 ± 4.2 b	0.5 ± 0.3	5.13 ± 4.4 b
	4 g	0.38 ± 0.4 b	0.75 ± 0.6	1.13 ± 0.7 b
ANOVA results		F = 1.9, P = 0.04	F = 1.3, P = 0.22	F = 2, P = 0.03

Means within a column with the same letter were not significantly different (LSD, $P < 0.05$).
[a]Amount of product per 30.5 cm of plant height.
[b]Four terminal shoots from each plants.
Cumulative precipitation (treatment to 60 DAT) measured on site with rain gauges was 22.9 cm.

Treatment Effects on Plant Quality

Plant assessments were taken before treatment (pre-treatment) and at 1, 2, and 12 MAT (Tables 3 and 4). The main effects of treatment were not significant for leaf injury or percent of damaged leaves per shoot (ANOVA for repeated measures). For leaf injury, time was significant ($P < 0.001$) but not the time × treatment interaction. Each evaluation period was significantly different from one another (LSD, $P < 0.05$) with leaf injury decreasing over time (Table 3). After 12 mo, average leaf injury ranged from 0-4.9%, compared to 12.2-19.5% in the pre-treatment sample.

Time ($P < 0.001$) and time× treatment interaction ($P = 0.028$) were significant for the percent of damaged leaves per shoot (ANOVA for repeated measures, Table 4). The 12 MAT evaluations were significantly lower than all earlier evaluations (LSD, $P < 0.05$). Numbers of damaged leaves per plant typically decreased from 0 to 2 MAT. After 12 mo, however, 35% of leaves, on average, were damaged on control plants. Percentage of damaged leaves on treated plants, however, was ≤ 9% with ten treatments having ≤1% of leaves per shoot with damage (Table 4). Safari 20SG, applied at 1.5 g, had significantly more damaged leaves than the higher rate of Safari 20SG. There were no other significant differences between rates of the other products.

Two-Choice Test

ALB adults did not avoid treated cuttings in the laboratory experiment (χ^2, $P > 0.1$). In fact, there was significant mortality of adult ALB despite the presence of untreated cuttings (Table 5). Most treatments had significantly greater mortality of ALB than the untreated controls ($F = 5.05$, $P = 0.013$, df = 4,12). In many instances, adult ALB were found dead on the treated cutting.

Discussion

This study was initiated to provide recommendations to ground managers on the use of soil-applied neonicotinoid insecticides for control of ALB in the landscape. Applications were made after plants had bloomed for 2 reasons. First, populations of ALB in central Alabama are more abun-

TABLE 3. LEAF INJURY ON SHOOTS HARVESTED FROM AZALEA PLANTS TREATED SYSTEMICALLY WITH VARIOUS NEONICOTINOID INSECTICIDES.

Treatments/ Formulation	Application rates[a]	Mean Percent (±SEM) Leaf Injury			
		Pre-trt	1 MAT[b]	2 MAT	12 MAT
UTC	NA	18.2 ± 4.4	16 ± 3.6	15 ± 3.6	0.7 ± 0.7
Safari 20SG	1.5 g	17.6 ± 4.5	14.7 ± 4.5	16.1 ± 4.3	2.5 ± 1.1
	3 g	16.6 ± 3.6	19.7 ± 4.4	16 ± 3.4	1.9 ± 1.8
Safari 2 G	47 g	19.5 ± 5.2	19.1 ± 5.2	16.9 ± 3.2	2.8 ± 1.9
	62 g	19.3 ± 3.9	14.8 ± 4.6	16.1 ± 4.3	4.9 ± 2.5
Arena 50WDG	1.2 g	15.7 ± 3.4	13.8 ± 3.5	11.2 ± 1.9	1.1 ± 0.7
Merit 2 F	3 ml	16.4 ± 4.3	17 ± 4.9	14.6 ± 5.1	2.3 ± 0.9
	6 ml	12.6 ± 3.6	11.6 ± 4.9	15.1 ± 3.6	0
CoreTect	2 tablets	15.8 ± 3.6	11.9 ± 3.1	18.1 ± 4.9	3.9 ± 2.3
	3 tablets	12.2 ± 3	14.3 ± 3.3	9.8 ± 1.4	3.2 ± 3.2
Meridian 0.33G	75 g	16.3 ± 3.7	16 ± 3.9	13.8 ± 1.4	0
	150 g	14.6 ± 3.2	16.7 ± 4.4	14.5 ± 2.3	0
Meridian 25WG	1 g	13.7 ± 3.8	14.3 ± 5	11.1 ± 2.9	0.5 ± 0.4
	2 g	17.4 ± 2.9	13.2 ± 2.5	13.8 ± 3.2	4.1 ± 2.8
	4 g	18.8 ± 3.9	20 ± 4.8	16.5 ± 2.9	1.7 ± 0.9

[a]Amount of product per 30.5 cm of plant height.
[b]Mo after treatment
ANOVA for repeated measures: no significant treatment effects ($F = 0.44$, $P = 0.96$, df = 14, 105), time was significant ($F = 185.9$, $P < 0.001$, df = 3, 315) but not the time treatment interaction ($F = 0.54$, $P = 0.99$, df = 42, 315). Each evaluation period was significantly different from one another (LSD, $P < 0.05$).

TABLE 4. PERCENT OF DAMAGED LEAVES ON TERMINAL SHOOTS OF AZALEAS 1, 2, AND 12 MONTHS AFTER TREATMENT WITH NEONICOTINOID INSECTICIDES.

Treatments/ Formulation	Application rates[a]	Mean (±SE) Percent of damaged leaves per shoot			
		Pre-trt	1 MAT[b]	2 MAT	12 MAT
UTC	NA	64 ± 10	55 ± 8	32 ± 6	35 ± 11 a
Safari 20SG	1.5 g	59 ± 10	37 ± 6	38 ± 3	0.7 ± 0.7 c
	3 g	65 ± 8	48 ± 5	44 ± 6	9 ± 6 b
Safari 2 G	47 g	62 ± 11	44 ± 8	38 ± 4	0.4 ± 0.4 c
	62 g	64 ± 8	47 ± 5	36 ± 7	0c
Arena 50WDG	1.2 g	63 ± 10	43 ± 8	31 ± 3	3 ± 2 bc
Merit 2 F	3 ml	64 ± 9	46 ± 6	31 ± 5	0c
	6 ml	56 ± 12	40 ± 7	36 ± 4	3.5 ± 3 bc
CoreTect	2 tablets	60 ± 12	41 ± 9	35 ± 4	1 ± 0.8 c
	3 tablets	62 ± 8	44 ± 7	29 ± 4	0c
Meridian 0.33G	75 g	57 ± 10	42 ± 8	35 ± 3	1.9 ± 1 c
	150 g	60 ± 8	46 ± 6	37 ± 2	0c
Meridian 25WG	1 g	54 ± 11	39 ± 8	29 ± 5	0.4 ± 0.4 c
	2 g	65 ± 8	43 ± 6	35 ± 5	0.2 ± 0.2 c
	4 g	62 ± 10	46 ± 7	40 ± 3	0.8 ± 0.8 c

[a]Amount of product per 30.5 cm high plant.
[b]Mo after treatment.
ANOVA for repeated measures: Treatment (F = 0.87, P = 0.59, df = 14, 105), Time (F = 462, P < 0.001, df = 3, 315) and time treatment interaction (F = 1.5, P = 0.028, df = 42, 315). The 12 MAT readings were significantly lower than all previous readings (LSD, P < 0.05). Means within a column followed by the same letter were not significantly different (unprotected LSD, P < 0.05).

TABLE 5. LABORATORY CHOICE TEST WITH AZALEA LACE BUG ADULTS EXPOSED TO TREATED AND UNTREATED CUTTINGS.

Treatment[a]	Number of ALB on:				
	Treated	Untreated	χ^2	P	Percent Mortality ± SEM
Control	11	15	2.1	0.55	42.7 ± 9.1 b
Safari 20SG	16	8	1.8	0.61	87.8 ± 5.9 a
Arena 50WDG	23	12	1.9	0.59	97.9 ± 2.1 a
Meridian 25WG	14	13	1.4	0.71	85 ± 15 a
Merit 2F	13	9	1.8	0.61	77.8 ± 4.4 ab

[a]See text for application rates.
Treatment effects on mortality (F = 5.05, P = 0.013, df = 4,12). Means within the column followed by the same letter are not significantly different (LSD test, P < 0.05).

dant after bloom drop and insects were required to evaluate treatment effects. Secondly, labels of several neonicotinoid products contain the statement, "Do not apply during bloom or when bees are present". Similar treatments applied before bloom (Feb-early Mar) are equally effective against ALB as those applied in Jul after bloom (unpublished data).

The literature regarding speed of uptake and residual efficacy of neonicotinoids is well established for trees (e.g., Sclar & Cranshaw 1996; Byrne et al. 2007; Ali & Caldwell 2010) and herbaceous crops (e.g., Sur and Stork 2003; Byrne et al. 2010). These examples primarily examine efficacy of imidacloprid alone or with 1 or 2 other neonicotinoids. Fewer studies, like the present study with ALB, have compared efficacy of multiple neonicotinoids under the same experimental conditions (Bryne et al. 2007; Ali & Caldwell 2010; Byrne et al. 2010). Furthermore, there are few examples of studies with pests of woody shrubs such as azalea. Cotoneaster (*Cotoneaster dammeri*), a woody shrub, treated once with imidacloprid, provided residual toxicity up to 800 d after treatment

(Szczepaniec & Raupp 2007). Roses, like azaleas, are another popular woody shrub in the landscape and another plant for which neonicotinoids are applied for control of pests. Mortality of Japanese beetles 1 MAT was low (9.1-30.1%) when fed foliage of roses treated with Merit 2F and tablet formulations similar to CoreTect (Gupta & Krischik 2007). This is similar to the results of laboratory assays with ALB and azalea foliage (Tables 1 and 5).

Three chemical properties: water solubility, octanol/water-partition coefficient (log P) and dissociation constant (pKa), determine the speed of uptake, movement through membranes, and the ultimate location of neonicotinoids and their metabolites in treated plants (Sur & Stork 2003; Tomizawa & Casida 2005).

Imidacloprid uptake is considered slower than dinotefuran, thiamethoxam (Bryne et al. 2007), and clothianidin (Ali & Caldwell 2010), which explains the obvious differences in efficacies of neonicotinoids that were evaluated early in the study. At 3 and 7 DAT, dinotefuran (Safari SG and 2G at the 62 g rate) and thiamethoxam (Meridian 25WG) were the best treatments and the efficacy of clothianidin was similar to these by 14 DAT (Table 1). A rate effect was also obvious at 3 and 7 DAT but primarily with the granular products (Table 1). Previous studies (e.g., Szczepaniec & Raupp 2007; Ali & Caldwell 2010) would predict better performance of imidacloprid at 30, 60, and possibly 12 MAT, however, the lowest survival in any imidacloprid treatment was 52.4%, which may be due to poorer water solubility. In fact, imidacloprid and clothianidin have the lowest water solubility (g/L) of the neonicotinoids in this study. Dinotefuran is >10 times more water soluble than thiamethoxam and >90 times more water soluble than imidacloprid and clothianidin (Tomizawa & Casida 2005). Dinotefuran is taken up quickly and not tightly bound to soil (log P = -0.64) versus imidcloprid, which is slower to uptake and can be bound to soils (log P = 0.57) (Sclar & Cranshaw 1996; Tomizawa & Casida 2005) particularly those soils with more organic matter (Byrne et al. 2010). The mulch and leaf litter were removed before application but soil test results show that most of the 8 plantings used in 2009 had clay soils with more organic matter (CEC >9 $cmol_c kg^{-1}$). Plantings treated in 2010 for the choice test had an average CEC = 6.2 $cmol_c kg^{-1}$ (range 4.2-8.7 $cmol_c kg^{-1}$). The higher organic matter content may explain why all imidacloprid formulations performed poorly in 2009, and why ALB survival was lower (23%) in the 2010 choice test (Table 5).

Shoot samples from plants 60 DAT revealed that field populations of ALB were lower than those on control plants (Table 2). The choice test (Table 5) was conducted to explain the difference in imidacloprid efficacy between field and laboratory populations of ALB. It failed to support a behavioral explanation for the better efficacy that we observed under field conditions (e.g., Nauen 1995; Nauen et al. 1998). Populations during the field sample were biased toward nymphs. This may have been a normal age distribution in the population or perhaps the treatments on each site may also act selectively on adult ALB. Since adult ALB do not avoid treated plants and have greater feeding rates (Buntin et al. 1996), they may ingest more neonicotinoid, and be more effectively controlled (Table 5). Similar life stage sensitivity among lace bugs has been reported. Hawthorn lace bugs nymphs, for example, are more sensitive to imidacloprid (Szczepaniec & Raupp 2007). The present study did not evaluate life stage sensitivity, however, such studies are planned with accompanying residue analyses in azalea foliage at post-treatment intervals for each of the neonicotinoids.

ALB feeding results in stippling damage that can persist on plants for multiple seasons on evergreen azalea taxa, but likely has minimal impact on flowering and plant growth (Buntin et al. 1996; Klingeman et al. 2001). Reduced leaf injury, therefore, is one of the primary reasons to control ALB. Treatments did not affect the amount of injury per leaf (Table 3). The overall canopy of treated plants, however, had significantly fewer damaged leaves (Table 4) at 1 year after treatment. Azaleas produce new growth in the spring and this new growth was likely protected from damage by ALB on treated plants. Cotoneaster plants treated with imidacloprid were free from damage from hawthorn lace bugs well into the second growing season after the application (Szczepaniec & Raupp 2007). Unfortunately, aesthetics rather than sampling often provokes treatment of ornamentals. In this case, application of all the neonicotinoids tested would result in an improved plant appearance past the season of the initial application.

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