Evaluation of Systemic Insecticides for Potato Leafhopper Control in Field-Grown Red Maple[1]

J.B. Oliver[2], D.C. Fare[3], N. Youssef[4], M.A. Halcomb[5], M.E. Reding[6], and C.M. Ranger[7]
Tennessee State University, School of Agriculture and Consumer Sciences
Otis L. Floyd Nursery Research Center, McMinnville, TN 37110

Abstract

Systemic insecticides and application methods were evaluated in two trials that began in 2005 and 2006 for control of potato leafhopper (*Empoasca fabae* [Harris]) on four red maple (*Acer rubrum* L.) cultivars and rated annually through 2007. Treatments evaluated in this study included surface drenches of imidacloprid plus cyfluthrin (Discus) or imidacloprid plus bifenthrin (Allectus SC), clothianidin (Arena 50WDG), dinotefuran (Safari 20SG), or thiamethoxam (Flagship 25WG); soil inserted treatments of imidacloprid formulated as an experimental tablet or as an experimental gel; or a plant root dip of Discus + Terra-Sorb hydrogel. In the 2005 trial, a one-time drench of Discus or two imidacloprid tablets significantly reduced leafhopper damage to red maple for a 3-year period. In the 2006 trial, a one-time drench of Allectus, Discus, Arena, Flagship, and Safari significantly reduced leafhopper damage for 2 years. In most cases, the Discus drench and root dip treatments were initially more effective than the imidacloprid tablets or the gel treatment. However, in general, the efficacy of imidacloprid tablet or gel treatments increased in subsequent years. Two imidacloprid tablets were more effective than one. Likewise, higher imidacloprid drench rates were more effective than lower rates. Most insecticide treatments significantly increased red maple trunk diameter, although this effect varied with cultivar and time. Allectus and Discus drench treatments significantly increased the branch and internode length of 'Franksred' maple in the 2005 trial. Results of this study indicate long-term potato leafhopper control with systemic insecticides and enhanced growth in red maple.

Index words: leafhopper, *Empoasca fabae*, *Acer rubrum*, neonicotinoid, insecticide, tree growth.

Species used in this study: red maple (*Acer rubrum* L.) cultivars 'Autumn Flame', 'Fairview Flame', 'Franksred', and 'October Glory'.

Chemicals used in this study: experimental imidacloprid tablet formulation (currently marketed as CoreTect); experimental imidacloprid gel formulation; imidacloprid + cyfluthrin (Discus); imidacloprid + bifenthrin (Allectus SC); clothianidin (Arena); dinotefuran (Safari); thiamethoxam (Flagship); potassium polyacrylamide acrylate copolymer (Terra-Sorb Fine Hydrogel).

Significance to the Nursery Industry

Red maples are one of the most widely grown landscape trees. A few red maple cultivars have some resistance to potato leafhopper, but most cultivars are susceptible. Typical potato leafhopper injury on red maple includes distorted leaf tissue and reduced shoot growth. This research identified systemic insecticides that controlled leafhopper damage up to three years after application and, depending on cultivar, resulted in increased shoot elongation and trunk diameter. Several treatment methods and insecticide formulations such as drenches, tablets and soil-applied gels were evaluated. These methods eliminate drift associated with conventional spray methods. Although systemic neonicotinoids have a higher initial application cost than contact sprays such as pyrethroids, they offer several advantages: fewer applications, control of leafhopper injury for longer periods, prevention of other pests like flatheaded borers, better plant aesthetics, and enhanced plant growth.

Introduction

Red maples (*Acer rubrum* L.) are popular ornamental trees widely grown by the U.S. nursery industry. Numerous cultivars have been developed for superior growth, fall color, insect resistance, and other plant qualities (4, 7, 16). Unfortunately, many red maple cultivars are susceptible to damage caused by the potato leafhopper, *Empoasca fabae* (Harris) (Hemiptera: Cicadellidae) (4, 5, 13). Potato leafhopper feeding disrupts vascular fibers, damages phloem elements, and interrupts movement of nutrients in phloem (3, 14). Symptoms of hopperburn include stunting and deformation of leaves, chlorosis of leaves and necrotic margins, cupping of leaf tissue, stunting of internodes (witches' broom), and death of apical tissues (4, 13). Leafhopper damage can prolong maple production time, decrease overall plant growth, reduce the aesthetic quality, increase pruning requirements, and lower the overall market value of red maples (6, 13, 14).

Potato leafhopper's emigration, dependent on warm south winds from the Gulf Coast states, may arrive in Tennessee as early as April (13, 14). In Kentucky, peak potato leafhopper activity varied by as much as a month between years (13). In Maryland, potato leafhopper arrived in early April; populations peaked in June, and then declined the remainder of the

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[2]Research Associate Professor of Entomology, Tennessee State University. joliver@tnstate.edu

[3]Research Horticulturist, USDA-ARS, U.S. National Arboretum, Otis L. Floyd Nursery Research Center, 472 Cadillac Lane, McMinnville, TN 37110. Donna.Fare@ars.usda.gov

[4]Research Associate of Entomology, Tennessee State University. nyoussef@tnstate.edu

[5]Associate Area Specialist — Nursery Production, University of Tennessee Extension, 201 Locust Street, McMinnville, TN 37110. mhalcomb@utk.edu

[6]Research Entomologist, USDA-ARS, Horticultural Insects Research Laboratory (HIRL), 1680 Madison Avenue, Wooster, OH 44691. Mike.Reding@ars.usda.gov

[7]Research Entomologist, USDA-ARS HIRL. Christopher.Ranger@ars.usda.gov

summer (6). Populations often decline in mid-July, which appears to coincide with decreasing availability of new apical leaf growth (13). Although potato leafhopper activity can be monitored with yellow sticky cards, most nursery producers do not monitor for leafhoppers, and the uncertainty regarding their presence can result in as many as 10 cover sprays per growing season (13).

A number of insecticides have been used to control potato leafhoppers in nursery trees, like pyrethroids [cyfluthrin (Decalthlon, Tempo), lambda-cyhalothrin (Scimitar), bifenthrin (Onyx, Talstar), and permethrin (Ambush, Astro, Perm-Up, Pounce)], carbamates [carbaryl (Sevin)], and organophosphates [acephate (Orthene), disulfoton (Di-Syston), dimethoate (Cygon), and diazinon], and neonicotinoids [imidacloprid (Marathon) and thiamethoxam (Flagship)] (13, 14). Contact insecticides have the disadvantage of requiring frequent applications to maintain leafhopper suppression. One study with snap beans reported thiamethoxam controlled potato leafhopper longer than imidacloprid (10). Imidacloprid, clothianidin, and thiamethoxam have demonstrated potential for potato leafhopper control when used as seed treatments of edible beans (1). Imidacloprid foliar sprays in apple orchards effectively controlled potato leafhopper, as well as other leafhopper species, at rates from 28 to 112 g imidacloprid per hectare (15). Few studies have examined systemic insecticides for long-term control of potato leafhopper damage in field-grown nursery trees. The objectives of this study were to 1) identify effective insecticides for potato leafhopper control on several red maple cultivars, 2) determine the length of control provided by systemic insecticides, and 3) to determine differences in tree growth.

Materials and Methods

History. A field production nursery transplanting large trunk diameter [> 2.5 cm (1 in)] tree liners in middle Tennessee was selected for an evaluation of systemic insecticides against flatheaded borers. The liners had originated from a West Coast nursery and were transplanted in a nursery block with in-row spacing of 1.5 and 3.0 m (5 and 10 ft) between rows. It was observed during the study that some of the insecticides tested for borer management also reduced potato leafhopper damage. This report addresses our field assessments of leafhopper damage.

2005 Trial. In May 2005, four insecticide treatments and an untreated control were assigned in a randomized complete block design in two fields of red maple cultivars, 'Autumn Flame' and 'Franksred', that had been planted in March 2005. Within each cultivar, treatments were randomly assigned to consecutive trees, which constituted an experimental block. Each block was replicated 44 and 47 times for 'Franksred' and 'Autumn Flame', respectively. The randomized complete block design was chosen due to the large field size and to ensure that all treatments were present in each area of the field. The soil type in the field planted with 'Franksred' was a silt loam, and the 'Autumn Flame' field was a clay loam soil.

To determine insecticide rates, trunk diameters on a subsample of nine replications were measured with a digital caliper (Mitutoyo Corp., Kanagawa, Japan) at 15 cm (6 in) above the soil line May 5, 2005. Trunks averaged 22.8 and 20.1 mm (0.9 and 0.8 in) for 'Franksred' and 'Autumn Flame', respectively. Discus drench rates were based on the insecticide label, which recommends 22 to 44 ml·25 mm^{-1} (0.75 to 1.5 fl oz·in^{-1}) of trunk diameter at breast height (DBH) [137 cm (4.5 ft) above the soil surface]. The DBH measurement is normally used for mature landscape trees and not smaller nursery trees. In this study, Discus and other insecticide rates were based on the trunk diameter at the height nursery trees are typically measured [15 cm (6 in) above the soil line].

All treatments were applied May 24, 2005, using two application methods (Table 1). Three treatments were applied as drenches including Allectus SC (Allectus) (imidacloprid + bifenthrin) [5.6 ml (0.2 fl oz) product·$tree^{-1}$) and Discus (imidacloprid + cyfluthrin) [22 or 44 ml (0.7 or 1.5 fl oz) product·$tree^{-1}$]. A 250-ml (8.5 fl oz) solution was poured into a 3.8 liter (1 gal) sprinkle can that was used to drench the lower trunk and the soil at the base of the tree [15 cm (5.9 in) circle at tree base]. Small divots were made at the base of each tree when necessary to keep the solution from flowing away from the root zone. In addition to drench treatments, an experimental imidacloprid tablet formulation (imidacloprid tablet) [0.5 g (0.02 oz) ai·$tablet^{-1}$] was tested. Two imidacloprid tablets were inserted 7.6 cm (3 in) below the soil surface

Table 1. Leafhopper damage on *Acer rubrum* 'Autumn Flame' and 'Franksred' treated on May 24, 2005, with imidacloprid-based insecticides and rated August 2005, 2006, and 2007.

				Mean leafhopper damage rating[y]					
				'Autumn Flame'			'Franksred'		
Treatment[z]	Treatment method	Product/ tree	Active ingredient/ tree	2005	2006	2007	2005	2006	2007
Allectus	Drench	5.6 ml	0.30 g	1.6a[x]	4.9b	3.0a	2.4b	7.1a	9.6a
Discus	Drench	22 ml	0.69 g	1.8a	2.0cd	1.6b	1.9c	5.6b	9.3ab
Discus	Drench	44 ml	1.38 g	1.6a	1.4d	0.8c	1.6d	3.4d	7.4c
Imidacloprid tablet	Soil insertion	2 tablets	1.00 g	2.2a	2.6c	0.5c	2.7b	4.3c	5.3d
Untreated	—	—	—	2.0a	9.0a	2.7a	3.6a	6.7a	9.1b
LSD				0.08	0.11	0.07	0.04	0.06	0.10

[z]Allectus and Discus are combination products with imidacloprid as the systemic active ingredient. The imidacloprid tablets were experimental, but are now marketed as CoreTect.

[y]Leafhopper ratings were performed August 23–26, 2005; August 29, 2006; and August 15, 2007. Leafhopper damage was rated on a visual scale of 0–10 with 0 = no damage and 10 = 100% damage. Only 19 replicates (out of 47) of 'Autumn Flame' were evaluated in 2005. In other years, all 'Autumn Flame' replicates (n = 47) and all 'Franksred' replicates (n = 44).

[x]Means within a column followed by different letters are significantly different (α = 0.05).

Table 2. **Height, trunk diameter and branch growth on *Acer rubrum* 'Autumn Flame' and 'Franksred' treated on May 24, 2005, with imidacloprid-based insecticides.**

Treatment[z]	Treatment method	Product/ tree	Active ingredient/ tree	Trunk diameter increase, mm				Height increase, cm				Mean length, cm	
				2005[yx]	2006	2007	Total	2005[y]	2006	2007	Total	Branch[w]	Internodes[v]
				'Autumn Flame'									
Allectus	Drench	5.6 ml	0.30 g	0.5ab[u]	10.2b	3.4b	13.7c	1.6a	33.1c	20.4ab	53.0b	—	—
Discus	Drench	22 ml	0.69 g	0.5ab	11.1ab	4.0ab	15.6ab	1.7a	37.6bc	17.4b	51.9b	—	—
Discus	Drench	44 ml	1.38 g	0.6a	11.6a	4.5a	16.5a	1.8a	43.6a	24.4a	65.8a	—	—
Imidacloprid tablet	Soil insertion	2 tablets	1.00 g	0.2c	10.4ab	4.1ab	14.5bc	1.0a	39.1ab	22.0ab	59.9ab	—	—
Untreated	—	—	—	0.3bc	7.8c	3.5b	11.6d	2.2a	33.4c	17.9b	53.2b	—	—
LSD				0.2	1.3	0.9	1.6	1.4	5.6	5.7	8.3		
				'Franksred'									
Allectus	Drench	5.6 ml	0.30 g	1.8a	10.8c	4.7a	17.2c	4.1a	35.5c	25.5a	62.5c	73.1b	4.9b
Discus	Drench	22 ml	0.69 g	1.7a	12.2b	5.0a	18.9ab	6.0a	40.0c	23.7a	67.6c	80.0ab	5.4a
Discus	Drench	44 ml	1.38 g	2.0a	13.1a	4.9a	19.8a	5.0a	58.0a	23.8a	82.9ab	81.8a	5.4a
Imidacloprid tablet	Soil insertion	2 tablets	1.00 g	1.7a	12.1b	5.2a	18.8b	12.4a	59.2a	26.4a	95.2a	64.3c	4.6bc
Untreated	—	—	—	1.7a	10.1d	4.4a	16.5c	4.5a	47.9b	23.7a	70.4bc	60.4c	4.2c
LSD				0.4	0.7	0.8	1.3	9.0	6.7	6.4	14.3	8.0	0.4

[z]Allectus and Discus are combination products with imidacloprid as the systemic active ingredient. The imidacloprid tablets were experimental, but are now marketed as CoreTect.

[y]Height and trunk diameter were measured on August 23, 2005; December 21, 2005; November 3, 2006; and October 19, 2007. The yearly growth increase for 2005, 2006, and 2007 was the difference between December 2005 and August 2005, November 2006 and December 2005, and October 2007 and November 2006, respectively. Total growth was the difference between the October 2007 and August 2005 measurements.

[x]Trunk diameter measured at 15 cm (6 in) above soil line.

[w]Branch length was obtained by randomly selecting two branches from a sub-sample of replicates 1 through 28 of the 'Franksred' selection and measuring the growth from the previous year's bud scale to the tip of the branch on August 23, 2005. The two branches measured on each tree were averaged and the mean used to calculate treatment averages.

[v]Internode length was determined by counting the number of internodes within each measured branch length and dividing the branch length by the number of internodes.

[u]Means within a column and tree variety followed by different letters are significantly different ($\alpha = 0.05$).

and 7.6 cm (3 in) from the trunk on opposite sides of the tree. A soil probe was used to open the hole, which was collapsed by hand following placement of the imidacloprid tablets.

Trunk diameter (measured as described above) and height were measured on all replicates on August 23, 2005; December 21, 2005; November 3, 2006; and October 19, 2007 (Table 2). The growth increase for 2005, 2006, and 2007 was considered the difference between December 2005 and August 2005, November 2006 and December 2005, and October 2007 and November 2006, respectively. Total growth was the difference between the October 2007 and August 2005 measurements (Table 2). For each cultivar, growth differences were compared among treatments by analysis of variance (ANOVA) and means separated using a least significant difference test. On August 23, 2005, a one-time sub-sample that consisted of replicates 1 through 28 in the 'Franksred' selection was used to measure branch length. On each tree, two branches were randomly selected and measured from the previous year's bud scale to the tip of the branch. The numbers of internodes per branch were counted. The average internode length was determined by dividing the branch length by the numbers of internodes. The data collected for each branch were averaged and then analyzed as described above (Table 2).

Trees were rated for hopperburn symptoms such as leaf cupping, chlorosis, necrotic leaf margins, and branch stunting in late summer (August 23–26, 2005; August 29, 2006; and August 15, 2007) to ensure less variability of ratings (16). In 2005, necrotic foliage on 'Autumn Flame' made leafhopper damage ratings difficult, thus only replicates 1 through 19 were rated. However, during 2006 and 2007 all replicates of 'Autumn Flame' (n = 47) and 'Franksred' (n = 44) were evaluated for hopperburn. Leafhopper damage was rated on the entire canopy in 2005 and 2006. In 2007, only shoot tips were rated due to the size of the canopy and the concentration of leafhopper damage on the tips. A visual scale of 0–10 with 0 = no damage and 10 = 100% leafhopper damage was used. Treatments were color-coded to prevent two independent raters from knowing the treatment identity during evaluations. The two-person ratings were averaged and used to calculate treatment means. Leafhopper data were transformed (arcsine square root [X]) before analysis to correct for unequal variance, then treatments were compared as described previously.

2006 Trial. In March 2006, 11 insecticide treatments and an untreated control were assigned in a randomized complete block design to two fields of red maple cultivars, 'Franksred' and 'Fairview Flame', planted in February 2006 at the same nursery as the 2005 trial. Treatments were randomly assigned as previously described with the exception that 16 and 39 replicates were used in the 'Fairview Flame' and 'Franksred' plots, respectively. The soil type was a silt loam in both nursery fields.

Insecticide treatments using different application methods and timings were evaluated (Table 3). Insecticide rates were based on initial trunk diameter as previously described. Diameters averaged 25.8 and 26.5 mm (1 in) for 'Fairview

Table 3. **Leafhopper damage on *Acer rubrum* 'Fairview Flame' and 'Franksred' treated in spring 2006 with systemic insecticides and rated August 2006 and 2007.**

Treatment[z]	Systemic active ingredient	Treatment method[y]	Treatment timing 2006	Product/ tree	Active ingredient/ tree	Mean leafhopper damage rating[x] 'Fairview Flame' 2006	'Fairview Flame' 2007	'Franksred' 2006	'Franksred' 2007
Allectus	Imidacloprid	Drench	May 15	5.6 ml	0.30 g	1.5d[w]	0.7d	2.4abc	0.6c
Discus	Imidacloprid	Drench	Mar. 23	22 ml	0.69 g	1.3def	0.7d	1.7de	0.6c
Discus	Imidacloprid	Drench	May 15	22 ml	0.69 g	3.3ab	0.7d	2.1abcd	0.5c
Discus + Terrasorb	Imidacloprid	Root dip	Mar. 13	~ 26 ml	~ 0.82 g	0.6f	0.8d	1.5e	0.6c
Imidacloprid gel	Imidacloprid	Soil insertion	Mar. 23	10 g	0.50 g	3.1b	1.4bc	2.5abc	0.6c
Imidacloprid tablet 1	Imidacloprid	Soil insertion	Mar. 17	1 tablet	0.50 g	3.3ab	1.5bc	2.6ab	1.0b
Imidacloprid tablet 2	Imidacloprid	Soil insertion	Mar. 17	2 tablets	1.00 g	2.9bc	1.0cd	2.5abc	0.7c
Arena 50WG	Clothianidin	Drench	Mar. 17	0.92 g	0.46 g	0.6ef	1.9b	1.5e	0.6c
Arena 50WG	Clothianidin	Drench	May 15	0.92 g	0.46 g	1.8cd	1.5bc	1.9cde	0.6c
Safari 20SG	Dinotefuran	Drench	May 15	6 g	1.20 g	0.9def	0.8cd	1.5de	0.4c
Flagship 25WG	Thiamethoxam	Drench	May 15	0.33 g	0.0812 g	1.3de	2.1b	2.0bcde	1.2ab
Untreated	None	—	—	—	—	4.5a	3.0a	2.8a	1.5a
LSD						0.15	0.11	0.10	0.05

[z]Allectus and Discus are combination products with imidacloprid as the systemic active ingredient. The imidacloprid tablets were experimental, but are now marketed as CoreTect.

[y]Root dips were prepared by mixing 45 g Terrasorb in 3 gal of water and then adding 1 gal of Discus. Tree roots were then dipped in the Discus + Terrasorb mixture with each tree removing about 105 g of material (based on post-dip weight change).

[x]Leafhopper ratings were performed August 29, 2006, and August 15, 2007. Leafhopper damage was rated on a visual scale of 0–10 with 0 = no damage and 10 = 100% damage.

[w]Means within a column followed by different letters are significantly different ($\alpha = 0.05$).

Flame' and 'Franksred', respectively. Drench treatments were applied as previously described and included Allectus, Discus, Flagship 25WG, Safari 20SG, and Arena 50WG. Most drenches were applied May 15, 2006, with the exception of additional March-only Arena and Discus treatments (March 23, 2006). Imidacloprid tablets were inserted into the soil on March 17, 2006, at a one- or two-tablet rate as previously described. On March 23, 2006, an experimental imidacloprid gel formulation was inserted with a caulk gun into the soil 7.6 cm (3 in) from the trunk in a hole [1.3 cm (0.5 in) wide and 7.6 cm (3 in) deep] to deliver a 10 g (0.35 oz) bead per tree [0.5 g (0.02 oz) ai·bead^{-1}].

Discus was also applied as a root dip on March 13, 2006. To prepare the root dip treatment, 45 g of Terra-Sorb, an absorbent hydrogel (Plant Health Care, Pittsburgh, PA) was thoroughly mixed into 11.4 liters (3 gal) of water. Then, 3.8 liters (1 gal) of Discus was added to the Terra-Sorb solution and thoroughly mixed. The liners had been previously planted in February 2006, but were still dormant. The trees were lifted from the soil with a shovel and soil was removed from the roots by gently dipping in plain water. Roots and the lower trunk were then dipped into the Terra-Sorb-Discus solution. Pre- and post-weighing of trees indicated about 105 g (3.7 oz) of Terra-Sorb-Discus solution adhered to the roots of each tree dipped, which was estimated to be about 0.82 g (0.03 oz) imidacloprid per tree. Trees were immediately replanted.

Height and trunk diameter were measured initially March 23, 2006, before spring bud break, October 18, 2006 (data not shown), and at termination October 18, 2007 (Table 4). The total growth was the difference between the October 2007 and March 2006 measurements. Trees were rated for leafhopper damage August 29, 2006, and August 15, 2007, as previously described. Growth differences and leafhopper damage ratings were analyzed as previously described under the 2005 trial.

Other non-experimental pesticides applied. The nursery producer continued to use standard nursery practices during our study period, which included fertilizer and pesticide applications. As a result, some of our experimental plots received additional insecticide treatments with an airblast sprayer. In the 2005 trial, Dursban 4E (chlorpyrifos) and non-ionic surfactant were applied to 'Franksred' as a directed trunk spray for borer control on July 8, 2005; June 23, 2006; and July 4, 2007. No additional insecticides were applied to 'Autumn Flame' in the 2005 trial.

In the 2006 trial, 'Franksred' and 'Fairview Flame' received Sevin (carbaryl), Dursban 4E, and non-ionic surfactant on June 22, 2006, for Japanese beetle control in the crown. On July 3, 2007, 'Franksred' received Dursban 4E and non-ionic surfactant as a directed trunk spray for borer control.

Results and Discussion

Potato leafhopper control. All of the red maple cultivars had some level of potato leafhopper damage in the study. However, in the 2005 and 2006 trials, most insecticide treatments significantly reduced potato leafhopper damage on red maple cultivars for more than one season (Tables 1 and 3). Some treatments apparently either released the active insecticide ingredient more rapidly or were in a form that was more readily available to plant uptake. For instance, most imidacloprid treatments formulated as a drench (Allectus, Discus) had less leafhopper damage during the first year than imidacloprid treatments formulated as a tablet or gel.

Table 4. **Height and trunk diameter increases on *Acer rubrum* 'Fairview Flame' and 'Franksred' from spring 2006 to fall 2007 for plants treated in spring 2006 with systemic insecticides.**

						Mean increase in growth[x]			
						'Fairview Flame'		'Franksred'	
Treatment[z]	Systemic active ingredient	Treatment method[y]	Treatment timing 2006	Product/ tree	Active ingredient/ tree	Trunk diameter[w] (mm)	Height (cm)	Trunk diameter[w] (mm)	Height (cm)
Allectus	Imidacloprid	Drench	May 15	5.6 ml	0.30 g	13.3abc[v]	23.2abc	7.5a	20.5abc
Discus	Imidacloprid	Drench	Mar. 23	22 ml	0.69 g	13.8ab	23.2abc	6.1b	17.2bcd
Discus	Imidacloprid	Drench	May 15	22 ml	0.69 g	14.3a	24.0abc	6.8ab	23.6a
Discus + Terrasorb	Imidacloprid	Root dip	Mar. 13	~ 26 ml	~ 0.82 g	11.8cd	16.3bc	4.8c	13.9d
Imidacloprid gel	Imidacloprid	Soil insertion	Mar. 23	10 g	0.50 g	12.7a–d	16.3bc	7.3ab	22.7ab
Imidacloprid tablet 1	Imidacloprid	Soil insertion	Mar. 17	1 tablet	0.50 g	12.2bcd	16.6bc	7.1ab	21.0ab
Imidacloprid tablet 2	Imidacloprid	Soil insertion	Mar. 17	2 tablets	1.00 g	13.6abc	15.6c	7.6a	23.2ab
Arena 50WG	Clothianidin	Drench	Mar. 17	0.92 g	0.46 g	13.4abc	22.1abc	6.1b	21.9ab
Arena 50WG	Clothianidin	Drench	May 15	0.92 g	0.46 g	13.9ab	27.7a	7.1ab	19.7a–d
Safari 20SG	Dinotefuran	Drench	May 15	6 g	1.20 g	13.5abc	26.1ab	7.7a	23.9a
Flagship 25WG	Thiamethoxam	Drench	May 15	0.33 g	0.0812 g	13.3abc	22.6abc	6.7ab	14.7cd
Untreated	None	—	—	—	—	11.0d	25.9ab	6.9ab	24.0a
LSD						2.0	10.1	1.2	6.2

[z]Allectus and Discus are combination products with imidacloprid as the systemic active ingredient. The imidacloprid tablets were experimental, but are now marketed as CoreTect.
[y]Root dips were prepared by mixing 45 g Terrasorb in 3 gal of water and then adding 1 gal of Discus. Tree roots were then dipped in the Discus + Terrasorb mixture with each tree removing about 105 g of material (based on post-dip weight change).
[x]Total height and trunk diameter growth was the difference between plants measured on October 18, 2007, and March 23, 2006, measurements.
[w]Trunk diameter measured at 15 cm (6 in) above soil line.
[v]Means within a column followed by different letters are significantly different ($\alpha = 0.05$).

However, by the third year, the imidacloprid tablet treatment in the 2005 trial had significantly less leafhopper damage than some of the drench treatments, suggesting the tablets provided longer suppression than some of the drenches (Table 1). The drench treatments were applied in a 250 ml (8.5 fl oz) solution per tree [equivalent to 14.1 liters·m^{-2} (44.7 fl oz·ft^{-2})], while no water was used during application of the imidacloprid tablet and gel treatments. The differences in leafhopper control between tablet and gel treatments versus the drench treatments were less pronounced in the 2006 trial than the 2005 trial (Table 3). In the 2006 trial, 'Fairview Flame' treated with Discus or Arena in March had significantly less leafhopper damage than plants treated with the same insecticides in May. However, March and May treatments were not statistically different with the 'Franksred' selection. During the second year of the 2006 trial, the timings of Discus and Arena treatments (applied the previous year) had similar leafhopper control on 'Fairview Flame' or 'Franksred', which differed from the first year when the May applications were less effective than the March applications. These findings suggest the May treatment had adequate imidacloprid concentrations in the plant tissues during the second year. During the first year after transplanting, there may be an advantage in early spring application of systemic insecticides to allow more time for active ingredient translocation to the foliage where potato leafhoppers feed. All Safari and Arena treatments significantly reduced leafhopper damage compared to the untreated plants. Dinotefuran (Safari) is the most water-soluble chemical in the study (39,800 ppm) and was apparently able to translocate rapidly enough with a May-application-timing to protect the trees from summer leafhopper populations (17). The active ingredients, thiamethoxam (Flagship) (4,100 ppm), imidacloprid (Allectus, Discus, imidacloprid tablet or gel) (510 ppm), or clothianidin (Arena) (327 ppm), are less water-soluble than dinotefuran (Safari) (2, 11, 19). However, the damage prevention was comparable among the May-applied drench formulations. Flagship significantly reduced leafhopper damage compared to the untreated plants during all evaluation periods, except in 2007 on 'Franksred' maple. Flagship had the highest leafhopper damage rating among insecticides in 2007 in both 'Fairview Flame' and 'Franksred', but had significantly less damage than the untreated 'Fairview Flame' plants. Arena provided leafhopper control that was generally equivalent to or greater than most imidacloprid treatments; the exception was significantly greater leafhopper control on 'Fairview Flame' with imidacloprid drench treatments in 2007.

Dinotefuran (Safari) has a short field dissipation half-life (22−68 d) compared to the other active ingredients: imidacloprid (Allectus, Discus, imidacloprid tablet and gel) (soil half-life 61−150 d), clothianidin (Arena) (chemical stability 90−120 d depending on temperature), or thiamethoxam (Flagship) (soil degradation half-life 25−132 d) (11, 18, 19). It could be predicted that some of the systemic insecticides may not be present in the soil during the second and third year after application based on reported dissipation rates. However, in this test most treatments generally conferred leafhopper protection in the second and third year, which suggests sufficient active ingredient may persist either in maple tissues or the soil.

In the 2005 trial drench treatments, leafhopper damage on 'Autumn Flame' (2006 and 2007) and 'Franksred' (2005 and 2006) tended to decrease as the rate of imidacloprid increased (Table 1). The imidacloprid tablet treatments had more active ingredient than the drench treatments (Allectus and Discus), but apparently, the tablets did not release sufficient imidacloprid to provide leafhopper control during the first year.

In the 2005 and 2006 trials, the differences in leafhopper damage between insecticide treatments and the untreated plants became more apparent after the first year. During the first year following transplanting, the low leaf quality made it difficult to quantify potato leafhopper damage. This was particularly true for many of the 'Autumn Flame' trees, which had severe foliar burn. However, some differences in leafhopper damage were still detected during the first summer after transplanting. Potter and Spicer (13) did not rate their potato leafhopper tests during the first growing season because of reported variation in leaf flush phenology related to transplanting. All of the trees in this study were grown without supplemental irrigation. In addition, the 'Autumn Flame' planting site was sloping with a western exposure, which subjected the trees to more drought stress and reduced new succulent growth preferred by leafhoppers. Because leafhopper damage was less distinct during the first growing season, some producers might question the need to apply insecticides in the first year. However, differences in cultivar susceptibility to leafhoppers may necessitate the need for insecticide application after transplanting. In addition, flatheaded borers were a significant problem during the first year and were controlled by these insecticides (J.B.O. and D.C.F., unpublished data).

Leafhopper damage in the 2006 trial was generally lower than the 2005 trial based on damage in the untreated control. During the second year of the 2006 trial (2007), an early April freeze that damaged tips was followed by a severe drought that affected overall growth throughout the rest of the growing period. Potato leafhoppers have shown less attraction to some water-stressed plants and alteration of probing behavior (1, 8); however, leafhopper damage on the water-stressed red maples was sufficient to detect some treatment differences. With the exception of 'Autumn Flame', all maple selections received additional insecticide applications by the nursery producer, which might also have reduced overall leafhopper damage during this trial. The majority of these producer-applied-insecticides were directed at the trunk for borer control rather than the foliar areas occupied by leafhoppers.

Chemical treatments. A concern regarding some of the labeled rates used in this study is the number of trees that can be treated in a given area without exceeding the maximum active ingredient allowed for one year. For example, Discus is currently restricted to 17.8 liters·ha^{-1} (244 fl oz·A^{-1}). A common field-grown nursery plant spacing is 1.8 × 2.1 m (6 × 7 ft), which equates to about 2,562 trees·ha^{-1} (1,037 trees·A^{-1}). Using a labeled Discus drench rate of 22 ml (0.75 fl oz) product per tree, a producer could only treat 804 trees·ha^{-1} (325 trees·A^{-1}) without exceeding active ingredient limits per unit area per year or half these numbers of trees if using the labeled 44 ml (1.5 fl oz) per tree. A possible solution to this problem could be a lower drench rate or a lower drench rate in combination with an imidacloprid tablet to benefit from an immediate and extended release formulation. It is probable that lower Discus rates may not provide multi-year leafhopper suppression. All of the products tested have active ingredient limitations that could restrict the number of trees treated per unit area; therefore, future evaluations may need to examine rates that can accommodate quantities of trees common to field nurseries. The value of a one-time treatment providing multi-year control is a reduction in application costs, but if reduced rates have unacceptable long-term leafhopper control, it may be necessary to apply lower rates annually. In addition to rate concerns, more research needs to be done to quantify the relationship between expressed leafhopper damage and economic consequences for tree producers.

Plant response. In the 2005 trial, red maple trunk growth was influenced by the insecticide treatments (Table 2). However, overall plant growth was minimal during the first year (2005), probably due to transplant establishment. 'Autumn Flame' maples were planted on a sloping field with a southwestern exposure and were stressed more than the 'Franksred' maples, which were located in a bottomland soil. Trunk diameter increase was greater with 'Autumn Flame' treated with Discus (44 ml) during year 1 compared to plants treated with imidacloprid tablets or the untreated plants. In the second year (2006), both maple cultivars treated with Allectus or Discus (22 or 44 ml) drenches or with imidacloprid tablets had greater trunk diameter growth than untreated plants. During the third year (2007), trunk diameter growth was significantly affected by the freeze and drought conditions as indicated by less growth in 2007 than 2006 in the untreated trees. However, total trunk growth during the 3-yr period was greater with plants treated with Allectus and Discus (22 and 44 ml) drenches and imidacloprid tablets compared to untreated trees, with the exception of 'Franksred' treated with Allectus. The Allectus treatment had the lowest imidacloprid rate among all the imidacloprid treatments, possibly indicating a rate-effect on growth.

Height growth in the 2005 trial was affected by insecticide treatments (Table 2). In the second year (2006), both 'Autumn Flame' and 'Franksred' treated with Discus (44 ml) and imidacloprid tablets had significantly greater increases in height compared to the untreated plants. Maples treated with Allectus and Discus (22 ml) had height growth similar to the untreated plants, and these treatments applied to 'Franksred' resulted in less height growth than the untreated plants. Height increases were not as pronounced during the third year (2007), likely due to a late freeze in April 2007 followed by a very dry growing season. However, in year 3, 'Autumn Flame' treated with Discus (44 ml) had 27 to 29% more height growth than untreated or plants treated with Discus (22 ml), respectively. 'Franksred' exhibited no difference in height growth during year 3. However, in general, total height growth with 'Autumn Flame' and 'Franksred' was greater for plants receiving the high rate of Discus (44 ml) or the imidacloprid tablets than untreated or trees treated with Discus (22 ml).

In the 2005 trial, trees in the Allectus and Discus (22 and 44 ml) drench treatments had significantly longer branches on 'Franksred' than trees with imidacloprid tablets or untreated trees when measured about 3 months after treatment (Table 2). 'Franksred' treated with Discus (22 and 44 ml) or Allectus had significantly longer internodes than the untreated plants. Both Discus drench treatments produced longer internodes than Allectus, which was applied at a lower imidacloprid concentration. The imidacloprid tablet treatments were similar to the untreated plants with regards to internode length. Some formulations like the tablets may be releasing imidacloprid at slower rates, which may prevent the distinct growth differences that were seen with formulations like the drenches.

In the 2006 trial, trunk growth was affected by insecticide treatments (Table 4). Cumulative growth data have been presented for the 2006 trial because like the 2005 trial, tree growth during the first year was inconsequential probably due to transplant establishment. Total trunk growth on 'Fairview Flame' was greater for insecticide treatments than the untreated plants, with the exception of plants treated with imidacloprid gel, one tablet of imidacloprid, or the Discus + Terrasorb dip. Trunk growth on 'Franksred' treated with insecticides did not differ statistically from the untreated plants; however, Discus + Terrasorb had less growth than other treatments. 'Fairview Flame' had almost twice as much trunk growth as 'Franksred', suggesting it is a faster growing cultivar.

Height growth in the 2006 trial was affected by insecticide treatment and cultivar response (Table 4). 'Fairview Flame' height was significantly lower in the two-tablet imidacloprid treatment compared to the untreated control, but no growth effects were indicated between other insecticide treatments and the untreated plants. The result with the two-tablet imidacloprid treatment may be questionable because in most cases in this study, higher imidacloprid rates generally improved height and trunk diameter growth or at least did not inhibit growth. For 'Franksred', no significant effects on height growth were detected for most insecticides compared to untreated plants; however, treatments with significantly less height growth than the untreated plants included Discus (March), Discus + Terrasorb, and Flagship. Height growth for some of these treatments was contrary to improved growth effects that are usually observed. Height growth in the 'Franksred' selection may have been influenced by other non-treatment-related factors like branch dieback from the April freeze. Discus + Terrasorb also had 30% less trunk diameter growth than the untreated plants.

It was not possible to determine the cause of insecticide-associated growth enhancement in this study. The increase in growth may have been indirectly related to the reduction in potato leafhopper herbivory, or conversely, the insecticides may have directly increased growth by altering the trees' physiology. Imidacloprid in the absence of whiteflies did not increase growth and yield in muskmelon, suggesting that insect damage prevention was the mechanism of imidacloprid-enhanced plant growth (12). In contrast, when predaceous ants were excluded from the crowns of *Acer pseudoplatanus* L., herbivory by leafhoppers, aphids, and caterpillars reduced radial tree growth by about 35% (20). Sap removal was two to three times higher on trees without protection from herbivory (20). Potato leafhopper feeding reduced the transport of photosynthates to lower stems and roots in alfalfa (9), which may explain the reduced trunk growth observed in untreated red maples.

In conclusion, many of the insecticides tested reduced leafhopper damage for more than one growing season while resulting in increased tree growth. Most of the systemic insecticides also provided enhanced borer protection (J.B.O. and D.C.F., unpublished data). Therefore, treatments offer significant advantages to maple producers. The treatment effects in this study were often multi-year; and it could be conceived that treatment benefits may carry over to the landscape for a period of time either through continued uptake of insecticide residues in the original nursery soil or retention in the tree tissues. Longevity of systemic treatments could offer producers significant cost savings over contact sprays like pyrethroids that require repeated applications.

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