Effects of Repeated Applications of Roundup Pro® Over the Top of Container-Grown Nursery Crops[1]

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Abstract

Three experiments studying the effects of repeated over-the-top applications of Roundup Pro® to container-grown nursery crops were conducted. Plants in 3.8 liter (1 gal) containers were treated with either single or multiple applications of Roundup Pro® at 1.12 kg ai·ha^{-1} (1.0 lb ai·A^{-1}) in July, August, September, or October, 2008 or 2009. Plants treated with multiple applications were treated in July and August (J+A); July, August, and September (J+A+S); July, August, September, and October (J+A+S+O); or July and September (J+S). Injury ratings were taken at multiple times after treatments. Growth indices (GI) [(height + width1 + width2) / 3] were taken in January and June 2009 and February and May 2010. Plants were rated for vigor and marketability in May 2009 or June 2010. *Liriope muscari* 'Big Blue,' *Camellia sasanqua* 'Shishigashira,' and *Gardenia jasminoides* 'Radicans' were evaluated in Experiment 1 (2008, Auburn). Liriope showed minor injury from two or more applications with reduced growth from 3 or 4 applications, but all plants were rated as marketable in June of the following season. 'Shishigashira' camellia exhibited no injury from any glyphosate application and all parameters were similar to non-treated controls (NTC). Gardenia showed fall chlorosis and stunting through early spring from multiple applications, but all plants were marketable. Even those treated 3 or 4 times were small but marketable. In Experiment 2 (2009, Auburn. AL), 'Big Blue' liriope, 'Radicans' gardenia, *Camellia sasanqua* 'Martha Sims,' and *Juniperus conferta* 'Blue Pacific' showed no injury from any treatment and GI in January and June were similar to NTC. *Ilex cornuta* 'Dwarf Burfordi' GI were similar to NTC with occasional chlorosis observed after July treatments. *Ternstroemia gymnathera* (cleyera) exhibited chlorosis, necrosis, and stunting of shoot tips for all treatments. Cleyera GI in January and June indicated that J+A+S, J+A+S+O, and J+S-treated plants were smaller than NTC, but regrowth was similar to NTC for all treatments the following spring. All plants were vigorous and marketable. In Experiment 3 (2009, Mobile, AL), 'Big Blue' liriope, 'Radicans' gardenia, 'Blue Pacific' juniper, 'Martha Sims' camellia, *Ilex cornuta* 'Carissa,' and cleyera GI were similar to NTC in February and late May. Slight injury occurred only on the new growth of cleyera and 'Carissa' holly with primary symptoms being chlorosis and/or slight stunting seen in mid-September and October from some single and double applications.

Index words: glyphosate, weed control.

Herbicide used in this study: Roundup Pro® (glyphosate), *N*-(phosphonomethyl) glycine, in the form of its isopropylamine salt.

Species used in this study: 'Big Blue' liriope (*Liriope muscari* 'Big Blue'), 'Radicans' gardenia (*Gardenia jasminoides* 'Radicans'), 'Shishigashira' camellia (*Camellia sasanqua* 'Shishigashira'), 'Martha Sims' camellia (*Camellia sasanqua* 'Martha Sims'), 'Blue Pacific' juniper (*Juniperus conferta* 'Blue Pacific'), cleyera (*Ternstroemia gymnathera*), 'Carissa' holly (*Ilex cornuta* 'Carissa'), 'Dward Burford' holly (*Ilex cornuta* 'Dward Burford').

Significance to the Nursery Industry

Over the past several years, many growers have had to lower their prices of container-grown plants in order to remain competitive in an industry hit hard by a major downfall in the nation's economy. Increased pressures including rising costs of fuel and chemicals, paralleled with a decrease in the availability of seasonal labor, have caused growers to have to make decisions about weed control that, at one time, may have been considered drastic.

Our research on repeated applications of Roundup Pro® over-the-top is intended to provide data for emergency or salvage weed control in nurseries and landscapes when labor is unavailable or when hand weeding would exceed budget limitations.

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As growers have increased their use of over-the-top glyphosate (varied formulations) applications, they are beginning to ask about how often they can apply glyphosate over the top. The objective of the experiment was to determine crop tolerance of container-grown nursery crops to repeated Roundup Pro® applications at 1.12 kg ai·ha^{-1} (1.0 lb ai·A^{-1}), a rate found to be adequate for control of most weeds found in container production.

Introduction

Between 1975 and 1980, glyphosate (various formulations) was evaluated over-the-top of numerous container-grown crops, with many exhibiting some degree of tolerance. In one study, glyphosate (Round-Up®) was applied either once, twice, or three times at 0.56, 0.84, 1.12 and 1.68 kg ai·ha^{-1} (0.50, 0.75, 1.00, and 1.50 lb ai·A^{-1}) on 7, 14, and 21 April over 18 ornamental cultivars (6). Total amounts of Round-Up® applied ranged from 0.56 to 5.00 kg ai·ha^{-1} (0.5 to 4.5 lb ai·A^{-1}). Of the 18 species evaluated, nine were not injured, including saucer magnolia (*Magnolia* × s*oulangeana*), shore juniper (*Juniperus conferta*), cypress (*Cupressus sp.*), 'Burford' holly (*Ilex cornuta* 'Burfordii'), 'Yellow Top' holly (*Ilex cornuta* 'Yellow top'), Fraser photinia (*Photinia* × *fraseri*), pittosporum (*Pittosporum tobira*), podocarpus (*Podocarpus sp.*), and windmill palm (*Trachycarpus fortunei*). 'Radicans'

gardenia (G*ardenia jasminoides* 'Radicans') was injured at 3.36 and 5.04 kg ai·ha^{-1} (3.0 and 4.5 total lb ai·A^{-1}). Of the remaining species, 'Hinodegiri' Kurume azalea (*Rhododendron obtusum* 'Hinodegiri') and 'Fashion' azaleas [*Azalea* × 'Fashion' (Girard Hybrid)] were the most sensitive, with injury occurring from as little as two applications of the 0.56 kg ai (0.5 lb) rate.

In another study, glyphosate (neither formulation nor product was identified) was applied at 0.28, 0.84, and 1.12 kg ai·ha^{-1} (0.25, 0.75, and 1.0 lb ai·A^{-1}) over the top of 10 species, once on August 3 and again on August 17, 1978 (5). Following two applications, no phytotoxicity was observed on Mentor barberry (*Berberis* × *mentorensis*), camellia (*Camellia japonica*), border forsythia (*Forsythia* × *intermedia*), and Golden privet (*Ligustrum vicaryi*) at any rate. Temporary slight yellowing was observed on wintergreen barberry (*Berberis julianae*), Japanese euonymus (*Euonymus japonicus*) and 'Dwarf Burford' holly (*Ilex cornuta* 'Dwarf Burford') at higher rates. Damage was more severe on 'Hinodegiri' Kurume azalea, 'Helleri' holly (*Ilex crenata* 'Helleri'), and 'Hetzii' japanese holly (*Ilex crenata* 'Hetzii') at rates ≥ 0.84 kg ai·ha^{-1} (0.75 lb ai·A^{-1}). All species overwintered well, but evaluation of root systems in late February indicated slightly less root density on plants treated with 1.12 kg ai·ha^{-1} (1.0 lb ai·A^{-1}).

In a 1985 study, ligustrum (*Ligustrum japonicum*) responded with a linear decrease in susceptibility between March and November to glyphosate [Carbon-14-labeled *N*-(phosphonomethyl)glycine] applications (4). 'Blue Pacific' shore juniper (*Juniperus conferta* 'Blue Pacific') sustained tip necrosis on young elongating tips from early summer applications, but applications at other growth stages resulted in no significant absorption of ^{14}C-glyphosate.

Glyphosate (Roundup Pro®) at 0.45 kg ai·ha^{-1} (0.4 lb ai·A^{-1}) can be used as a cleanup treatment for effective control of spurge (*Euphorbia maculata*) (96%) in 'Big Blue' liriope (*Liriope muscari* 'Big Blue') with no short-term or long-term injury (1). In separate experiments, glyphosate (Roundup Pro®) at 1.79 kg ai·ha^{-1} (1.6 lb ai·A^{-1}), the maximum rate tested, was applied to recently-divided liners of 'Variegata' liriope (*Liriope muscari* 'Variegata') and 'Big Blue' liriope infested with mature and flowering spurge. Effective control of spurge (93 and 100% respectively) with no short-term or long-term injury to 'Variegata' liriope was reported. 'Big Blue' liriope showed slight initial injury which was outgrown at 60 days after treatment (DAT). In another study, glyphosate (neither formulation nor product was identified) applied on September 6, 2005, in a 1% solution of 1.82 kg ai in 378 liters (4.00 lb ai in 100 gal) caused no injury on either liriope or asiatic jasmine (*Trachelospermum asiaticum*) (9).

Minimal injury has been reported on 'Blue Pacific' juniper, 'Blue Star' juniper (*Juniperus squamata*), and 'Parsons' juniper (*Juniperus davurica* 'Parsonii') when glyphosate (applied as RoundupPro®; 4.0 lb·gal^{-1} glyphosate in the form of its isopropylamine salt) was applied at rates up to 2.8 kg ai·ha^{-1} (2.5 lb ai·A^{-1}) on May 29, 2004, and May 13, 2005 (2). Injury ratings and dry weights were similar to non-treated controls at 4, 8, and 12 weeks after treatment (WAT) in both experiments when 1.12 kg ai·ha^{-1} (1.00 lb ai·A^{-1}) was applied.

Nine species of ornamentals in containers were treated over-the-top with glyphosate [*N*-(phosphonomethyl)glycine] at four rates 0.28, 0.56, 1.12 and 2.24 kg ai·ha^{-1} (0.25, 0.50, 1.00 and 2.00 lb ai·A^{-1}) once in June 2007, August 2007, or February 2008 (3). A fourth group was treated on all three dates. Dwarf mondo grass (*Ophiopogon japonicus* 'Nana'), mondo grass (*Ophiopogon japonicus*), 'Cleopatra' liriope (*Liriope muscari* 'Cleopatra'), and 'Variegata' liriope were tolerant to all rates and application dates. 'Blue Pacific' juniper was slightly injured by February applications but recovered quickly. Asiatic jasmine and 'Stoke's Dwarf' dwarf yaupon (*Ilex vomitoria* 'Stoke's Dwarf') suffered significant injury after February applications. 'Blue rug' juniper (*Juniperus horizontalis*) was tolerant in August but injured at ≥ 1.12 kg ai·ha^{-1} (≥ 1 lb ai·A^{-1}) for all other dates. 'Pink Gumpo' azalea (*Rhododendron eriocarpum* 'Gumpo Pink') was injured at all rates and application dates. Growth indices were taken in March and June 2008. Mondo grass, dwarf mondo grass, 'Cleopatra' liriope, 'Variegata' liriope and 'Blue Pacific' juniper were not affected by over-the-top glyphosate applications except at 2.24 kg ai·ha^{-1} (2.0 lb ai·A^{-1}) applied 3 times. The remainder of the species had reduced growth as glyphosate rate increased.

In the current economic conditions, many growers have had to lower prices to remain competitive in the nursery industry, while production costs have increased due to increased costs for substrates, chemicals, and labor. While over the top applications of glyphosate should not replace a solid program of weed management consisting of monitoring, hand weeding, and application of pre-emergence herbicides, growers are turning towards using glyphosate on hardy ornamental species in emergency situations. Earlier research evaluated 13 ornamental container species for their response to single over the top applications of Roundup Pro® (in June 2007, September 2007, or February 2008) and multiple over the top applications (June 2007 + September 2007 + February 2008) (7). Species evaluated included dwarf mondo grass (*Ophiopogon japonicus* 'Nana'), mondo grass (*O. japonicus*), liriope (*Liriope muscari* 'Cleopatra'), variegated liriope (*L. muscari* 'Variegata'), 'Blue Pacific' Juniper (*Juniperus rigida* subsp. *conferta* 'Blue Pacific'), 'Blue Rug' Juniper (*J. horizontalis* 'Blue Rug'), Asiatic jasmine (*Trachelospermum asiaticum*), dwarf yaupon (*Ilex vomitoria* 'Stoke's Dwarf'), 'Pink Gumpo' azalea (*Rhododendron eriocarpum* 'Gumpo Pink'), 'Hardy Daisy' gardenia (*Gardenia jasminoides* 'Hardy Daisy'), Sky Pencil holly (*Ilex crenata* 'Sky Pencil'), purpleleaf wintercreeper euonymus (*Euonymus fortunei* 'Coloratus'), and wintergreen boxwood (*Buxus sempervirens* 'Wintergreen'). Most plants were reported to be tolerant to single applications in June after the spring growth flush through September. Injury from February single applications was mostly gone by mid to late June. 'Blue Rug' juniper was the exception to this rule, having exhibited injury from the June and September single applications, but no injury from the February single application.

During recent economically difficult times, growers have increased use of over-the-top glyphosate applications, and now they are asking how often they can apply glyphosate over-the-top. The objective of the experiment was to determine crop tolerance of container-grown nursery crops to repeated glyphosate (Roundup Pro®) applications at 1.12 kg ai·ha^{-1} (1.0 lb ai·A^{-1}), a rate reported to be adequate for control of most weeds found in container production (8).

Materials and Methods

Three separate experiments were conducted; one in 2008–2009 (Experiment 1 in Auburn, AL) and two in

2009–2010 (Experiment 2 in Auburn, AL, and Experiment 3 in Mobile, AL). All test plants were obtained from local nurseries and were grown in 3.8 liter (1 gal) containers in a 6:1 (v:v by vol) pinebark:sand substrate. Plants received 1.0 cm (0.4 in) of daily overhead irrigation. The species included in each experiment varied. All experiments included both single and multiple applications of Roundup Pro®. All treatments were applied at 1.12 kg ai·ha^{-1} (1.0 lb ai·A^{-1}) with a CO_2-pressurized backpack sprayer, calibrated to deliver 280 liters·ha^{-1} (30 GPA). Treated plants were allowed to dry for at least 6 hours after herbicide application. Plants were grouped by species in a completely randomized block design with 8 single-pot replications. A non-treated control (NTC) was included in all three experiments. Plant injury ratings (1 = no injury, 10 = dead) were taken at 11–19 day intervals after test initiation and continued until the end of the growing season. Growth indices (GI) [(height + width1 + width2) / 3] were collected twice after completion of all treatments; once during dormancy before spring growth had begun (January 2009 for Experiment 1, January 2010 for Experiment 2, February 2010 for Experiment 3), and once after spring growth flush (June 2009 for Experiment 1, June 2010 for Experiment 2, and May 2010 for Experiment 3). Plant vigor (1 = healthy, 5 = chlorotic) and marketability (1 = marketable, 3 = not marketable) was also rated. Data was analyzed using the SAS® statistical software package (SAS® 9.1.3, SAS Institute, Cary, NC). Treatment means were separated using the Waller-Duncan k-ratio t-test ($p \leq 0.05$). Data for each sampling date were analyzed separately.

Experiment 1. Experiment 1 was initiated in July 2008 in Auburn, AL (Hardiness zone 7b–8a). The following three species were evaluated: 'Big Blue' liriope (*Liriope muscari* 'Big Blue'), 'Radicans' gardenia (*Gardenia jasminoides* 'Radicans'), and 'Shishigashira' camellia (*Camellia sasanqua* 'Shishigashira'). Single Roundup Pro® applications were applied in either July, August, September, or October 2008. Multiple applications were applied in July and August (J+A), July, August, and September (J+A+S), July, August, September, and October (J+A+S+O), and July and September (J+S) of 2008. Plant GI measurements were recorded in January and June 2009. Plant vigor was evaluated in May 2009, and marketability in June 2009.

Experiment 2. Experiment 2 was initiated in July 2009 in Auburn, AL. The following six species were evaluated: liriope and gardenia (same as Experiment 1), 'Martha Sims' camellia (*Camellia sasanqua* 'Martha Sims'), 'Blue Pacific' juniper (*Juniperus conferta* 'Blue Pacific'), 'Dwarf Burford' holly (*Ilex cornuta* 'Dwarf Burford'), and common cleyera (*Ternstroemia gymnathera*). Single Roundup Pro® applications were applied in July, August, September, or October 2009. Multiple applications were applied in either J+A, J+A+S, J+A+S+O, and J+S of 2009. Plant GI measurements were recorded in January and June 2010. Injury ratings were collected a total of 17 times; i.e., every 11–19 days beginning July 24, 2010, and ending November 13, 2010.

Experiment 3. Experiment 3 was initiated in July 2009 in Mobile, AL (Hardiness zone 8b). The following six species were evaluated: liriope, gardenia, juniper, 'Martha Sims' camellia, and cleyera (same as Experiment 2), and 'Carissa' holly (*Ilex cornuta 'Carissa*'). Single Roundup Pro® applications were applied in either July, August, September, or October 2009. Multiple applications were applied in J+A, J+A+S, J+A+S+O, or J+S and 2009. Plant GI measurements were recorded in February and May 2010. Plant vigor and marketability were rated in late May 2010.

Results and Discussion

Experiment 1. Injury ratings for liriope treated with single applications in July or September, and multiple applications in J+S were similar to the NTC through the end of October (Table 1), concurring with other research (1, 8, 9). However, at the end of October, slight injury was observed characterized by 1 to 4 yellow leaf blades per plant. All treatments with a single application in August had the highest percentage of plants with yellow leaf blades. Plants were rated for vigor on May 14, 2009, and no differences were observed. GI taken on January 21, 2009, showed that single application treatments in September and October and multiple application treatments in J+A were similar to the NTC. Single application treatments in July and August, and multiple application treatments in J+A and J+S resulted in smaller plants than the NTC plants. Liriope receiving three or more applications tended to be smallest. GI taken on June 9, 2009, followed a similar trend to the January 21 ratings. Comparison of the differences in GI between January 21and June 9 showed no significant difference in spring growth from the NTC for any single or multiple application treatments except for the J+A multiple application treatment and the four successive applications (J+A+S+O) (data not shown). Although some treatments received up to 4.48 kg ai·ha^{-1} (4.0 lb ai·A^{-1}) total, regrowth was similar to the NTC. All plants were similar to NTC in plant vigor ratings on May 14, 2009. Plants were rated for marketability on June 6, 2009. All treatments except the four application treatment (J+A+S+O), or a single application in August treatment, were similar to the NTC; however, all plants were marketable.

No injury was noted on 'Shishigashira' camellia in any treatment (Table 1). Plant GI was similar in camellia for all treatments and the NTC on both January 21 and June 9, 2009. There was no difference in plant vigor or color on May 14, 2009. Differences in GI between January and June were similar as well, except for the J+A+S multiple application treatment. Plant vigor for all treatments was similar to the NTC. All camellia treatments were rated as marketable. Our data concurs with previous research where no phytotoxicity was reported when 1.12 kg ai·ha^{-1} (1.0 lb ai·A^{-1}) of glyphosate was applied once on August 3, and again on August 17 over camellia (5).

Injury on gardenia from single application treatments appeared as chlorotic leaves about 7 days after treatment (Table 2). However, within three weeks, treated plants were similar to the NTC. Chlorosis and stunting was more evident with the multiple application treatments. Single application treatments applied in July were significantly different from the NTC when rated on August 8. Within one month, all plants recovered from the single application July treatment and were visually similar to the NTC. On September 12, the single application July treatment was similar to the NTC and three J+A multiple application treatments (September and October not applied yet) were similar to each other and had significantly greater injury than all other treatments. On September 29, the day of the September application, all gardenia treated in J+A had the most injury while plants

Table 1. 'Big Blue' liriope and 'Shishigashira' camellia responses to repeated Roundup Pro® applications at 1.0 lb ai·A^{-1}, Exp 1.

		'Big Blue' liriope				'Shishigashira' camellia			
Treatment	Injury[z] 10/16/2008	Plant vigor[y] 5/14/2009	Growth indices[x] 1/21/2009	Growth indices 6/9/2009	Marketability[w] 6/9/2009	Plant vigor 5/14/2009	Growth indices 1/21/2009	Growth indices 6/9/2009	Marketability 6/9/2009
Control	1.1cd[v]	1.0[ns]	32.0a	44.4a	1.1b	1.0[ns]	23.6[ns]	30.8[ns]	1.0[ns]
Single Applications									
July 28	1.5bc	1.0	28.5cd	40.2c	1.1b	1.0	22.7	28.7	1.0
Aug 28	1.9ab	1.0	30.2bc	40.8bc	1.4a	1.3	21.1	27.4	1.7
Sept 29	1.0d	1.0	33.2a	43.6ab	1.2b	1.4	24.7	30.3	1.9
Oct 29	—	1.0	32.2ab	44.9a	1.0b	1.0	22.9	32.0	1.0
Multiple Applications									
July + Aug	1.9ab	1.0	30.7abc	44.9a	1.0b	1.7	20.2	24.9	2.3
July + Aug + Sept	1.9ab	1.0	26.7d	38.1cd	1.2b	1.4	23.0	26.0	2.0
July + Aug + Sept + Oct	2.0a	1.0	27.0d	35.9d	1.7a	1.0	24.5	29.1	1.0
July + Sept	1.3bc	1.0	29.7bc	40.0c	1.2b	1.0	22.9	31.5	1.0

[z]Injury ratings (1 = no injury, 5 = 50% injury, 10 = dead plant).
[y]Plant vigor (1 = healthy, green plant, 5 = yellow, chlorotic plant).
[x]Growth indices (cm) = [(height + width1 + width2) / 3].
[w]Marketability (1 = marketable, 2 = small, but marketable, 3 = unmarketable).
[v]Treatment means within a column followed by the same letter are not significantly different based on the Waller-Duncan k-ratio t-test ($P \leq 0.05$).
[ns]No significant differences within column.

treated with a single application in July only were similar to the NTC plants. Plants treated only with a single application in August exhibited slight injury. October ratings were similar to the September ratings, with all plants that received J+A multiple applications exhibiting the most injury. Injury among all other treatments was minimal, with the single application in August treatment having slightly greater injury than the NTC. Single application treatments in September were similar to the NTC.

GI for gardenia on January 21, 2009, were similar for NTC and the single application treatments in either August, September, or October. All gardenia treated with a single application in July were smaller than NTC. Those receiving two Roundup Pro® applications were smaller than all other plants. GI taken after the spring flush on June 9, 2009, indicated that the NTC and single applications in August, September, and October were similar. All gardenia receiving multiple applications were smaller than the NTC. As previously noted, gardenia treated any time in July were smaller in size. Ratings for plant vigor on May 14 showed that all single applications were similar to the NTC, while gardenia receiving multiple treatments were rated lower due to slight leaf stunting. Marketability ratings showed that all single application treatments were similar to the NTC, while plants receiving multiple application treatments had slightly higher ratings due to smaller leaf size; however, all plants were rated as marketable.

Experiment 2. All GI values before and after the spring flush the following year were similar to the NTC for 'Big

Table 2. 'Radicans' gardenia response to repeated Roundup Pro® applications at 1.0 lb ai·A^{-1}, Exp 1.

	Injury[z]					Plant vigor[y]	Growth indices[x]		Marketability[w]
Treatment	8/8/2008	8/27/2008	9/12/2008	9/29/2008	10/16/2008	5/14/2009	1/21/2009	6/9/2009	6/9/2009
Control	1.0d[v]	1.0[ns]	1.0c	1.0c	1.0d	1.0d	40.5a	45.7a	1.0c
Single Applications									
July 28	2.5ab	1.0	1.5c	1.6b	2.0bc	1.2d	35.6bc	38.9c	1.0c
Aug 28			2.0b	2.0b	2.4b	1.0d	38.7ab	43.5abc	1.0c
Sept 29				1.0c	1.1d	1.0d	41.2a	44.1ab	1.1c
Oct 29						1.0d	42.1a	42.8abc	1.1c
Multiple Applications									
July + Aug	2.9a	1.0	5.0a	4.5a	4.1a	2.0c	30.2d	33.0d	1.7ab
July + Aug + Sept	2.7ab	1.0	4.7a	4.9a	4.7a	2.4b	29.7d	33.1d	2.0ab
July + Aug + Sept + Oct	2.4b	1.0	4.7a	4.9a	4.7a	2.9a	28.5d	31.7d	2.1a
July + Sept	1.9c	1.0	1.2c	1.1c	1.5bcd	1.0d	32.7cd	39.8bc	1.6b

[z]Injury ratings (1 = no injury, 5 = 50% injury, 10 = dead plant).
[y]Plant vigor (1 = healthy, green plant, 5 = yellow, chlorotic plant).
[x]Growth indices (cm) = [(height + width1 + width2) / 3].
[w]Marketability (1 = marketable, 2 = small, but marketable, 3 = unmarketable).
[v]Treatment means within a column followed by the same letter are not significantly different based on the Waller-Duncan k-ratio t-test ($P \leq 0.05$).
[ns]No significant differences within column.

Table 3. Growth indices[z] of six species treated with Roundup Pro® at 1.0 lb ai·A^{-1}; measured on 1/25/10, Exp 2.

Treatment	Ornamental species					
	'Big Blue' liriope	'Radicans' gardenia	'Martha Sims' camellia	'Blue Pacific' juniper	'Dward Burford' holly	Common cleyera
Control	39.0[y, ns]	55.0[ns]	65.5ab	29.0[ns]	38.5[ns]	57.0bc
Single applications						
July 28	41.6	55.6	61.1ab	28.5	40.6	55.8bcd
Aug 28	41.1	54.6	62.6ab	28.0	38.1	56.8bcd
Sept 29	40.3	55.6	65.8ab	28.0	38.8	62.1a
Oct 29	40.6	53.4	67.7a	28.2	38.0	59.3ab
Multiple applications						
July + Aug	39.2	52.6	61.6ab	27.4	37.6	54.0cde
July + Aug + Sept	40.0	55.3	60.3ab	27.8	35.1	49.9ef
July + Aug + Sept + Oct	40.0	52.2	59.6b	29.4	34.8	47.2f
July + Sept	40.2	54.1	58.4b	29.3	40.0	51.8def

[z]Growth indices (cm) = [(height + width1 + width2) / 3].

[y]Treatment means within a column followed by the same letter are not significantly different based on the Waller-Duncan k-ratio t-test ($P \leq 0.05$).

[ns]No significant differences within column.

Table 4. Growth indices[z] of six species treated with Roundup Pro® at 1.0 lb ai·A^{-1}; measured on 6/2/10, Exp 2.

Treatment	Ornamental species					
	'Big Blue' liriope	'Radicans' gardenia	'Martha Sims' camellia	'Blue Pacific' juniper	'Dward Burford' holly	Common cleyera
Control	60.0[y, ns]	62.9[ns]	77.4ab	32.9[ns]	50.8ab	69.8abc
Single applications						
July 28	63.0	64.3	73.8ab	32.8	55.8a	67.8bcd
Aug 28	62.5	62.7	77.0ab	33.3	53.6ab	72.5ab
Sept 29	60.8	65.6	77.0ab	33.1	53.5ab	73.8a
Oct 29	57.8	63.5	79.2a	31.0	53.6ab	70.9ab
Multiple applications						
July + Aug	58.7	62.9	76.6ab	33.6	53.5ab	65.1cd
July + Aug + Sept	58.3	64.3	69.1b	31.3	53.0ab	64.5d
July + Aug + Sept + Oct	58.6	65.2	70.6b	34.1	48.7b	63.2d
July + Sept	60.0	63.0	71.1ab	31.9	54.4ab	63.7d

[z]Growth indices (cm) = [(height + width1 + width2) / 3].

[y]Treatment means within a column followed by the same letter are not significantly different based on the Waller-Duncan k-ratio t-test ($P \leq 0.05$).

[ns]No significant differences within column.

Blue' liriope, 'Radicans' gardenia, 'Martha Sims' camellia, 'Blue Pacific' juniper, and 'Dwarf Burford' holly (Tables 3, 4). Temporary foliar injury on juniper as reported by Neal et al. (1985) and Perry and Knowles (1979) was not seen (data not shown). Our results concurred with Czarnota (2008), who reported no significant injury at the 1.12 kg ai·ha^{-1} (1.0 lb ai·A^{-1}) rate. Occasional slight chlorosis from single application treatments in July was seen on holly, similar to temporary symptoms reported by Perry and Knowles (1979). Cleyera exhibited chlorosis, necrosis, and stunting of shoot tips for all treatments (data not shown). January and June GI showed that cleyera treated with multiple applications in J+A+S, J+A+S+O, and J+S were significantly smaller than the NTC (Tables 3, 4). Cleyera injury ratings for single application treatments indicated less injury as plants were treated later in the growing season (data not shown). Multiple application treatments began with a July treatment and thus showed similar patterns of injury and stunting for each treatment of two, three, or four applications (Fig 1). For

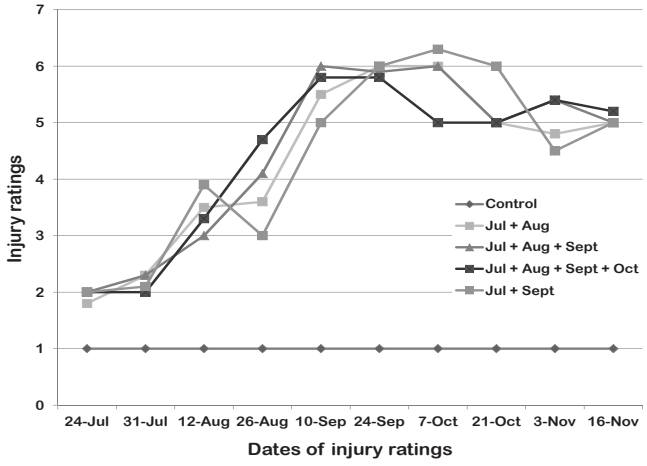

Fig. 1. Injury ratings from multiple applications of Roundup Pro® (1.0 lb ai·A^{-1}) over the top of cleyera, Expt. 2. Injury rating: 1 = no injury; 2–3 = chlorosis; 4–5 = stunting; 6 = stunting and chlorosis; 10 = dead plant.

J+S treatments, there was some recovery in August from the July application treatment. This recovering tissue was then treated again in September, causing additional injury not seen on plants treated 2, 3, or 4 months in a row. All injury was restricted to immature tissue. Mature tissue was not affected and remained completely healthy while immature leaves and stems became necrotic and died back. Spring growth revealed significant branching and normal growth, with plants treated multiple times appearing fuller and more compact than the NTC and much more desirable in appearance. All plants were vigorous and marketable.

Experiment 3. Liriope, gardenia, juniper, 'Carissa' holly, and cleyera GI were similar to the NTC in February (Table 5) and May (Table 6). Spring growth was similar to or larger than the NTC for all species. All plants were vigorous and marketable (data not shown). Camellia GI indicated that all treatments were similar to the NTC. The tolerance of liriope to single Roundup Pro® applications concurs with data in Experiment 2 and previous research (1, 8, 9). No injury on juniper was seen in this study, similar to a report of no significant injury at the 1.12 kg ai·ha^{-1} (1.0 lb ai·A^{-1}) rate (2), but contrary to other reports (4, 8). Injury on cleyera was much lower in Experiment 3 than in Experiment 2. Cleyera in Experiment 2 grew constantly throughout the test period, presenting new tissue which was affected by Roundup Pro® applications. Cleyera in Experiment 3 did not grow as much, thus presenting less new tissue.

This research demonstrates that multiple applications of Roundup Pro® at 1.12 kg ai·ha^{-1} (1.0 lb ai·A^{-1}) are relatively safe when applied over the top of selected nursery crops. Our research shows that several ornamentals are very tolerant, especially when applications are applied from July through the end of the growing season. After application to some species, growth was slightly reduced and slight visual differences could be detected as compared to the NTC. However,

Table 5. Growth indices[z] of six species treated with Roundup Pro® at 1.0 lb ai·A^{-1}; measured on 2/8/10, Exp 3.

	Ornamental species					
Treatment	**'Big Blue' liriope**	**'Radicans' gardenia**	**'Martha Sims' camellia**	**'Blue Pacific' juniper**	**'Dward Burford' holly**	**Common cleyera**
Control	29.8[y, ns]	38.1[ns]	30.2[ns]	46.8[ns]	25.7ab	44.5ab
Single applications						
28-July	31.5	35.3	30.0	43.0	24.2ab	44.6ab
28-Aug	28.8	38.8	28.4	47.3	26.6a	43.7ab
29-Sept	28.1	35.7	30.3	49.0	26.2ab	43.7ab
29-Oct	27.9	39.6	30.0	46.8	24.5ab	46.5a
Multiple applications						
July + Aug	31.0	38.6	29.9	50.1	23.6b	41.8b
July + Aug + Sept	30.8	38.7	27.2	46.3	24.8ab	45.2ab
July + Aug + Sept + Oct	27.9	36.9	30.6	48.4	25.0ab	43.9ab
July + Sept	29.2	36.8	30.0	45.7	25.9ab	42.8ab

[z]Growth indices (cm) = [(height + width1 + width2) / 3].

[y]Treatment means within a column followed by the same letter are not significantly different based on the Waller-Duncan k-ratio t-test ($P \leq 0.05$).

[ns]No significant differences within column.

Table 6. Growth indices[z] of six species treated with Roundup Pro® at 1.0 lb ai·A^{-1}; measured on 5/28/10, Exp 3.

	Ornamental species					
Treatment	**'Big Blue' liriope**	**'Radicans' gardenia**	**'Martha Sims' camellia**	**'Blue Pacific' juniper**	**'Dward Burford' holly**	**Common cleyera**
Control	47.3abc[y]	46.3ab	23.4ab	51.5ns	33.8a	50.1b
Single applications						
28-July	49.3a	40.8c	23.7ab	47.5	32.8a	52.7ab
28-Aug	47.1abc	47.3a	30.9a	49.5	33.8a	51.9ab
29-Sept	45.0bcd	42.2cd	31.8a	51.0	33.2a	51.8ab
29-Oct	48.0ab	46.4ab	24.8ab	51.9	32.8a	51.8ab
Multiple applications						
July + Aug	44.2c	46.0ab	27.5a	49.9	32.2ab	52.7ab
July + Aug + Sept	44.0c	45.0abc	17.0b	48.3	29.8b	53.3a
July + Aug + Sept + Oct	44.3c	43.0abc	22.0ab	50.2	31.3ab	51.9ab
July + Sept	43.8c	40.5c	24.2ab	50.3	32.6a	54.3a

[z]Growth indices (cm) = [(height + width1 + width2) / 3].

[y]Treatment means within a column followed by the same letter are not significantly different based on the Waller-Duncan k-ratio t-test ($P \leq 0.05$).

[ns]No significant differences within column.

re-growth was similar for all treatments except some plants treated four times in successive months.

Our research shows that 'Big Blue' liriope, 'Radicans' gardenia, 'Shishigashira' camellia, 'Martha Sims' camellia, 'Blue Pacific' juniper, 'Carissa' holly, and 'Dwarf Burford' holly are tolerant to repeated applications 28 days apart starting in July. Plants that were not affected by fall applications had normal spring growth and marketability similar to the NTC. Individual species should be tested for tolerance before large groups of plants are treated. Our research is intended to provide data for emergency measures for weed control in nurseries and landscapes when labor is unavailable or when hand weeding would exceed budget limitations. It should not replace a solid program of weed management consisting of monitoring, hand weeding, and application of preemergence herbicides.

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