Comparison of Standard (Granular and Drench) and Novel (Tablet, Stick Soak, and Root Dip) Imidacloprid Treatments for Cottonwood Leaf Beetle (Coleoptera: Chrysomelidae) Management on Hybrid Poplar

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ABSTRACT Standard soil application methods (granular and drench) were compared with novel methods (tablet, stick soak, and root dip) for efficacy and duration in hybrid poplar (*Populus* spp.) against adult and larval cottonwood leaf beetle, *Chrysomela scripta* F. (Coleoptera: Chrysomelidae). Beetle feeding can kill saplings and significantly damage trees by reducing tree height, diameter, and biomass. Tablets offer lower risk to applicators and beneficial insects, because insecticides do not need to be measured and sprayed. In field- and container-grown plants, standard granular and drench application methods had similar efficacy and duration compared with tablets. In field-grown plants, adult and larval survivorship was reduced for 12 mo with the two highest rates of tablet (0.25× and 0.5×) treatments, and in container-grown plants, with all rates of tablet (0.25×, 0.5×, and 1×) treatments that were used. Two other novel application methods, stick soak and root dip, offer new methods for protecting vulnerable transplants in nursery propagation. In container-grown plants, adult survivorship was reduced for 8 mo and larval survivorship for 12 mo for all rates of stick soak (0.5×, 1×, and 2×) and all rates of root dip (1×, 2×, and 4×) treatments. Literature searches revealed little data on the efficacy and duration of soil-applied imidacloprid for trees, even though it is the primary insecticide used for defoliators and some borers in landscape and in nurseries for field and container production.

KEY WORDS *Chrysomela scripta*, hybrid poplar, imidacloprid, novel application methods

Standard imidacloprid application methods, such as granular and drench, are used in landscape, field nurseries, and container production, against a variety of defoliators, sucking insects, borers, and invasive species, such as emerald ash borer, *Agrilus planipennis* Fairmaire and hemlock woolly adelgid, *Adelges tsugae* Annand. (Krischik and Davidson 2004, Smitley et al. 2005). However, for woody plants the duration and efficacy for various applications is rarely compared and merits attention, as proper methods reduce insecticide use and maintain tree health. Although this study is confined to soil applications, it is important to understand the efficacy and duration of trunk injections compared with soil-applied methods. Trunk injections are often limited to a few years, because injections damage the cambium, so subsequent soil-applied methods are used.

Imidacloprid is widely used and marketed under many names depending on formulation and application site (trade names include Merit [turfgrass and landscape], Marathon [nursery], Admire [field crops and poplar drip irrigation], Provado [field crops and poplars], Imicide [trunk injections], Confidor [landscape and nursery], and Gaucho [crop seed coating]). Imidacloprid is registered in ≈120 countries and used on >140 different agricultural crops (Buffin 2005).

The majority of the published field studies on efficacy and duration of imidacloprid were on invasive species, such as *A. planipennis* and *A. tsugae.* In the first year, a 1× (label rate) of an imidacloprid drench demonstrated 63% less galleries of *A. planipennis* than controls on ash. After three consecutive years of 1× rate drench, dieback was 54% on treated trees and 88% on controls (1.42 g of active ingredient [AI] used; Merit 75 WP, 75% [AI], Bayer CropScience, Research Triangle Park, NC; 1.9 g of product per 2.5-cm diameter measured at breast height of 1.8 m [dbh] in 5.7 liters of water per tree) (Smitley 2006). A 1× trunk injection controlled 63–77% of *A. planipennis* for 24 mo (0.08 g [AI] used; IMA-jet, 5% [AI], Arborjet, Inc., Woburn, MA, 4 ml of product per 2.5 cm dbh for trees <30.5 cm in dbh and 0.16 g [AI], 8 ml of product per 2.5 cm dbh for trees >30.5 cm in dbh) (Smitley et al. 2005).

Three studies documented that imidacloprid offered 5–24 mo protection in Eastern hemlock, *Tsuga canadensis* (L.), against *A. tsugae.* In the first study, treated trees with a 1× drench had significantly better appearance, more new growth, and greater increase in trunk diameter at 24 mo compared with untreated controls (1.5 g [AI] used; Merit 75 WP, 2 g of product

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in 0.95 liter of water per 2.5 cm dbh) (Webb et al. 2003). In another study, a 1× drench reduced *A. tsugae* populations by 50–100% at 12 mo and 83–100% at 24 mo. Furthermore, residue analysis revealed imidacloprid concentrations of >120 ppb in *T. canadensis* twigs, needles, and sap up to 36 mo after application (1 g [AI] used, Bayer Advanced Garden Tree and Shrub Insect Control, 1.47% [AI], Bayer Advanced LLC, Birmingham, AL; 68 ml of product in 3.8 liters of water per 2.5 cm dbh) (Cowles et al. 2006). In the third study, a 1.5× soil injection managed *A. tsugae* for 5 mo (1.8 g [AI] used; Merit 2 F, 21.4% [AI], Bayer CropScience, Research Triangle Park, NC, 7.4 ml of product in 3.8 liters of water per 2.5 cm dbh by using a Hypro Corp. diaphragm sprayer with a Deep Root Feeding gun) (Steward and Horner 1994).

A literature review found only one article on efficacy and duration of imidacloprid for tree defoliators. A 1× trunk injection for elm leaf beetle, *Xanthogaleruca luteola* Müller, reduced defoliation at 1 mo to 2% compared with 28% in controls and at 4 mo to 1% compared with 23% in controls. At 1 mo, larval mortality was 100% (0.17 g [AI] used; Imicide, 10% [AI], J. J. Mauget Co., Arcadia, CA, 3 ml capsules per 2.5 cm dbh or 0.33 g [AI] per 15.2 cm circumference) (Lawson and Dahlsten 2003).

For containerized trees, we could not find any references on efficacy and duration of soil-applied imidacloprid for leaf feeders. Only one article reported that in container-grown Swingle citrumelo, *Citrus paradisi* Macf. × *Poncirus trifoliata* L. Raf., root weevil, *Diaprepes abbreviatus* (L.), larvae showed reduced survivorship at 6 wk after a 0.25–1× drench (0.0075–0.03 g [AI] used; Admire 2 F, 21.4% [AI], Bayer CropScience, 0.03–0.13 ml of product in 150 ml of water) (Quintela and McCoy 1997).

The current research used the native cottonwood leaf beetle, *Chrysomela scripta* F. (Coleoptera: Chrysomelidae), an important defoliator of hybrid poplar clone NM6 that is cultivated for biomass, pulp, and timber (Harrell et al. 1981, Johnson and Lyon 1991, Robison and Raffa 1998). Adults and larvae prefer to feed on shoot terminals (Leaf Plastochron Index [LPI] 0 (smallest expanded leaf) to LPI 8 (numbered sequentially below LPI 0) (Bingaman and Hart 1992). The beetle has three documented generations in Minnesota (Krischik and Tenczar 2007) and seven generations in Mississippi (Oliveria and Solomon 2004). Feeding can kill saplings and significantly damage trees by reducing tree height, diameter, and biomass (Reichenbacker et al. 1996, Andersen and Nelson 2002, Fang et al. 2002). During the first 3 yr of growth, insecticides are needed to control *C. scripta* (USDA Forest Service 1989), because young poplars contain higher percentages of desirable foliage than do older trees (Bingaman and Hart 1992, Coyle et al. 2002). The cottonwood leaf beetle–hybrid poplar system is a good model system, because the beetle is multivoltine, and larval and adult beetles are available for bioassays continuously during the summer.

Our objectives were to determine the efficacy and duration of imidacloprid for field and container-grown hybrid poplar. We compared 1) standard granular and drench application methods with 2) novel methods: tablets, stick soak (propagative dormant cuttings soaked in imidacloprid), and root dip (bare roots soaked in imidacloprid). Tablets are easier to apply, are safer for applicators, and eliminate the need to measure or dissolve imidacloprid in water. Soaking of bare root plants or propagative cuttings offer protection for young plants before they grow can grow roots to absorb granular and drench imidacloprid applications.

Materials and Methods

Experimental Organisms. Poplar clone NM6, *Populus nigra* × *maximowiczii,* was developed in Europe and is used for biomass and pulp production (AURI 2001, Broadacres Nursery 2003). It is propagated with dormant stem cuttings (sticks) that are harvested in November, stored in a cooler at 4°C, and then soaked for 2 d before planting in spring. For this study, sticks were obtained from an International Paper nursery (Alexandria, MN).

C. scripta were collected in Minnesota and raised year-round in 33- × 80-cm bags made from no-see-um netting (97 holes per cm^2, Eastex Products, Inc., Holbrook, MA) covering small NM6 trees in the greenhouse. Additionally, beetles were raised in 14-liter rectangular plastic containers (Sterilite, Townsend, MA) in an incubator at 23°C in which NM6 terminals were placed in 25 ml water tubes with plastic lids (Syndicate Sales, Kokomo, IN).

Experiment 1: Novel and Standard Treatments in Field-Grown Poplar. *Treatments.* Three blocks of treatments with 12 sticks (23 cm in length) per treatment were planted at 0.9- by 0.9-m intervals on the St. Paul Campus, University of Minnesota, on 14 June 2004. Imidacloprid treatments (granular, drench, and tablets) were applied to the soil at the base of the growing saplings on 6 August 2004 (Table 1). Granular treatments were applied at 0.12–0.5× label rate to match the amount of AI with other treatments. Tablets were 2.5-g compressed, solid formulations of imidacloprid with 5–10% (AI). A traditional T-bar (1-m-tall iron bar with 30-cm bar welded to the top of the vertical bar, used to make holes when planting sticks) was used to make holes for tablets adjacent to the sticks. Stick soak treatments were soaked in imidacloprid-treated water for 48 h before planting, which is the traditional hydration method. Root dip treatments were made by dipping container-grown transplants in solution for 5 min before planting.

Bioassays. Leaves were excised and bioassayed at intervals over the growing season. Leaves were placed on moist filter paper in 100- by 15-mm petri dishes with adult and larval *C. scripta* for 4 d, and survivorship was recorded. Each experiment contained three replicated blocks. Replicates were combined, and data were analyzed by PROC GLM for treatment, replicate, and treatment by replicate interactions (SAS Institute 2003). Data were analyzed for homogeneity using Levene's test. When data could not meet the assumptions of homoge-

Table 1. Treatments and rates of imidacloprid applied on 6 August 2004 to field-grown poplar that were planted on 14 June 2004

Treatment, label rate	(AI) per tree	Label rate	Product, (AI)	Amount applied per tree
Control (untreated)	N.A.	N.A.	N.A.	N.A.
Standard treatments				
Granular 0.12×	0.125 g	1.06 g (AI)[a]	Merit 2.5 G 2.5%	5 g of product
Granular 0.25×	0.25 g	1.06 g (AI)	As above	10 g of product
Granular 0.5×	0.5 g	1.06 g AI	As above	20 g of product
Drench 0.25×	0.12 g	0.72–1.4 g (AI)[b]	Merit 2F 21.4%	0.5 ml/500 ml solution
Drench 0.5×	0.24 g	0.72–1.4 g (AI)	As above	1 ml/500 ml solution
Drench 1×	0.48 g	0.72–1.4 g (AI)	As above	2 ml/500 ml solution
Novel treatments				
Tablet 0.12×	0.125 g	Not labeled[c]	Tablet 5%	2.5 g of product (1 tablet)
Tablet 0.25×	0.25 g	Not labeled	Tablet 10%	2.5 g of product (1 tablet)
Tablet 0.5×	0.5 g	Not labeled	Tablet 20%	2.5 g of product (1 tablet)
Stick soak 0.5×	0.24 g AI/liter	0.21–0.66 g (AI)/liter[d]	Merit 2F 21.4%	1 ml/liter soak
Stick soak 1×	0.48 g (AI)/liter	0.21–0.66 g (AI)/liter	As above	2 ml/liter soak
Stick soak 2×	0.96 g (AI)/liter	0.21–0.66 g (AI)/liter	As above	4 ml/liter soak
Root dip 0.5×	0.24 g (AI)/liter	Not labeled[e]	As above	1 ml/liter, 5-min dip
Root dip 1×	0.48 g (AI)/liter	Not labeled	As above	2 ml/liter, 5-min dip
Root dip 2×	0.96 g (AI)/liter	Not labeled	As above	4 ml/liter, 5-min dip

N.A., not applicable.
[a] Merit 2.5 G label rate is 1.06 g (AI) (42.5 g of product) for plants <1.2 m in height.
[b] Merit 2F label rate is 0.72–1.4 g (AI) (3–6 ml) per 2.5 cm dbh or 0.3 m in height. Rates used in this study were provided by Bayer CropSciences.
[c] Imidacloprid tablets are not labeled. Rates given are based on label rate of Merit 2.5 G.
[d] Admire Pro (42.8% [AI]) is labeled for stick soak in poplar. Label rate of Admire Pro is 0.21–0.66 g (AI)/liter (0.44–1.4 ml/liter, which is equivalent to 0.88–2.7 ml/liter Merit 2F).
[e] Merit 2F is not labeled as a root dip. Rates given are based on label rate of Admire Pro stick soak.

neity, the Welch's test was recorded. Means were compared using Tukey–Kramer honestly significant difference (HSD) test (SAS Institute 2005).

Growth Studies. The effect of imidacloprid on plant growth was determined by measuring relative growth rate (RGR), total height, internode length, trunk basal diameter, leaf area (LI-COR leaf area meter, LI-COR, Lincoln, NE), and leaf chlorophyll content (Field Scout CM 1000, Spectrum Technologies, Plainfield, IL). Phytotoxicity parameters, such as leaf browning, lack of shoot elongation, and plant stunting, were evaluated. Wet and dry leaf and wood biomass were measured at 16 mo. Leaves and wood were placed in paper bags, weighed, and dried at 140°C for 10 d

Table 2. Treatments and rates of imidacloprid applied on 30 July 2004 to container-grown poplar that were planted on 14 June 2004

Treatment, label rate	(AI) per tree	Label rate	Product, (AI)	Amount applied per tree
Control (untreated)	N.A.	N.A.	N.A.	N.A.
Standard treatments				
Granular 0.12×	0.125 g	1.06 g (AI)[a]	Merit 2.5 G 2.5%	5 g of product
Granular 0.25×	0.25 g	1.06 g (AI)	As above	10 g of product
Granular 0.5×	0.5 g	1.06 g (AI)	As above	20 g of product
Drench 0.5×	0.24 g	0.72–1.4 g (AI)[b]	Merit 2F 21.4%	1 ml/500 ml solution
Drench 1×	0.48 g	0.72–1.4 g (AI)	As above	2 ml/500 ml solution
Drench 2×	0.96 g	0.72–1.4 g (AI)	As above	4 ml/500 ml solution
Novel treatments				
Tablet 0.25×	0.25 g	Not labeled[c]	Tablet 10%	2.5 g product (1 tablet)
Tablet 0.5×	0.5 g	Not labeled	Tablet 20%	2.5 g product (1 tablet)
Tablet 1×	1.0 g	Not labeled	Tablet 20%	5.0 g product (2 tablets)
Stick soak 0.5×	0.24 g (AI)/liter	0.21–0.66 g (AI)/liter[d]	Merit 2F 21.4%	1 ml/liter soak
Stick soak 1×	0.48 g (AI)/liter	0.21–0.66 g (AI)/liter	As above	2 ml/liter soak
Stick soak 2×	0.96 g (AI)/liter	0.21–0.66 g (AI)/liter	As above	4 ml/liter soak
Root dip 1×	0.48 g (AI)/liter	Not labeled[e]	As above	2 ml/liter, 5-min dip
Root dip 2×	0.96 g (AI)/liter	Not labeled	As above	4 ml/liter, 5-min dip
Root dip 4×	1.9 g (AI)/liter	Not labeled	As above	8 ml/liter, 5-min dip

N.A., not applicable.
[a] Merit 2.5 G label rate is 1.06 g (AI) (42.5 g of product) for plants <1.2 m in height.
[b] Merit 2F label rate is 0.72–1.4 g (AI) (3–6 ml) per 2.5 cm dbh or 0.3 m in height. Rates used in this study were provided by Bayer CropSciences.
[c] Imidacloprid tablets are not labeled. Rates given are based on label rate of Merit 2.5 G.
[d] Admire Pro (42.8% [AI]) is labeled for stick soak in poplar. Label rate of Admire Pro is 0.21–0.66 g (AI)/liter (0.44–1.4 ml/liter, which is equivalent to 0.88–2.7 ml/liter Merit 2F).
[e] Merit 2F is not labeled as a root dip. Rates given are based on label rate of Admire Pro stick soak.

Table 3. Percentage of survivorship of adult *C. scripta* at 96 h fed leaves from field-grown poplar planted on 14 June 2004 and treated with imidacloprid on 6 August 2004

Treatment, label rate	Mo after treatment		
	1 mo	10 mo	12 mo
Control (untreated)	91.7 ± 3.1a	88.9 ± 7.0a	99.1 ± 0.9a
Standard treatments			
Granular 0.12×	38.3 ± 7.3cde	16.7 ± 10.5bc	100.0a
Granular 0.25×	8.3 ± 4.7de	41.7 ± 20.1abc	94.9 ± 2.3a
Granular 0.5×	6.7 ± 3.8e	8.3 ± 8.3c	67.1 ± 5.4c
Drench 0.25×	83.3 ± 7.2a	83.3 ± 10.5a	98.1 ± 1.3a
Drench 0.5×	40.0 ± 6.8bcd	75.0 ± 17.1ab	95.4 ± 2.3a
Drench 1×	10.0 ± 5.3de	25.0 ± 17.1abc	92.1 ± 4.0ab
Novel treatments			
Tablet 0.12×	43.3 ± 10.8bc	25.0 ± 11.2abc	97.2 ± 1.9a
Tablet 0.25×	23.3 ± 8.3cde	16.7 ± 10.5bc	71.8 ± 5.9c
Tablet 0.5×	71.7 ± 9.1ab	25.0 ± 17.1abc	79.4 ± 5.0bc
Stick soak 0.5×	88.3 ± 6.4a	75.0 ± 11.2ab	100.0a
Stick soak 1×	93.3 ± 3.8a	50.0 ± 18.3abc	99.0 ± 1.0a
Stick soak 2×	81.7 ± 7.5a	66.7 ± 10.5abc	99.0 ± 1.0a
F (df), *P* one-way	49.1 (12, 70), <0.001	4.4 (12, 65), <0.001	13.3 (12, 217), <0.001
F (df), *P* model	9.0 (38, 156), <0.001	4.7 (38, 39), <0.001	5.3 (38, 191), <0.001
F (df), *P* treatment	25.8 (12), <0.001	8.1 (12), <0.001	13.8 (12, 191), <0.001
F (df), *P* block	2.8 (2), 0.063	11.5 (2), <0.001	2.5 (2, 191), 0.086
F (df), *P* trt × blk	1.2 (24), 0.287	2.4 (24), 0.007	1.2 (24, 191), 0.212

Means in the same column followed by different letters are significantly different; PROC GLM and Tukey–Kramer HSD comparison of means, $\alpha = 0.05$.

(leaves) and 20 d (wood). Wood was considered dry when weight did not decrease by 0.001 kg or more after 24 h. Each experiment contained three replicated blocks. Replicates were combined and data were analyzed by PROC GLM for treatment, replicate, and treatment by replicate interactions (SAS Institute 2003). Data were analyzed for homogeneity by using Levene's test. When data could not meet the assumptions of homogeneity, the Welch's test was recorded. Means were compared using Tukey–Kramer HSD test (SAS Institute 2005).

Experiment 2: Novel and Standard Treatments in Container-Grown Poplar. *Treatments.* Three blocks of treatments with 10–12 sticks (23 cm in length) per treatment were planted in 10-cm^2 × 35-cm pots at the St. Paul Campus, University of Minnesota, on 14 June 2004 and grown the greenhouse. Imidacloprid treatments (granular, drench, and tablets) were applied to the soil at the base of the growing saplings on 30 July 2004 (Table 2). Granular treatments were applied at 0.12–0.5× label rate to match the amount of (AI) with other treatments. Root dip treatments were made by dipping container-grown transplants in solution for 5 min and then replanting in containers. For stick soak treatments, hardwood cuttings (sticks) were soaked in imidacloprid-treated water for 48 h before planting.

Bioassays. Same as bioassays described above.

Growth Studies. Same as growth studies described above, except biomass was not measured.

Results

Experiment 1: Novel and Standard Treatments in Field-Grown Poplar. In field-grown poplar, survivorship of adults was reduced for 12 mo with the highest rate of granular (0.5×) and two highest rates of tablet (0.25× and 0.5×) treatments (Table 3). Survivorship of adults was reduced for 1 mo with the two highest rates of drench (0.5× and 1×) treatments. Survivorship of adults was not reduced by stick soak (0.5×, 1×, and 2×) treatments. Trees exposed to root dip treatments in the field were extremely stunted or died; therefore, they were excluded from analysis.

Survivorship of larvae was lower than adults in all treatments. Survivorship of larvae was reduced for 12 mo with all rates of granular (0.12×, 0.25×, and 0.5×), two highest rates of drench (0.5× and 1×), and two highest rates of tablet (0.25× and 0.5×) treatments (Table 4). Survivorship of larvae was reduced for 10 mo with the lowest rate of tablet (0.12×) treatment. Survivorship of larvae was reduced for 1 mo with lowest rate of drench (0.25×) and all rates of stick soak (0.5×, 1×, and 2×) treatments.

Imidacloprid treatments showed no phytotoxicity (leaf browning, lack of shoot elongation, and plant stunting). There were no significant differences in chlorophyll content among all treatments (Table 5). For other parameters (RGR, internode length, and leaf area), there were significant differences among rates but not treatments. Stick soak treatments had lower height and trunk basal diameter compared with controls, but not all other treatments. Results are reported for 15 mo after planting, because 3 and 9 mo measurements revealed similar trends. For biomass, there were significant differences among rates but not treatments (Table 6).

Experiment 2: Novel and Standard Treatments in Container-Grown Poplar. In container-grown plants, survivorship of adults and larvae was reduced for 12 mo with all granular (0.12×, 0.25×, and 0.5×), all drench (0.5×, 1×, and 2×), all tablet (0.25×, 0.5×, and 1×), and the highest rate of stick soak (2×) treatments (Tables 7 and 8). Larval survivorship was reduced for 12 mo and adult survivorship for 8 mo for

Table 4. Percentage of survivorship of larval *C. scripta* at 96 h fed leaves from field-grown poplar planted on 14 June 2004 and treated with imidacloprid on 6 August 2004

Treatment, label rate	Mo after treatment		
	1 mo	10 mo	12 mo
Control (untreated)	90.0 ± 3.0a	100.0a	91.2 ± 4.3a
Standard treatments			
Granular 0.12×	3.3 ± 2.6ef	33.3 ± 16.7bc	55.6 ± 6.7bcd
Granular 0.25×	0.0f	16.7 ± 16.7bc	41.7 ± 7.3cd
Granular 0.5×	0.0f	0.0c	0.0e
Drench 0.25×	30.8 ± 8.5cd	50.0 ± 12.9abc	73.6 ± 7.4ab
Drench 0.5×	0.8 ± 0.8f	25.0 ± 17.1bc	36.1 ± 8.9d
Drench 1×	3.3 ± 2.6ef	0.0c	24.1 ± 8.2de
Novel treatments			
Tablet 0.12×	15.0 ± 7.2def	16.7 ± 16.7bc	68.5 ± 9.3abc
Tablet 0.25×	20.8 ± 9.3cdef	0.0c	2.8 ± 2.8e
Tablet 0.5×	54.2 ± 9.7b	0.0c	2.8 ± 2.8e
Stick soak 0.5×	55.0 ± 8.6b	100.0a	76.5 ± 7.9ab
Stick soak 1×	42.5 ± 8.8bc	75.0 ± 17.1ab	70.3 ± 6.9abc
Stick soak 2×	22.8 ± 9.2cde	75.0 ± 17.1ab	70.1 ± 8.1abc
F (df), *P* one-way	17.6 (12, 182), <0.001	10.1 (12, 65), <0.001	21.8 (12, 216), <0.001
F (df), *P* model	6.3 (38, 156), <0.001	3.5 (38, 39), <0.001	9.0 (38, 190), <0.001
F (df), *P* treatment	17.8 (12), <0.001	9.4 (12), <0.001	24.1 (12), <0.001
F (df), *P* block	0.8 (2), 0.462	0.1 (2), 0.872	0.9 (2), 0.429
F (df), *P* trt × blk	1.1 (24), 0.372	0.9 (24), 0.618	2.0 (24), 0.005

Means in the same column followed by different letters are significantly different; PROC GLM and Tukey–Kramer HSD comparison of means, $\alpha = 0.05$.

all rates of stick soak (0.5×, 1×, and 2×) and all rates of root dip (1×, 2×, and 4×) treatments.

Imidacloprid treatments showed no phytotoxicity (leaf browning, lack of shoot elongation, and plant stunting). All treatments were similar for RGR, total height, internode length, trunk basal diameter, leaf area, and chlorophyll (Table 9). Results are reported for 14 mo after planting, because 4- and 9-mo measurements revealed similar trends.

Discussion

Hybrid poplar is used for biomass and pulp production (AURI 2001, Broadacres Nursery 2003). Soil applications of imidacloprid are safer for workers and reduce harm to beneficial insects, because the insecticide is not sprayed. For example, coccinellids *Hippodamia convergens* Guérin-Méneville and *Harmonia axyridis* (Pallas) were killed by 1× foliar sprays of imidacloprid and carbaryl, but they were not killed when placed on leaves from poplars treated with 1.5× and 3× stick soak (Tenczar and Krischik 2006). In addition to nontarget effects on biological control agents, aerial spraying of carbaryl in Minnesota created issues with honey bee keepers who thought carbaryl killed foraging honey bees (Beyond Pesticides 2006).

In the field, larvae were killed for 12 mo with all granular (0.12×, 0.25×, and 0.5×), two highest rates of drench (0.5× and 1×), and two highest rates of tablet (0.25× and 0.5×) treatments. Our data on tablets are similar to that for a study on *Eucalyptus globulus* (Labill.), which showed little herbivory for 1.7 yr after application of a 0.5× tablet (0.5 g [AI] used; 20% [AI], Bayer CropScience, 2.5-g tablet) (Collett and McBeath 2007). Two studies documented that 1× drenches controlled *A. tsugae* for 12 mo (Webb et al. 2003, Cowles et al. 2006). Also, a 1× drench protected fruit trees [peach, *Prunus persica* (L.); nectarine, *Prunus persica* variety *nectarine,* and Japanese plum, *Prunus salicinia* Lindl.] for 4.5 yr from sharpshooters that vectored phony peach disease and plum leaf scald, both caused by *Xylella fastidiosa* (0.7 g [AI] used; Admire 2 F, 2.9 ml of product in 1–2 liters of water per tree, applied twice per year for 3 yr, then once per year for 2 yr) (Dutcher et al. 2005). All other published studies for woody plants were on tree injections.

It is important to know whether drench or granular applications will control insects for similar duration to injections, because trees can only have a few injections before cambium damage occurs, after which soil-applied methods must be used. Published studies on trunk injections revealed 4–24-mo duration compared with 12 mo for granular, drench, and tablet treatments in this study. Injections at 1× controlled elm leaf beetle for 4 mo (Lawson and Dahlsten 2003); red gum lerp psyllid, *Glycaspis brimblecombei* Moore, for 15 mo (0.17 g [AI] used; Imicide, 3-ml capsules per 2.5 cm dbh) (Young 2002); and *A. planipennis f*or 24 mo (Smitley et al. 2005).

In the field, stick soak treatments killed larvae for 1 mo, but they did not kill adults; consequently, this treatment cannot be recommended. Interestingly, the stick soak application was added to the Admire PRO label for poplars (Bayer CropScience 2005). Root dips in the field were stunted and excluded from analysis. Root dips are usually performed on dormant plants; however, the transplants in this study were growing. In another study in our lab, high rates of root dip (3×, 18×, and 30×) on dormant poplars did not kill trees (1.4, 8.6, and 14.4 g [AI]/liter used; Merit 2 F) (Tenczar and Krischik, unpublished data). A valid explana-

Table 5. Growth parameters of field-grown poplar planted on 14 June 2004 and treated with imidacloprid on 6 August 2004 at 15 mo after planting

Treatment, label rate	Growth parameter					
	RGR (cm/wk)	Ht (cm)	Internode length (cm)	Basal diam (mm)	Leaf area (cm²)	Chlorophyll (field scout)
Control (untreated)	16.9 ± 1.5abc	402.9 ± 10.7a	6.1 ± 0.1ab	40.3 ± 1.1a	182.9 ± 9.6a	254.1 ± 5.5a
Standard treatments						
Granular 0.12×	14.7 ± 1.3abc	365.0 ± 11.9ab	6.2 ± 0.1a	37.4 ± 1.0abc	161.1 ± 7.0abc	253.7 ± 8.6a
Granular 0.25×	18.0 ± 1.3ab	381.7 ± 13.2a	6.2 ± 0.1ab	37.1 ± 1.8abc	185.4 ± 7.5a	263.6 ± 7.8a
Granular 0.5×	17.4 ± 1.0abc	376.5 ± 10.9a	6.1 ± 0.1ab	36.2 ± 1.6abc	167.4 ± 6.2ab	266.2 ± 5.7a
Drench 0.25×	17.1 ± 1.1abc	390.6 ± 10.4a	6.4 ± 0.1a	41.8 ± 1.2a	175.2 ± 17.0a	267.7 ± 6.1a
Drench 0.5×	16.1 ± 1.4abc	378.9 ± 11.9a	5.6 ± 0.1bc	36.1 ± 1.2abc	147.0 ± 7.7abc	255.7 ± 6.1a
Drench 1×	16.0 ± 1.1abc	361.0 ± 12.1ab	6.2 ± 0.1a	35.3 ± 1.9abc	163.8 ± 7.4abc	250.6 ± 7.5a
Novel treatments						
Tablet 0.12×	14.9 ± 1.5abc	376.5 ± 16.3ab	6.2 ± 0.2ab	39.8 ± 1.5ab	177.4 ± 8.8a	252.3 ± 8.5a
Tablet 0.25×	15.3 ± 1.3abc	376.6 ± 11.4a	5.9 ± 0.1abc	37.2 ± 1.1abc	174.5 ± 7.8a	257.4 ± 4.7a
Tablet 0.5×	20.1 ± 1.1a	416.1 ± 6.8a	5.9 ± 0.1abc	42.0 ± 1.3a	175.7 ± 6.0a	254.6 ± 4.4a
Soak 0.5×	11.5 ± 1.8c	296.2 ± 16.3c	5.4 ± 0.2c	32.1 ± 1.8c	125.4 ± 12.2c	245.4 ± 7.3a
Soak 1×	13.4 ± 1.5bc	315.5 ± 15.3bc	5.6 ± 0.1bc	32.1 ± 1.6c	146.8 ± 12.1abc	240.6 ± 8.1a
Soak 2×	12.7 ± 1.8bc	312.6 ± 18.3bc	5.5 ± 0.1c	33.0 ± 1.9bc	132.4 ± 12.2bc	239.3 ± 7.6a
F (df), *P* one-way	3.0 (12, 200), <0.001	12.5 (12, 76), <0.001	6.9 (12, 203), <0.001	4.9 (12, 213), <0.001	3.4 (12, 83), <0.001	1.6 (12, 144), 0.094
F (df), *P* model	6.0 (38, 174), <0.001	7.1 (38, 174), <0.001	3.8 (38, 177), <0.001	7.8 (38, 187), <0.001	5.0 (38, 189), <0.001	2.5 (38, 118), <0.001
F (df), *P* treatment	4.9 (12), <0.001	13.4 (12), <0.001	7.5 (12), <0.001	8.6 (12), <0.001	6.5 (12), <0.001	2.1 (12), 0.021
F (df), *P* block	39.1 (2), <0.001	5.8 (2), 0.004	2.3 (2), 0.106	9.9 (2), <0.001	11.1 (2), <0.001	12.3 (2), <0.001
F (df), *P* trt × blk	3.6 (24), <0.001	4.0 (24), <0.001	2.0 (24), 0.005	7.1 (24), <0.001	3.8 (24), <0.001	1.9 (24), 0.011

Means in the same column followed by different letters are significantly different; PROC GLM and Tukey–Kramer HSD comparison of means, $\alpha = 0.05$.

Table 6. Biomass (kilograms) of field-grown poplar planted on 14 June 2004 and treated with imidacloprid on 6 August 2004 at 16 mo after planting

Treatment, label rate	Wet wood	Dry wood	Wet leaves	Dry leaves
Control (untreated)	1.9 ± 0.2abc	1.0 ± 0.1abc	0.64 ± 0.07ab	0.21 ± 0.02ab
Standard treatments				
Granular 0.12×	2.0 ± 0.2abc	1.1 ± 0.1abc	0.54 ± 0.08ab	0.19 ± 0.02ab
Granular 0.25×	2.0 ± 0.2abc	1.1 ± 0.1abc	0.53 ± 0.05ab	0.18 ± 0.02ab
Granular 0.5×	2.0 ± 0.2abc	1.1 ± 0.1abc	0.43 ± 0.04b	0.16 ± 0.02b
Drench 0.25×	2.1 ± 0.2ab	1.1 ± 0.1ab	0.66 ± 0.09ab	0.23 ± 0.03ab
Drench 0.5×	2.2 ± 0.2ab	1.2 ± 0.1a	0.55 ± 0.08ab	0.22 ± 0.02ab
Drench 1×	1.8 ± 0.3abc	1.0 ± 0.1abc	0.47 ± 0.10b	0.16 ± 0.03b
Novel treatments				
Tablet 0.12×	2.2 ± 0.2a	1.2 ± 0.1a	0.89 ± 0.08a	0.30 ± 0.02a
Tablet 0.25×	1.8 ± 0.1abc	1.1 ± 0.1abc	0.48 ± 0.04b	0.17 ± 0.01b
Tablet 0.5×	2.5 ± 0.2a	1.3 ± 0.1a	0.74 ± 0.03ab	0.25 ± 0.01ab
Stick Soak 0.5×	1.2 ± 0.2c	0.6 ± 0.1c	0.56 ± 0.10ab	0.19 ± 0.03ab
Stick soak 1×	1.2 ± 0.2c	0.6 ± 0.1c	0.53 ± 0.11ab	0.19 ± 0.03ab
Stick soak 2×	1.3 ± 0.2bc	0.7 ± 0.1bc	0.61 ± 0.11ab	0.21 ± 0.03ab
F (df), *P* one-way	4.8 (12, 144), <0.001	5.1 (12, 144), <0.001	4.3 (12, 35), <0.001	4.4 (12, 35), <0.001
F (df), *P* model	11.3 (38, 118), <0.001	10.5 (3, 118), <0.001	6.0 (25, 79), <0.001	4.9 (25, 79), <0.001
F (df), *P* treatment	13.0 (12), <0.001	12.9 (12), <0.001	4.7 (12), <0.001	4.1 (12), <0.001
F (df), *P* block	43.6 (2), <0.001	27.4 (2), <0.001	25.5 (1), <0.001	8.8 (1), 0.004
F (df), *P* trt × blk	7.8 (24), <0.001	7.9 (24), <0.001	5.8 (12), <0.001	5.4 (12), <0.001

Means in the same column followed by different letters are significantly different; PROC GLM and Tukey–Kramer HSD comparison of means, $\alpha = 0.05$.

tion is that trees in our field study were stunted due to drying out of roots after planting, rather than a phytotoxic response from the imidacloprid. In containers, plants were watered daily so roots did not dry out.

In field-grown poplars, no major differences in growth parameters (RGR, total height, internode length, trunk basal diameter, leaf area, and chlorophyll) were found. Stick soak treatments (0.5×, 1×, and 2×) had lower height and trunk basal diameter compared with controls, but not all other treatments. However, in a subsequent study, we found no differences in height or basal diameter of 1.5× stick soaks compared with controls (0.74 g [AI]/liter used; Merit 2 F, 3.1 ml/liter) (Tenczar and Krischik 2007).

In container-grown plants, survivorship of adults and larvae were reduced for 12 mo with all granular (0.12×, 0.25×, and 0.5×), all tablet (0.25×, 0.5×, and 1×), and all drench (0.5×, 1×, and 2×) treatments. In the literature, we could not find any studies on duration of granular treatments in containerized plants.

Table 7. Percentage of survivorship of adult *C. scripta* at 96 h fed leaves from container-grown poplar planted on 14 June 2004 and treated with imidacloprid on 30 July 2004

Treatment, label rate	Mo after treatment		
	1 mo	8 mo	12 mo
Control (untreated)	98.6 ± 1.4a	100.0a	95.8 ± 4.2a
Standard treatments			
Granular 0.12×	5.6 ± 2.5c	0.0b	4.2 ± 4.2c
Granular 0.25×	8.3 ± 3.5c	0.0b	4.2 ± 4.2c
Granular 0.5×	2.8 ± 1.9c	0.0b	0.0c
Drench 0.5×	2.8 ± 1.9c	8.3 ± 8.3b	0.0c
Drench 1×	9.7 ± 3.0c	0.0b	0.0c
Drench 2×	4.2 ± 2.3c	0.0b	0.0c
Novel treatments			
Tablet 0.25×	47.2 ± 8.1b	0.0b	4.2 ± 4.2c
Tablet 0.5×	38.9 ± 5.8b	0.0b	4.5 ± 4.5c
Tablet 1×	33.3 ± 7.0b	0.0b	4.5 ± 4.5c
Stick soak 0.5×	1.4 ± 1.4c	25.0 ± 17.1b	66.7 ± 9.4ab
Stick soak 1×	5.6 ± 2.5c	8.3 ± 8.3b	75.0 ± 7.5ab
Stick soak 2×	6.9 ± 3.4c	25 ± 17.1b	50.0 ± 12.3b
Root dip 1×	8.3 ± 3.5c	8.3 ± 8.3b	81.8 ± 7.6ab
Root dip 2×	11.7 ± 4.8c	8.3 ± 8.3b	64.3 ± 18.0ab
Root dip 4×	0.0c	8.3 ± 8.3b	65.0 ± 13.0ab
F (df), *P* one-way	44.5 (15, 269), <0.001	10.7 (15, 80), <0.001	28.7 (15, 166), <0.001
F (df), *P* model	15.4 (47, 237), <0.001	8.8 (47, 48), <0.001	13.8 (47, 134), <0.001
F (df), *P* treatment	45.5 (15), <0.001	20.4 (15), <0.001	37.9 (15), <0.001
F (df), *P* block	1.8 (2), 0.175	17.3 (2), <0.001	4.5 (2), 0.013
F (df), *P* trt × blk	1.2 (30), 0.248	2.4 (30), 0.004	2.6 (30), <0.001

Means in the same column followed by different letters are significantly different; PROC GLM and Tukey–Kramer HSD comparison of means, $\alpha = 0.05$.

Table 8. Percentage of survivorship of larval *C. scripta* at 96 h fed leaves from container-grown poplar planted on 14 June 2004 and treated with imidacloprid on 30 July 2004

Treatment, label rate	Mo after treatment		
	1 mo	9 mo	12 mo
Control (untreated)	88.8 ± 2.79a	76.2 ± 8.8a	86.4 ± 7.0a
Standard treatments			
Granular 0.12×	0.0c	0.0b	0.0c
Granular 0.25×	0.0c	0.0b	0.0c
Granular 0.5×	0.0c	0.0b	0.0c
Drench 0.5×	0.0c	0.0b	0.0c
Drench 1×	0.0c	0.0b	0.0c
Drench 2×	0.0c	0.0b	0.0c
Novel treatments			
Tablet 0.25×	27.9 ± 8.0b	0.0b	0.0c
Tablet 0.5×	13.9 ± 7.3bc	0.0b	0.0c
Tablet 1×	13.9 ± 6.1bc	0.0b	0.0c
Stick soak 0.5×	0.0c	0.0b	20.8 ± 11.4bc
Stick soak 1×	0.7 ± 0.7c	0.0b	20.8 ± 9.6bc
Stick soak 2×	0.0c	0.0b	8.3 ± 5.6c
Root dip 1×	0.0c	0.0b	39.4 ± 13.2b
Root dip 2×	0.0c	0.0b	7.1 ± 7.1bc
Root dip 4×	0.0c	0.0b	5.0 ± 5.0c
F (df), *P* one-way	49.8 (15, 269), <0.001	62.6 (15, 81), <0.001	15.3 (15, 165), <0.001
F (df), *P* model	16.54 (47, 237), <0.001	14.3 (47, 49), <0.001	6.8 (47, 133), <0.001
F (df), *P* treatment	49.5 (15), <0.001	44.7 (15), <0.001	17.7 (15), <0.001
F (df), *P* block	0.3 (2), 0.732	0.2 (2), 0.814	1.1 (2), 0.352
F (df), *P* trt × blk	1.0 (30), 0.478	0.3 (30), 0.999	1.8 (30), 0.012

Means in the same column followed by different letters are significantly different; PROC GLM and Tukey–Kramer HSD comparison of means, $\alpha = 0.05$.

We found two studies that documented that 1× drench applications lasted 6 wk in containerized citrus for *D. abreviatus* root weevil (Quintela and McCoy 1997) and 5 wk in containerized tobasco pepper, *Capsicum frutescen* L., for green peach aphid, *Myzus persicae* (Sulzer) (0.72 mg [AI] used; Admire 2 F, 0.06 ml of product in 500 ml of water, 25 ml solution per plant) (Diaz and McLeod 2005). In containers, stick soak and root dip treatments reduced survivorship of larvae for 12 mo and adults for 8 mo at 1×, 2×, and 4× rates. In the only other published study on root dips of imidacloprid, containerized *P. persicae* were protected for 2.5 mo from black peach aphid, *Brachycaudis persicae* (Passerini), at 0.4×, 0.8×, and 1.6× rates (0.19, 0.38, and 0.75 g [AI] used; Admire 2 F, 0.8, 1.6, and 3.13 ml of product per liter of water) (Shearer and Frecon 2002).

There are few insecticide labels that permit root dips or seedling dips. The Lorsban 75 WG label (75% chlorpyrifos, Dow AgroSciences, Indianapolis, IN) permits dormant bare root or root ball dips for fruit, nut, and Christmas trees (Dow AgroSciences 2007), and the Talstar Nursery Flowable label (7.9% bifenthrin, FMC Corporation, Philadelphia, PA) permits dormant root dips for ornamentals for black vine weevil, *Otiorhynchus sulcatus* F. (FMC Corporation 2003). Root dips of chlorpyrifos for *Popillia japonica* Newman are part of the Japanese beetle harmonization agreement (NPB 1998). The protocol states that imidacloprid can be used as a granular or drench treatment, but imidacloprid is not approved as a root dip. A dip of chlorpyrifos protected field-grown white ash, *Fraxinus americana* L.; cherry plum, *Prunus cerasifera* J. F. Ehrh.; and crabapple (*Malus* sp.) for 6 mo from *P. japonica* larvae (Oliver et al. 2007). Dormant root dips (1.5×) of containerized *Rosa* sp. 'Mr. Lincoln' hybrid tea rose killed *P. japonica* adults on leaves for 3 mo (0.74 g [AI]/liter used; Merit 2 F, 3.1 ml/liter) (Gupta and Krischik 2007). In another study, 30× dips of dormant saplings of cottonwood, *Populus deltoides* Bartr. ex Marsh. 'Siouxland', killed *C. scripta* larvae for 12 mo (Tenczar and Krischik 2007).

None of the treatments in our study caused any signs of phytotoxicity. In 0.5–1× drenches, cauliflower plugs experienced only slight marginal necrosis on leaves (90–360 g [AI]/ha used, Admire 2 F) (Natwick et al. 1996). In *Eucalyptus nitens* (Deane & Maiden) seedlings, 1× and 3.3× drenches did not cause leaf necrosis (0.5 and 1.8 g [AI] used, Confidor 350 SC, Bayer CropScience, Santiago, Chile, 350 g [AI]/liter, 1.5–5.0 ml of product per liter of water) (Hurley and Patel 2003).

In some studies, imidacloprid applications demonstrated enhanced plant growth, which was first documented in cotton (Oosterhuis and Brown 2003). Container-grown hybrid poplars treated with 1.5× and 3× stick soak showed increased growth for 10 mo (0.72 and 1.4 g [AI]/liter used; Admire 2 F) (Tenczar and Krischik 2006). Root dips (30×) of dormant saplings of *P. deltoides* Siouxland demonstrated increased leaf area at 4 mo (Tenczar and Krischik 2007). Granular (0.5× and 1.5×), drench (1×), and tablet (0.5×) applications increased leaf size in roses (granular: 0.5 and 1.5 g [AI] used; Merit 2.5 G, 2.5% [AI], 20 and 60 g of product; drench: 0.5 g [AI] used; Merit 2 F; and tablet: 0.5 g [AI] used, 20% [AI], 2.5-g tablet) (Gupta and Krischik 2007).

Table 9. Growth parameters of container-grown poplar planted on 14 June 2004 and treated with imidacloprid on 30 July 2004 at 14 mo after planting

Treatment, label rate	Growth parameter					
	RGR (cm/wk)	Ht (cm)	Internode length (cm)	Basal diam (mm)	Leaf area (cm^2)	Chlorophyll (field scout)
Control (unteated)	3.0 ± 0.5ab	185.3 ± 7.8a	2.9 ± 0.1a	9.2 ± 0.4a	64.8 ± 3.9a	133.7 ± 6.2a
Standard treatments						
Granular 0.12×	1.6 ± 0.3ab	189.8 ± 5.4a	3.0 ± 0.2a	8.7 ± 0.2a	73.4 ± 6.7a	125.9 ± 3.5a
Granular 0.25×	2.3 ± 0.4ab	209.8 ± 8.3a	2.9 ± 0.2a	9.8 ± 0.3a	81.3 ± 7.3a	143.4 ± 5.5a
Granular 0.5×	2.6 ± 0.2ab	197.4 ± 9.8a	2.9 ± 0.2a	9.0 ± 0.4a	86.5 ± 9.8a	147.2 ± 7.5a
Drench 0.5×	2.8 ± 0.4ab	192.8 ± 5.4a	3.0 ± 0.1a	8.8 ± 0.3a	67.6 ± 4.3a	137.4 ± 6.1a
Drench 1×	3.4 ± 0.6a	212.1 ± 12.0a	2.9 ± 0.2a	8.5 ± 0.5a	72.0 ± 4.6a	137.9 ± 3.9a
Drench 2×	2.9 ± 0.2ab	190.2 ± 8.4a	2.7 ± 0.2a	8.5 ± 0.4a	68.4 ± 4.2a	133.0 ± 4.6a
Novel treatments						
Tablet 0.25×	2.0 ± 0.4ab	201.3 ± 7.1a	2.9 ± 0.2a	9.2 ± 0.2a	76.7 ± 5.2a	136.7 ± 2.8a
Tablet 0.5×	2.1 ± 0.4ab	193.4 ± 8.1a	2.8 ± 0.2a	9.1 ± 0.3a	72.9 ± 5.4a	138.5 ± 6.8a
Tablet 1×	2.2 ± 0.3ab	205.3 ± 5.7a	2.8 ± 0.2a	9.4 ± 0.2a	65.0 ± 4.3a	138.8 ± 5.8a
Soak 0.5×	1.9 ± 0.4ab	173.7 ± 6.4a	2.8 ± 0.1a	8.4 ± 0.3a	73.8 ± 6.9a	138.1 ± 4.6a
Soak 1×	2.3 ± 0.4ab	173.0 ± 8.1a	3.4 ± 0.2a	8.3 ± 0.4a	72.2 ± 6.5a	143.7 ± 5.7a
Soak 2×	2.9 ± 0.3ab	187.5 ± 7.3a	3.2 ± 0.1a	9.0 ± 0.3a	70.6 ± 4.2a	140.7 ± 2.7a
Dip 1×	2.0 ± 0.4ab	173.9 ± 9.6a	3.1 ± 0.2a	9.3 ± 0.4a	73.2 ± 7.6a	132.0 ± 7.2a
Dip 2×	1.4 ± 0.3b	190.1 ± 10.9a	3.2 ± 0.2a	9.3 ± 0.5a	76.2 ± 6.1a	134.8 ± 4.8a
Dip 4×	2.1 ± 0.5ab	186.8 ± 18.4a	3.2 ± 0.2a	9.5 ± 0.7a	66.8 ± 5.0a	122.6 ± 4.9a
F (df), *P* one-way	2.0 (15, 81), 0.023	2.1 (15, 119), 0.015	1.2 (15, 125), 0.302	1.4 (15, 137), 0.099	1.0 (15, 291), 0.479	1.4 (15, 135), 0.179
F (df), *P* model	1.9 (47, 189), 0.002	1.4 (47, 296), 0.045	1.6 (47, 308), 0.011	1.2 (47, 340), 0.245	1.2 (47, 259), 0.158	1.8 (47, 103), 0.009
F (df), *P* treatment	2.7 (15), 0.001	2.2 (15), 0.007	1.4 (15), 0.170	1.6 (15), 0.069	1.1 (15), 0.365	1.6 (5), 0.082
F (df), *P* block	4.4 (2), 0.014	1.2 (2), 0.307	8.1 (2), <0.001	4.3 (2), 0.014	1.7 (2), 0.184	8.0 (2), <0.001
F (df), *P* trt × blk	1.8 (30), 0.013	1.1 (30), 0.286	1.3 (30), 0.161	0.8 (30), 0.785	1.3 (30), 0.145	1.4 (30), 0.108

Means in the same column followed by different letters are significantly different; PROC GLM and Tukey–Kramer HSD comparison of means, $\alpha = 0.05$.

In summary, this study documents for field- and container-grown poplar trees that tablet treatments offer similar duration and efficacy as granular and drench applications. Tablets are easy to apply, they reduce the risk of accidental pesticide exposure, and they have lower impacts on beneficial insects, because the insecticide is not sprayed. Tablets offer an easy application method for plantations of trees. In containerized plants, stick soak and root dips offer protection for valuable transplants. Stick soak and root dip applications can be used in Christmas tree and ornamentals transplants against root weevils, white grubs, and defoliators.

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