Management of Cottonwood Leaf Beetle (Coleoptera: Chrysomelidae) with a Novel Transplant Soak and Biorational Insecticides to Conserve Coccinellid Beetles

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ABSTRACT Biorational foliar sprays and a novel application method of soaking transplants in imidacloprid were evaluated for control of adult and larval cottonwood leaf beetle, *Chrysomela scripta* F., on hybrid poplar, with emphasis on conservation of coccinellid predators. Foliar sprays of four biorational insecticides killed adult and larval *C. scripta*: *Bacillus thuringiensis* (*B.t.*) variety *tenebrionis* (Novodor), *B.t.* variety *kurstaki* (Raven), spinosad (Conserve SC), and azadirachtin (Azatin XL) (larvae only) but did not kill two species of coccinellids, *Hippodamia convergens* Guérin-Meneville and *Harmonia axyridis* (Pallas). Only imidacloprid (Admire 2) and carbaryl (Sevin XLR Plus) killed two species of coccinellids and adult and larval *C. scripta*. We evaluated a novel stick soak method for systemically applying imidacloprid by soaking poplar sticks in Admire 2 solutions of 3 and 6 ml/liter for 48 h before planting. The imidacloprid in the sticks was translocated to the leaves and reduced survivorship of adult and larval *C. scripta* for 10 mo without any symptoms of phytotoxicity. The novel stick soak method did not kill two species of coccinellids when foraging on leaves.

KEY WORDS *Chrysomela scripta*, coccinellids, imidacloprid, biorational insecticides, novel stick soak

THE COTTONWOOD LEAF BEETLE, *Chrysomela scripta* F. (Coleoptera: Chrysomelidae), is an important defoliator of hybrid poplar cultivated for biomass, pulp, and timber. Clone NM6 (*Populus nigra*× *maximowiczii*) is an important clone used for biomass and pulp production (AURI 2001, Broadacres Nursery 2003), and it is highly preferred for feeding by *C. scripta*. *C. scripta* occurs throughout the United States, where it feeds on *Populus* and some *Salix* spp. (Johnson and Lyon 1991). Three to four generations occur in Minnesota, and up to seven generations occur in the south, such as Mississippi (Oliveria and Solomon 2004). Adults overwinter under bark or leaf litter (Johnson and Lyon 1991, Andersen and Nelson 2002) and emerge in spring to feed on new twigs and buds.

Adults and larvae prefer to feed on shoot terminals (leaf plastochron index [LPI] 0–8, where LPI 0 is the smallest expanded leaf from the terminal, and the leaves are numbered sequentially below LPI 0) (Bingaman and Hart 1992). Feeding can kill saplings and significantly damage growing trees by reducing tree height, diameter, and biomass (Reichenbacker et al. 1996, Andersen and Nelson 2002, Fang et al. 2002). One egg mass causes 75% terminal defoliation and reduces biomass by 33% over two seasons (Fang and Hart 2000). In addition, defoliation for three seasons reduces aboveground biomass by 50–73%, and chemically treated trees grow 1.25 m taller than controls in the second and third seasons (Coyle et al. 2002). Furthermore, damage to terminal leaders causes multiple leaders (Coyle et al. 2002, Oliveria and Solomon 2004), making trees harder to debark after harvesting. Damage also can contribute to tree mortality from *Septoria musiva* stem canker (Coyle et al. 2002). During the first 2 yr, poplars are vulnerable to mortality from *C. scripta* because the beetles remove the terminal shoots of the young saplings. Poplars are cultivated by planting 0.2-m dormant woody cuttings (sticks) in the ground. Because only one bud remains above ground to produce terminals, beetle feeding can kill saplings.

During the first 3 yr of growth, insecticides are needed to control *C. scripta* (USDA–FS 1989) because poplars of this age class contain higher percentages of desirable foliage than do older trees (Bingaman and Hart 1992, Coyle et al. 2002). During the first 2 yr, ground spraying is used, but as the trees grow and the canopy fills in the area between the rows, aerial spraying is needed. Broad-spectrum conventional insecticides are used, such as carbaryl, chlorpyrifos, acephate, and lambda-cyhalothrin (Krischik and Hahn 2003, Kelly Registration Systems 2004), which kill adult and larval *C. scripta* as well as foraging coccinellid beetles, the primary biological control agents. Coccinellids, such as *Coleomegilla maculata* (DeGeer), *Hippodamia convergens* Guérin-Meneville, and *Harmonia axyridis* (Pallas) consume eggs and pupae (Oliveria and Solomon 2004). *C. maculata* also has been observed feeding on eggs and small larvae of the

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elm leaf beetle, *Pyrrhalta luteola* (Müller) (Weber and Holman 1976). The pteromalid wasp *Shizonatus latus* (Walker) and a tachinid fly parasitize *C. scripta* (Neel et al. 1976), but parasitoids will not control outbreaks. After the first 3 yr of growth, coccinellid predators may control *C. scripta* populations (USDA–FS 1989). In addition to killing the primary biological control agents, aerial spraying of carbaryl in Minnesota has created issues on nontarget effects on honey bee, *Apis mellifera* L., mortality.

An integrated pest management (IPM) program for *C. scripta* needs to be developed that uses conventional insecticides when damage from beetles is high but biorational insecticides that conserve beneficial insects when beetle populations are low. Although *Bacillus thuringiensis* (*B.t.*) variety *tenebrionis* (Novodor, which contains coleopteran toxin) and *B.t.* variety *kurstaki* (Raven, which contains a mix of lepidopteran and coleopteran toxins that act synergistically) were demonstrated to reduce survivorship of larvae and adults (Coyle et al. 2000), they are not widely used. The abilities of other newer biorational insecticides, such as spinosad, azadirachtin, and *Beauveria bassiana*, to manage *C. scripta* and conserve beneficial insects have not been studied.

We studied two conventional insecticides: imidacloprid (Admire 2) and carbaryl (Sevin XLR Plus), and several biorational insecticides: *B.t.* variety *tenebrionis* (Novodor), *B.t.* variety *kurstaki* (Raven), spinosad (Conserve SC), azadirachtin (Azatin XL), and *B. bassiana* (Botanigard). Imidacloprid is labeled as a systemic insecticide and is applied to soil or foliage. It has been used for controlling *P. luteola* (Lawson and Dahlsten 2003). Spinosad, which targets leaf beetles and other pests, has replaced malathion for control of the Mediterranean fruit fly, *Ceratitis capitata* (Weidemann) (Peck and McQuate 1999), with little harm to coccinellids and honey bees (Michaud 2003). Azadirachtin also is used for controlling leaf beetles with little effect on coccinellids (Smith and Krischik 2000). *B. bassiana* has been used against a variety of beetle pests, such as Colorado potato beetle, *Leptinotarsa decemlineata* (Say) (Fernandez et al. 2001), which belongs to the same subfamily, Chrysomelinae, as *C. scripta.*

Systemic imidacloprid has been used on other crops with minimal phytotoxic affects on plants. In drench treatments of plant plugs, cauliflower transplants experienced only slight marginal necrosis on leaves, whereas in-furrow treatments experience almost no phytotoxicity at labeled rates (Natwick et al. 1996). In greenhouse soil granular applications of imidacloprid (1/8 to 1 tsp per 4.5 in.) on tomato and cucumber, leaf chlorosis, distortion, and necrosis occurred within 7 d after treatment (Ebel et al. 2000). Leaf area and shoot dry weight also were lower in treatments compared with controls (Ebel et al. 2000). However, a subsequent study on cucumber using the same rates as Ebel et al. (2000) revealed no significant differences in leaf area and shoot dry weight between treatments and controls (Wallace et al. 2000). These authors speculated that wilting and high temperatures in Ebel et al. (2000) contributed to plant damage rather than the chemical itself. In a study of 8-wk-old *Eucalyptus nitens* (Deane and Maiden) seedlings, leaf necrosis did not occur when treated with 1.5–5.0 ml/liter imidacloprid (Hurley and Patel 2003), and muskmelon treated with 0.02–0.08 g (AI) imidacloprid experienced similar growth rate and yield as controls from which whiteflies were excluded (Palumbo and Sanchez 1995). Peach tree roots dipped in imidacloprid for 2 s or 5 min at rates of 0.8, 1.6, 3.1, and 6.3 ml/liter had longer shoots and wider girth compared with controls at 5 wk after treatment, and treated trees experienced lower mortality than controls (Shearer and Frecon 2002). Furthermore, in cotton, imidacloprid (Trimax) is labeled as a growth enhancer as well as an insecticide (Bayer CropScience 2004).

We investigated novel methods for applying imidacloprid to poplar transplants that protect coccinellids from harmful insecticidal sprays. According to its label, imidacloprid can be used as a soil drench or foliar spray. The chemical is systemic, so a soil drench kills insects that feed on leaves, but not those that walk on leaves, such as coccinellids. Because poplar transplants or sticks are soaked for 48 h before planting and because imidacloprid is systemic, we hypothesized that sticks soaked in imidacloprid-treated water for 48 h should absorb imidacloprid, which would be translocated to leaves and protect the vulnerable transplants from *C. scripta* while conserving coccinellids.

An IPM program for poplar transplants that manages adults and larvae of *C. scripta* and conserves beneficial coccinellids needs to be implemented. First, we determined which conventional and biorational insecticides could be used to manage larval and adult *C. scripta* and conserve coccinellids. Second, we determined efficacy and duration of soaking transplants (sticks) for managing larval and adult *C. scripta* and for conserving coccinellid beetles.

Materials and Methods

Experimental Organisms. Poplar clone NM6 (*Populus nigra* × *maximowiczii*) was developed in Europe (Broadacres Nursery 2003) and is used in poplar plantations harvested for biomass and pulp. It is propagated with dormant stem cuttings (sticks) that are harvested in November and then soaked for 2 d before planting in early spring. Our sticks were obtained from an International Paper nursery (Alexandria, MN). Dormant cuttings were stored in a walk-in refrigerator until use and then soaked in water or imidacloprid-treated water for 48 h before planting.

C. scripta are multivoltine; therefore, beetles were raised year-round in the greenhouse in cages covering small NM6 trees. Additionally, beetles were raised in 14-liter rectangular plastic containers in an incubator at 23°C in which poplar terminals were placed in 25-ml water tubes with plastic lids (Syndicate Sales, Kokomo, IN).

Two species of coccinellids (*H. convergens* and *H. axyridis*) were ordered from a biological control in-

sectary (Rincon-Vitova, Ventura, CA) and used to test nontarget effects of insecticides. Beetles were housed in cages 31 by 31 cm. Paper towels were placed on the bottoms of cages. Beetles were fed a variety of foods, including commercial coccinellid diets, bee pollen, honey, apples, aphids, and water (with and without honey added) in 25-ml water tubes covered with cotton.

Experiment 1: Conventional and Biorational Foliar Sprays. NM6 poplar sticks (23 cm in length) were planted in 1.2–3.5-liter pots and allowed to grow for 7–15 mo in the greenhouse. The leaders were cut repeatedly to create multiple stems because *C. scripta* prefer to feed on LPI 0–8 (Bingaman and Hart 1992). Foliar sprays of insecticides were applied at labeled rates using 8-liter lawn and garden sprayers and allowed to dry for 24 h. Leaves were then excised and bioassayed. Insecticides used were the following: imidacloprid (Admire 2, Bayer CropScience, Research Triangle Park, NC, 21.5% [AI], label rate 0.7 ml/liter), carbaryl (Sevin XLR Plus, Bayer CropScience, 44.1% [AI], label rate 2.6 ml/liter), spinosad (Conserve SC, Dow Agrosciences, Indianapolis, IN, 11.6% [AI], label rate 0.5 ml/liter), *B.t.* variety *tenebrionis* (Novodor, Valent Biosciences Corp., Libertyville, IL, 10% [AI], label rate 100 ml/liter), *B.t.* variety *kurstaki* (Raven, Ecogen Inc, Langhorne, PA, 25% [AI], label rate 60 ml/liter), azadirachtin (Azatin XL, Olympic Horticultural Sciences, Roswell, GA, 3% [AI], label rate 1.3 ml/liter), and *B. bassiana* (Botanigard ES, Emerald Bio Agriculture Corp., Placitas, NM, 11.3% [AI], label rate 2 qt/100 gal).

Leaves were placed on moist filter paper in petri dishes (100 by 15 mm), and adults and larvae were fed on treated or untreated leaves for 7 d. Filter paper was changed once during the bioassays, and leaves were added as needed. Two species of coccinellids were tested using the same design, except artificial diet was placed on leaves. Three replicate studies were conducted sequentially to avoid limitations on beetle numbers for bioassays (treatment dates 24 July 2003, 31 July 2003, and 2 April 2004), and survivorship was recorded. Replicates were combined, and data were analyzed by PROC GLM for treatment, replicate, and treatment by replicate interactions. Data were analyzed for homogeneity by using Levene's test and transformed when necessary. Means were compared using Tukey's honestly significant difference (HSD) test (SAS Institute 2003).

Experiment 2: Stick Soak, a Novel Method of Applying Imidacloprid. NM6 poplar sticks (23 cm in length) were soaked for 48 h in Admire 2 F (21.4% imidacloprid). Because stick soak is a novel application method, and there is no label rate, we used 3.0 and 6.0 ml/liter. Poplars were then planted in cylindrical pots (6.3 by 25.4 cm) in the greenhouse. After they initiated growth and roots began to reach out of pots, poplars were transplanted into larger pots (10 cm^2 by 35 cm). Every few months leaves were excised and bioassayed. Leaves were placed on moist filter paper in petri dishes (100 by 15 mm) with adult and larval *C. scripta* or two species of coccinellids. Adults and larvae were fed on treated or untreated leaves for 4 d, and coccinellids were fed on artificial diet placed on leaves. Two replicate studies were conducted (treatment dates 22 May 2003 and 3 July 2003), and survivorship was recorded. Replicates were combined, and data were analyzed by PROC GLM for treatment, replicate, and treatment by replicate interactions. Data were analyzed for homogeneity using Levene's test and transformed when necessary. Means were compared using Tukey's HSD test. When replicates were analyzed separately by analysis of variance (ANOVA), data were analyzed for homogeneity using Levene's and Welch's tests. Means were compared using Tukey's HSD test (SAS Institute 2003).

To determine whether the stick soak method affected plant growth, relative growth rates, were measured. Phytotoxicity parameters, such as leaf browning, lack of shoot elongation, and plant stunting, were evaluated. Data on growth rates were presented as separate replicates, because they were started 2 mo apart, and measurements were not done at the same time intervals. We were concerned that seasonal influences, such as light levels, light quality, and temperature, affected our data. Replicates were not combined, and data were analyzed separately by analysis of variance (ANOVA) and transformed when necessary. Data were analyzed for homogeneity using Levene's and Welch's tests. Means were compared using Tukey's HSD test (SAS Institute 2003).

Results

Experiment 1: Conventional and Biorational Foliar Sprays. The biorational insecticides spinosad (Conserve SC), *B.t.* variety *tenebrionis* (Novodor), and *B.t.* variety *kurstaki* (Raven), killed adult *C. scripta* as well as conventional insecticides carbaryl (Sevin XLR Plus) and foliar imidacloprid (Admire 2). Adults were not killed by azadirachtin (Azatin XL) and *B. bassiana* (Botanigard) ($F = 221.6$; df = 7, 115; $P < 0.0001$) (Fig. 1). There were no significant differences between replicates ($F = 1.4$; df = 2, 115; $P = 0.2627$), and there was not a significant treatment by replicate interaction ($F = 1.0$; df = 13, 115; $P = 0.5005$).

The biorational insecticides spinosad, *B.t.* variety *tenebrionis*, *B.t.* variety *kurstaki*, and azadirachtin killed larval *C. scripta* as well as conventional insecticides carbaryl and foliar imidacloprid. *B. bassiana* did not kill larvae ($F = 507.1$; df = 7, 110; $P < 0.0001$) (Fig. 1). Although there was a marginally significant treatment by replicate interaction ($F = 1.9$; df = 12, 110; $P = 0.0469$), there were no significant differences between replicates ($F = 0.8$; df = 2, 110; $P = 0.4432$).

The coccinellid *H. convergens* was killed only by foliar sprays of carbaryl and imidacloprid ($F = 88.6$; df = 6, 70; $P < 0.0001$) (Fig. 2). Although there were significant differences between replicates ($F = 4.9$; df = 1, 70; $P = 0.0298$) and a significant treatment by replicate interaction ($F = 7.7$; df = 6, 70; $P < 0.0001$), treatment effects did not change when replicates were analyzed separately (replicate 1: $F = 26.1$; df = 6, 63; $P < 0.0001$; and replicate 2: $F = 73.4$; df = 6, 63; $P <$

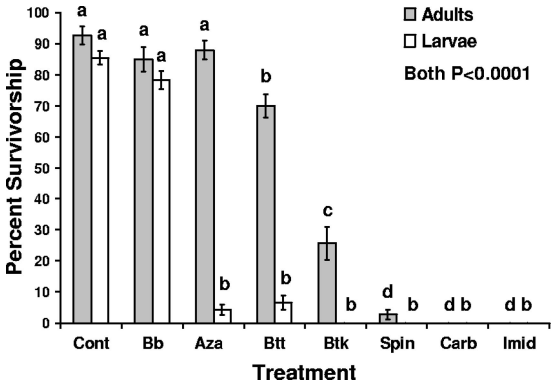

Fig. 1. Percentage of survivorship of adult and larval *C. scripta* at 7 d fed poplar leaves treated with foliar sprays of water (Cont), *B. bassiana* (Bb), azadirachtin (Aza), *B.t.* variety *tenebrionis* (Btt), *B.t.* variety *kurstaki* (Btk), spinosad (Spin), carbaryl (Carb), and imidacloprid (Imid). For adults and larvae, bars of the same color with different letters are significantly different; Tukey's HSD comparison of means, $\alpha = 0.05$.

0.0001). The coccinellid *H. axyridis* was killed only by foliar sprays of carbaryl and imidacloprid ($F = 250.7$; df = 6, 70; $P < 0.0001$) (Fig. 2). Although there was a significant treatment by replicate interaction ($F = 3.4$; df = 6, 70; $P = 0.0050$), there were no significant differences between replicates ($F = 1.9$; df = 1, 70; $P = 0.1730$).

Experiment 2: Stick Soak, a Novel Method of Applying Imidacloprid. In replicates 1 and 2, adult and larval *C. scripta* fed with leaves from sticks that were treated with 3 and 6 ml/liter imidacloprid were killed for 10 mo after treatment (Tables 1 and 2; Figs. 3 and 4).

H. convergens was not affected in the stick soak bioassays ($F = 0.1$; df = 2, 54; $P = 0.9091$). There were no significant differences between replicates ($F = 0.1$;

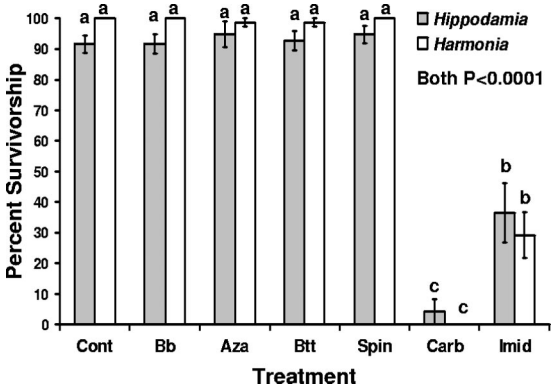

Fig. 2. Percentage of survivorship of adult coccinellids on poplar leaves treated with foliar sprays of water (Cont), *B. bassiana* (Bb), azadirachtin (Aza), *B.t.* variety *tenebrionis* (Btt), spinosad (Spin), carbaryl (Carb), and imidacloprid (Imid). For *Hippodamia* and *Harmonia*, bars of the same color with different letters are significantly different; Tukey's HSD comparison of means, $\alpha = 0.05$.

Table 1. Percentage of survivorship of adult *C. scripta* at 96 h fed poplar leaves from sticks soaked in imidacloprid

Treatment	% survivorship ± SE						
	1 mo	3 mo	4.5 mo	5.5 mo	6.5 mo	8 mo	10 mo
Control	80.2 ± 4.6a	79.3 ± 4.3a	88.9 ± 3.6a	96.3 ± 2.0a	92.5 ± 3.7a	88.6 ± 4.2a	95.0 ± 2.3a
1×, 3 ml/liter	0.0b	9.8 ± 4.1b	25.0 ± 7.6b	7.5 ± 4.1b	29.6 ± 7.8b	66.3 ± 5.5b	70.6 ± 4.8b
2×, 6 ml/liter	0.0b	6.5 ± 3.9b	12.5 ± 5.8b	0.0b	22.5 ± 7.5b	51.3 ± 7.1b	66.3 ± 6.0b
F (df), P treatment	286.8 (2, 123), <0.0001	141.1 (2, 63), <0.0001	86.0 (2, 48), <0.0001	454.4 (2, 54), <0.0001	56.4 (2, 54), <0.0001	12.3 (2, 54), <0.0001	14.0 (2, 54), <0.0001
F (df), P replicate	6.7 (1, 123), 0.0110	37.2 (1, 63), <0.0001	16.4 (1, 48), 0.0002	4.1 (1, 54), 0.0493	34.3 (1, 54), <0.0001	0.0 (1, 54), 0.8937	14.1 (1, 54), 0.0004
F (df), P treatment*replicate	6.7 (2, 123), 0.0018	0.5 (2, 63), 0.5905	17.9 (2, 48), <0.0001	2.6 (2, 54), 0.0867	3.0 (2, 54), 0.0598	5.7 (2, 54), 0.0057	2.0 (2, 54), 0.1488

Survivorship was measured for 10 mo after treatment. Means in the same column followed by different letters are significantly different; PROC GLM and Tukey's HSD comparison of means, $\alpha = 0.05$.

Table 2. Percentage of survivorship of larval *C. scripta* at 96 h fed poplar leaves from sticks soaked in imidacloprid

Treatment	% survivorship ± SE					
	2.5 mo	4.5 mo	5.5 mo	6.5 mo	8 mo	10 mo
Control	88.9 ± 2.2a	88.3 ± 3.3a	80.2 ± 6.9a	95.8 ± 2.7a	91.1 ± 3.7a	71.5 ± 6.1a
1×, 3 ml/liter	0.0b	15.8 ± 5.3b	9.4 ± 3.4b	20.6 ± 6.4b	25.8 ± 6.7b	19.5 ± 5.1b
2×, 6 ml/liter	0.0b	0.8 ± 0.8c	9.2 ± 3.5b	26.9 ± 6.0b	23.8 ± 6.4b	38.6 ± 7.8b
F (df), *P* treatment	1621.7 (2, 108), <0.0001	155.0 (2, 72), <0.0001	89.6 (2, 74), <0.0001	55.9 (2, 74), <0.0001	45.9 (2, 74), <0.0001	24.8 (2, 75), <0.0001
F (df), *P* replicate	8.5 (1, 108), 0.0043	1.7 (1, 72), 0.1969	2.3 (1, 74), 0.1327	6.0 (1, 74), 0.0168	15.3 (1, 74), 0.0002	38.9 (1, 75), <0.0001
F (df), *P* treatment*replicate	8.5 (2, 108), 0.0004	4.1 (2, 72), 0.0214	8.2 (2, 74), 0.0006	4.5 (2, 74), 0.0148	2.2 (2, 74), 0.1150	1.7 (2, 75), 0.1824

Survivorship was measured for 10 mo after treatment. Means in the same column followed by different letters are significantly different; PROC GLM and Tukey's HSD comparison of means, $\alpha = 0.05$.

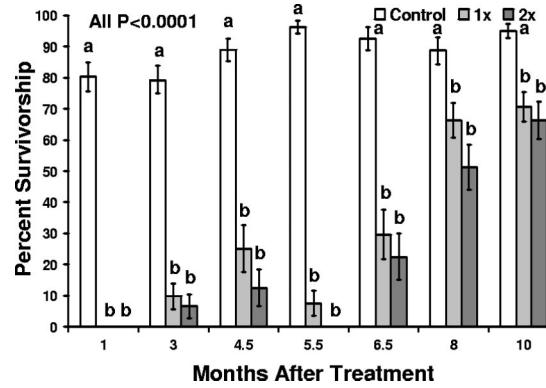

Fig. 3. Percentage of survivorship of adult *C. scripta* at 96 h fed poplar leaves from sticks soaked in imidacloprid, control (0 ml/liter), 1× (3 ml/liter), and 2× (6 ml/liter). Each set of bars represents a time interval from 1 to 10 mo. For each month, bars with different letters are significantly different; Tukey's HSD comparison of means, $\alpha = 0.05$.

df = 1, 54; $P = 0.7490$), and there was not a significant treatment by replicate interaction ($F = 0.7$; df = 2, 54; $P = 0.4894$). *H. axyridis* was not affected in stick soak bioassays, and statistics were not computed because survivorship over all treatments and replicates was 100%.

For relative growth rate measurements, replicates were not combined for analysis because measurements were taken at slightly different time intervals. Imidacloprid-treated plants in replicate 1 had significantly higher growth rates than untreated controls at 1.5–2 mo after treatment ($F = 11.6$; df = 2, 81; $P < 0.0001$) and 2–5 mo after treatment ($F = 10.4$; df = 2, 81; $P < 0.0001$). There were no significant differences in growth rates at 0–1 mo after treatment ($F = 2.3$; df = 2, 81; $P = 0.1019$), 5–6 mo after treatment ($F = 2.7$; df = 2, 81; $P = 0.0726$), and 6–9 mo after treatment ($F = 1.9$; df = 2, 47; $P = 0.1655$) (Fig. 5). Imidacloprid-treated

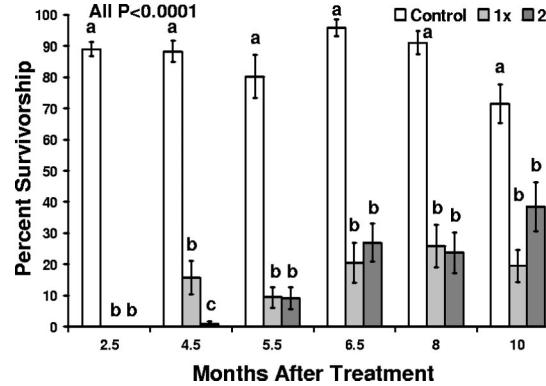

Fig. 4. Percentage of survivorship of larval *C. scripta* at 96 h fed leaves from sticks soaked in imidacloprid, control (0 ml/liter), 1× (3 ml/liter), and 2× (6 ml/liter). Each set of bars represents a time interval from 2.5 to 10 mo. For each month, bars with different letters are significantly different; Tukey's HSD comparison of means, $\alpha = 0.05$.

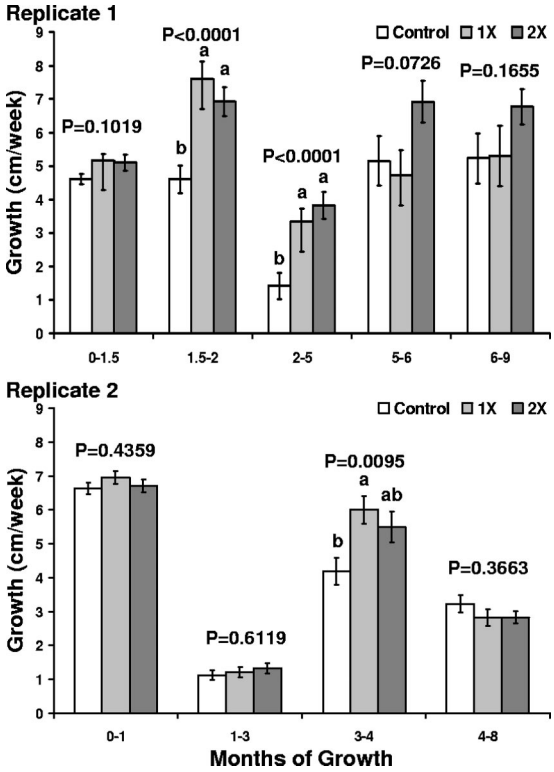

Fig. 5. Relative growth rates of NM6 poplars treated on 22 May 2003 (replicate 1) and 3 July 2003 (replicate 2) with imidacloprid stick soak, control (0 ml/liter), 1× (3 ml/liter), and 2× (6 ml/liter). For each growth interval, bars with different letters are significantly different; Tukey's HSD comparison of means, $\alpha = 0.05$.

plants in replicate 2 had significantly higher growth rates than untreated controls at 3–4 mo after treatment ($F = 4.9$; df = 2, 87; $P = 0.0095$). There were no significant differences in growth rates at 0–1 mo after treatment ($F = 0.8$; df = 2, 87; $P = 0.4359$), 1–3 mo after treatment ($F = 0.5$; df = 2, 87; $P = 0.6119$), and 4–8 mo after treatment ($F = 1.0$; df = 2, 84; $P = 0.3663$) (Fig. 5). Phytotoxicity parameters, such as leaf browning, lack of shoot elongation, and plant stunting, were not observed.

Discussion

Foliar sprays of biorational insecticides spinosad (Conserve SC), *B.t.* variety *tenebrionis* (Novodor), and *B.t.* variety *kurstaki* (Raven) reduced survivorship of adult and larval *C. scripta* without harm to coccinellids. The insect growth regulator azadirachtin (Azatin XL) reduced survivorship of larval *C. scripta* without harm to coccinellids. Carbaryl (Sevin XLR Plus) and foliar imidacloprid (Admire 2) killed *C. scripta* and coccinellids. Our results were similar to another study, in which foliar imidacloprid (Admire 240 FS) was highly toxic to adult and larval *C. maculata* as well as larval *L. decemlineata*, whereas biorational insecticides cryolite (Kryocide WP), cyromazine (Trigard 75 WP), and *B.t.* variety *tenebrionis* (Novodor) killed larval *L. decemlineata* with little harm to adult and larval *C. maculata* (Lucas et al. 2004). In addition, foliar sprays of *B. thuringiensis* (Dipel DF), azadirachtin (Nemix 4.5 EC), and spinosad (Spintor 2 SC) showed low or zero toxicity to larval *C. maculata* (Elzen and James 2002), and spinosad was nontoxic to *H. convergens* (Elzen et al. 1998).

We developed a novel method of applying imidacloprid by soaking poplar sticks in imidacloprid-treated water before planting. The imidacloprid was translocated to poplar leaves and reduced survivorship of adult and larval *C. scripta* without harming coccinellids that walk on the leaves. Treated plants showed no signs of phytotoxicity, but instead imidacloprid seemed to enhance growth in two replicates. In both replicates, treatment effects lasted 10 mo. The novel stick soak may be applicable in woody plant propagation because soaking the cuttings would reduce the amount of (AI)/acre used each season, because the maximum amount permitted is 0.5 lb (AI)/acre/yr (Admire 2 label).

Imidacloprid has been used systemically against a variety of pests in many commodities with soil drench and granular applications. In addition, imidacloprid used as seed potato tuber treatments reduced survivorship of *L. decemlineata* for 55–70 d after treatment (Igrc-Barčić et al. 2000). Peach trees treated with root dips of imidacloprid experienced reduced colonization of black peach aphid, *Brachycaudis persicae* (Passerini), as well as increased survivorship, longer shoots, and wider girth compared with untreated controls (Shearer and Frecon 2002). Another insecticide, bifenthrin (Talstar), has been used to manage black vine weevil, *Otiorhynchus sulcatus* (F.), and white grubs with root dip applications (Sidebottom 2004, Talstar Nursery Flowable label p 3).

An IPM program that uses imidacloprid stick soak in the first two seasons and aerial sprays of biorational insecticides thereafter may control *C. scripta* without harming coccinellids and other beneficial insects. The novel stick soak method can be used in high density tree plantations and other woody propagation systems to reduce insect damage on young trees. The stick soak method permits the use of imidacloprid in high density poplar plantations, where soil applications may exceed the yearly limit of active ingredient. Using the stick soak method also will permit conservation of coccinellid beetles that are important predators of *C. scripta* eggs and reduce the need for aerial spraying that may impact foraging honey bees.

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