

Roundup over the Top of Container-Grown Nursery Crops

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
August 9, 2010

Keywords: glyphosate, container production,
landscape, weed control

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Abstract

Nine species of container-grown plants were treated over-the-top with Roundup Pro[®] at 4 rates: 0.28, 0.56, 1.12, and 2.24 kg ai/ha (0.25, 0.5, 1.0 and 2.0 lb ai/A) once in June 2007, September 2007, or February 2008. A fourth group was treated on all three dates (JSF). The experiment was repeated on eight species in 2008-2009. Growth indices (GI) were taken before the spring growth flush in March 2008 and after the first growth flush in June. In experiment one, dwarf mondo grass (*Ophiopogon japonicus* 'Nana'), mondo grass (*O. japonicus*), liriopse (*Liriope muscari* 'Cleopatra') variegated liriopse (*L. muscari* 'Variegata'), and 'Blue Pacific' juniper (*Juniperus rigida* subsp. *conferta* 'Blue Pacific') were not affected by rates up to 1.12 kg ai/ha (1.0 lb ai/A) applied singly or JSF, except for temporary injury on 'Blue Pacific' from Feb applications. The remainder of the species had reduced growth as Roundup Pro[®] rates increased. 'Blue Rug' juniper (*J. horizontalis* 'Wiltonii') was tolerant in Feb but injured at ≥ 1.12 kg ai/ha (1.0 lb ai/A) in June and Sept (JS). Asiatic jasmine (*Trachelospermum asiaticum*) was tolerant of single applications at rates ≤ 1.12 kg ai/ha (1.0 lb ai/A) in JS, but showed stunting of new foliage from all Feb applications. Dwarf yaupon (*Ilex vomitoria* 'Stoke's Dwarf') showed injury at 74 DAT after June applications, no injury at rates ≤ 1.12 kg ai/ha (1.0 lb ai/A) in Sept, and stunting and delay of new foliage from all Feb applications and rates ≥ 0.56 kg ai/ha (0.5 lb ai/A) in June. 'Pink Gumpo' azalea (*Rhododendron eriocarpum* 'Gumpo Pink') was injured by rates ≥ 1.12 kg ai/ha (1.0 lb

ai/A) applied in June, Feb, and JSF. In experiment two, dwarf mondo and mondo tolerated all single application rates up to 1.12 kg ai/ha (1.0 lb ai/A). Asiatic jasmine was injured by all Feb treatments and growth was reduced and stunted by ≥ 1.12 kg ai/ha (1.0 lb ai/A) in Feb and JSF. Dwarf yaupon GI were reduced by rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) in Feb, 2.24 kg ai/ha (2.0 lb ai/A) in June, and by all treatments in JSF. Feb treatments ≥ 0.28 kg ai/ha (0.25 lb ai/A) delayed shoot growth of dwarf yaupon for at least 6 weeks. 'Hardy Daisy' gardenia (*Gardenia jasminoides* 'Hardy Daisy') showed slight injury from Feb rates ≥ 1.12 kg ai/ha (1.0 lb ai/A), but growth was reduced at 2.24 kg ai/ha (2.0 lb ai/A) for June and JSF. Sky pencil holly (*Ilex crenata* 'Sky Pencil') showed stunting from all Feb applications, but was tolerant up to 2.24 kg ai/ha (2.0 lb ai/A) in June and Sept; GI were similar for all treatments. Purpleleaf wintercreeper euonymus (*Euonymus fortunei* 'Coloratus') was injured by rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) in June and JS, all Feb treatments, and stunted by two or three applications of 2.24 kg ai/ha (2.0 lb ai/A), but all other treatments had similar GI. Wintergreen boxwood (*Buxus sempervirens* 'Wintergreen') was injured at 2.24 kg ai/ha (2.0 lb ai/A) in June, ≥ 1.12 kg ai/ha (1.0 lb ai/A) in JS, and all Feb applications. Growth was reduced by rates of 2.24 kg ai/ha (2.0 lb ai/A) in Feb and ≥ 1.12 kg ai/ha (1.0 lb ai/A) in JSF.

Three additional experiments were conducted to determine the effects of repeated applications of Roundup Pro[®] over the top of container-grown nursery crops. Plants were treated with single applications of Roundup Pro[®] at 1.12 kg ai/ha (1.0 lb ai/A) in July, August, September, or October, 2008 or 2009. Other plants were treated in July and August ; July, August, and September; July, August, September, and October; or July and September. Experiment 1 (2008): *Liriope muscari* 'Big Blue,' *Camellia sasanqua*

‘Shishigashira,’ and *Gardenia jasminoides* ‘Radicans’ were evaluated. ‘Big Blue’ liriop showed minor injury from multiple applications with reduced growth from 3 or 4 applications, but all plants were marketable in June of the following season. Camellia exhibited no injury from any Roundup application and all parameters were similar to controls. ‘Radicans’ gardenia showed fall chlorosis and stunting through early spring from multiple applications, but all plants were marketable, with those treated 3 or 4 times rated small but marketable. Experiment 2 (2009, Auburn): ‘Big Blue’ liriop, ‘Radicans’ gardenia, *C. sasanqua* ‘Martha Simms,’ and *Juniperus conferta* ‘Blue Pacific,’ showed no injury from any treatment and growth indices in January and June were similar to controls. *Ilex cornuta* ‘Dwarf Burfordi’ growth indices were similar to controls with occasional chlorosis seen after July treatments. *Ternstroemia gymnanthera* (cleyera) exhibited chlorosis, necrosis, and stunting of shoot tips for all treatments, but regrowth was similar to controls for all treatments the following spring. All plants were vigorous and marketable. Experiment 3 (2009, Mobile, AL): ‘Big Blue’ liriop, ‘Radicans’ gardenia, ‘Blue Pacific’ juniper, *I. cornuta* ‘Carissa,’ and cleyera growth indices were similar to controls 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.

Results of the rate and timing study for plants treated in June, September, or February or all three dates demonstrated that dwarf mondo, liriop ‘Cleopatra’ and ‘Variegata,’ and ‘Blue Pacific’ juniper were tolerant to single or multiple rates up to 2 lb ai/A and were not affected by time of year, except for ‘Blue Pacific,’ which was temporarily injured by spring applications at rates ≥ 0.5 lb ai/A but recovered quickly.

Mondo grass was tolerant up to 1.0 lb ai/A in February and multiple applications and up to 2.0 lb in June or September. 'Blue Rug' juniper was tolerant of rates up to 2 lb applied in February but injured or stunted by rates ≥ 1.0 lb ai/A in June and September. All plants in experiment 1 except 'Blue Rug' juniper and all in experiment 2 were tolerant up to 2 lb when applied in September.

Results for the repeated application studies demonstrated that all growth indices for 'Big Blue' liriop, 'Radicans' gardenia, camellia 'Martha Simms,' 'Blue Pacific' juniper, dwarf burford holly, carissa holly, and cleyera were similar to non-treated controls in experiment 2 and 3 of this study regardless of the number of treatments, with the exception of cleyera in experiment 2. Data showed that plants were more tolerant as they were treated later in the season. All plants treated once or multiple times with 1.0 lb ai/A Roundup Pro[®] in July through October were marketable at the end of the following spring flush. Data also showed that regrowth the following year was similar to controls with up to 4 applications of 1.0 lb ai/A applied 28 days apart. Despite the fact that multiple applications caused lower growth indices on 'Radicans' gardenia and 'Big Blue' liriop in experiment 1 and cleyera in experiment 2 of this series, plants were marketable the following year.

Acknowledgments

The author wishes to express sincere gratitude for Dr. Charles Gilliam for providing the opportunity to pursue the Master of Science Degree at Auburn University and to work on a fascinating research project. Furthermore, Dr. Gilliam's character and embodiment of his religious faith will always serve as beacons for the author in his professional career and private life. The author is likewise indebted to his wife Becky and her mother, Barbara Britton, for their endless support and encouragement. The author wishes to thank Chris Marble for advice and help on countless occasions, Sara Rogers for computer help, and Matt Wilson for always walking in at just the right time with the answer to any question. The author also wishes to thank Department of Horticulture faculty, staff, and graduate students for their friendship, support, and assistance. The author was honored to be among such fine people.

Table of Contents

Abstract	ii
Acknowledgments	vi
List of Tables	ix
List of Figures	xi
I. Introduction and Literature Review.....	1
Glyphosate tolerance in woody plants	16
Roundup over the top of nursery crops.....	21
List of species tested in literature.....	26
Literature Cited	52
II. Roundup Pro [®] over the Top of Nursery Crops in Containers Rates and Timing.....	64
Abstract	64
Introduction.....	67
Materials and Methods.....	70
Results and Discussion	72
Literature Cited	82
III. Effects of Repeated applications of Roundup Pro [®] over the Top of Container-Grown Nursery Plants.....	92
Abstract.....	92
Introduction.....	93

Materials and Methods.....	96
Results and Discussion	97
Literature Cited.....	103
IV. Final Discussion.....	113

List of Tables

Chapter II

Table 2.1 Injury rating on nine species following applications of Roundup Pro [®] , expt. 1	84
Table 2.2 Growth indices of nine species treated with Roundup Pro [®] , expt. 1, recorded on 3/3/08	85
Table 2.3 Growth indices of nine species treated with Roundup Pro [®] , expt. 1, recorded on 6/13/08	86
Table 2.4 Marketability of nine species treated with Roundup Pro [®] , expt. 1, recorded on 10/11/08	87
Table 2.5 Effects of Roundup Pro [®] applications over the top of eight species, expt. 2	88
Table 2.6 Growth indices of eight species treated with Roundup Pro [®] , expt. 2, recorded on 2/23/09	89
Table 2.7 Growth indices of eight species treated with Roundup Pro [®] , expt. 2, 3 recorded on 7/6/09	90
Table 2.8 Marketability of eight species treated with Roundup Pro [®] , expt. 2, recorded on 10/23/09	91

Chapter III

Table 3.1	Liriope and camellia responses to repeated Roundup Pro [®] applications at 1.0 lb ai/A, expt. 1	104
Table 3-2	Gardenia responses to repeated Roundup Pro [®] applications at 1.0 lb ai/A, expt. 1	105
Table 3.3	Growth indices of six species treated with single or multiple Roundup Pro [®] applications at 1.0 lb ai/A, expt. 2, Auburn, AL, recorded on 1/25/10.....	106
Table 3.4	Growth indices of six species treated with single or multiple Roundup Pro [®] applications at 1.0 lb ai/A, expt. 2, Auburn, AL, recorded on 6/2/10.....	107
Table 3.5	Growth indices of six species treated with single or multiple Roundup Pro [®] applications at 1.0 lb ai/A, expt. 2, Mobile, AL, recorded on 2/8/10.....	108
Table 3.6	Growth indices of six species treated with single or multiple Roundup Pro [®] applications at 1.0 lb ai/A, expt. 2, Mobile, AL, recorded on 5/28/10	109

Final Discussion

Table 4.1	Roundup Pro [®] rates up to 1.0 lb ai/A causing differences from controls in selected ornamentals, 2008	117
Table 4.2	Roundup Pro [®] rates up to 1.0 lb ai/A causing differences from controls in selected ornamentals, 2009	118

List of Figures

Chapter III

Figure 3.1 Injury ratings from single applications of Roundup (1.0 lb ai/A) over the top of cleyera, expt. 2.....	110
Figure 3.2 Injury ratings from multiple applications of Roundup (1.0 lb ai/A) over the top of cleyera, expt. 2.....	111
Figure 3.3 Comparison of single and multiple applications of Roundup Pro [®] on <i>Ternstroemia gymnathera</i>	112

Chapter I

Literature Review

Introduction

Growers are facing increasingly greater challenges in tough economic times. Minimum wage has gone up twice since early 2008 from \$5.75 to \$7.50 per hour. Several years of drought have impacted sales significantly. Current economic conditions have caused a significant slump in new home construction and subsequent sales of landscape plants. Immigration reform is always of concern, and growers sometimes face delays in the return of regular immigrant workers going through the proper legal steps to return to work. If weed populations exceed growers' ability to control them, they may face the prospect of spending more on hand weeding than what the plant is worth, or they may not have the manpower to control weeds at all. Landscape maintenance companies may find themselves without the workers to fulfill contracts signed a year in advance. Therefore, a rescue plan is needed should all other alternatives fail.

Nursery container crops must be weed-free before application of pre-emergent herbicides which are applied 5-6 times per year. Therefore the crops may potentially require hand-weeding 5-6 times as well. A good preemergent herbicide program can greatly minimize the need for hand weeding, but often such applications are delayed for

too long or missed during busy times. Once weed seedlings emerge, hand weeding must be performed to remove weeds from the media surface.

Hand weeding can be very expensive. A survey by Boyer and South (1984) reported that 25% of southern forest nurseries required more than 100 work-hours of hand-weeding per acre. At that time, the cost of hand-weeding at one nursery exceeded \$1700 per acre. In 1990, hand weeding alone in Alabama nurseries ranged from \$246 - 567 per acre annually (Gilliam et al., 1990). More current research by Judge et al. (2004) reported that hand weeding costs ranged from \$967 - \$2228 per acre in North Carolina nurseries. The cost for weeding 3-gallon pots in early 2005 was 5.63 cents per pot, assuming labor costs of \$9.52 per hour (Florida Agricultural Statistics Service, 2005).

Since the development of glyphosate, this herbicide has been evaluated numerous times to determine its effects on landscape and nursery plants. In the past, labor for hand weeding has been relatively affordable. However, with increasing economic pressure on nurseries and landscapers, hand labor has become prohibitively expensive in some cases. In addition, growers had been concerned about damage to their crops from glyphosate applications, but recent research has shown the product to be safe when applied to certain crops at specific rates and times of the year.

Development of Roundup[®] (Glyphosate)

Glyphosate was discovered by J. E. Franz of Monsanto in 1971 and released commercially as Roundup[®] in 1974. All available supplies of the product were first sold to railroad and utility companies for right-of-way maintenance, with other interests waiting for the product to become available by 1975 (Neel and Burt, 1974). Starting in 1983 and every year since, Roundup[®] has had world-wide sales of more than \$1 billion.

It has become the world's leading agrochemical and is still the fastest-growing in sales volume (Woodburn 2000). Commercial introduction of genetically engineered glyphosate-resistant soybeans in 1996 signaled the beginning of a new era in row crop agriculture. By 2004, 85% of all soybeans, 60% of all cotton, and 18% of all maize grown in the USA were herbicide resistant, the majority of which were glyphosate-resistant (Economic Research Service, 2004). World-wide in 2002, 55.5 million combined acres of soybeans, maize, cotton and canola were herbicide resistant (James, 2003).

Environmental impact

Glyphosate has proven to be environmentally friendly. Glyphosate inhibits ESPS synthase, an enzyme found only in plants, and thus is virtually nontoxic to mammals, fish, and insects. The acute oral LD50 in rats is 5,600 mg/kg. In human volunteers, patch tests showed no visible skin changes or sensitization (Exttoxnet, 1994).

Formulations of the compound with added surfactant can have significant environmental impacts. Roundup[®], a formulation of the isopropylamine (ipa) salt of glyphosate and polyethoxylated tallowamine (POEA) surfactant, is 10-100 times more toxic to indicator species than Rodeo[®], which contains only ipa glyphosate and no surfactant (Vencill, 2002). 96-hour LC50 levels for Rodeo[®] and Roundup[®] for Bluegill sunfish were >1000 and 5.8-14 mg/L respectively and for rainbow trout, >1000 and 8.2-26. Thus, glyphosate itself is very safe. Environmental concerns arise when surfactants are added.

Glyphosate has no residual soil activity, even when applied at high rates, binding tightly to soil particles. Lange et al. (1975) applied up to 16.0 lb ai/A of Roundup Original[®] and saw no residual effects on annual crops or weeds 3 and 4 months after

surface application. The compound is so strongly attracted to the soil that little is transferred by rainfall or irrigation. The U.S. Forest Service (1984) estimated that less than 2 % of the chemical is lost to runoff, with the herbicide moving when attached to soil particles in erosion run-off.

Glyphosate formulations

The active ingredient in glyphosate products can be formulated as salts or esters, giving great flexibility to the compound. Glyphosate is an anion, sold as a salt with different cations (e.g., isopropyl amine, trimethylsulfonium, diammonium) (Cedeira and Duke, 2006). Glyphosate acid is generally less active than the commercially available salts, which may be up to 6 times more active than the acid (Baylis, 2000). Through the use of appropriate cations and adjuvants, it has been possible to tailor glyphosate herbicides to meet the particular needs of farmers and applicators within a wide variety of agricultural and other applications. There are 40 trade names under which glyphosate is sold (Mathers, 2008). Isopropylamine (ipa) salt is the active ingredient of most formulations, but trimesium, diammonium, and potassium salt formulations are available as well. A range of adjuvants from none to partial to full loads further modify the activity of the glyphosate compound.

Roundup Original[®] and Roundup Pro[®] were the only glyphosate products on the market until September 2000, when Monsanto's US patent for the chemical expired. Glyphosate research involved only the original product from 1973 until 1995, when Roundup Pro[®] with an improved surfactant was introduced (Diamond and Durkin, 1997). The surfactant improved rainfastness and weed control but was more toxic to desirable

plants (Neal, 1998). In the spring of 2010, Roundup Pro Concentrate[®], containing 5.0 lb of glyphosate, was released, replacing Roundup Pro[®], which contains 4.0 lb.

Gallons per acre and droplet size effects

Increasing coverage by increasing spray volume has improved the efficacy of a number of systemic herbicides (Knoche, 1994). However, glyphosate has shown a different volume effect than other systemic herbicides. Ambach and Ashford (1982) experimented with barley (*Hordeum vulgare* L. ‘Bonanza’), treating plants with 1- μ L drops applied with a microsyringe. In each experiment, application of a single concentrated drop (0.50 μ g ai/ μ L) of technical grade glyphosate and 0.50 % v/v surfactant) proved more effective in reducing shoot growth than the drop diluted 3 times and applied in 3 drops or the original drop diluted 9 times and applied in 9 drops, even though the amount of herbicide per plant (0.50 μ g ai/ μ L) was the same. When the surfactant in the diluted drops was adjusted to the same level in each drop (0.5% v/v), the loss in efficacy of the dilute drops was eliminated. Addition of surfactant to dilute drops increased phytotoxicity, but at very low herbicide concentrations, additional surfactant did not eliminate the dilution effect. The authors concluded that the efficacy of glyphosate can be increased by reducing the volume per acre. Therefore, it may be possible to “soften” an application over container ornamentals by increasing the volume per acre.

Liu et al. (1996) experimented with the effects of droplet size, droplet number, and herbicide concentration on absorption and translocation in aspen (*Populus tremuloides* Michx.). The total amount of glyphosate for each leaf was held constant as droplet sizes and numbers were manipulated. When herbicide concentration was

constant, absorption of ¹⁴C-glyphosate increased with increasing droplet size, but translocation of herbicide away from the treated area decreased as droplet size increased. It was reported that increased absorption and translocation with increased herbicide concentration were responsible for improved phytotoxicity with low spray volumes. Droplet coverage was not reported to be important in glyphosate absorption.

A wide range in gallons per acre (GPA) of solution applied was used in work with glyphosate over the top of ornamentals. Some treatments were applied in 100 to 125 GPA (Cobb and Self, 1979; Jones and Fulmer, 1978; Self, 1978; Self and Washington, 1977), while others were applied in 20 to 25 GPA (Neal and Skroch, 1985; Czarnota, 2008; Harrington and Miller, 2005), and 40 GPA (Altland et al., 2002). It is interesting to note that early work in the 1970's was done with high volumes, but after Ambach and Ashford (1982) reported that glyphosate efficacy increased with lower volumes, spray volumes were much lower. It is possible that early research showed less phytotoxicity because of high rates of total solution applied.

Effects of Rainfall and Irrigation

Rainfall after application is always of concern. It was recommended that Roundup Original[®] be allowed to dry for 4 to 6 hours following application. Roundup Pro[®], which replaced the original, calls for 1 to 2 hours before rainfall or irrigation (Monsanto, 1998). Reddy and Singh (1992) reported that simulated rainfall within 1 hour after application reduced glyphosate efficacy on velvet leaf, yellow nutsedge, yellow foxtail, sicklepod, and barnyardgrass. Reddy (2000) reported that 48 rain-free hours were required for maximum absorption of applied glyphosate, and simulated rain 1 or 6 hours after application reduced redvine control by 25% compared with no rainfall.

In studies of two *Erythroxylum* species of coca plants, woody shrubs with a productive life of 10 to 15 years, Ferreira et al. (1997) reported that at 6 and 24 hours after application, *E. coca* absorbed 1.2 and 4.2 % of the glyphosate applied, while *E. novogranatense* absorbed 1.8 and 3.2%. This suggests that woody plants could be sprayed over-the-top with glyphosate and sprinkler irrigated to wash the herbicide off the plants after weeds have absorbed sufficient glyphosate with little or no damage to desirable woody plants.

Mode of action

Glyphosate can be extensively metabolized by some plants while remaining intact in others (Grossbard and Atkinson, 1985). Most plants metabolically degrade glyphosate very slowly or not at all, and it readily translocates to metabolically active tissues such as root and apical meristems. Glyphosate's relatively slow mode of action allows movement of the herbicide throughout the plant before symptoms occur (Cedeira and Duke, 2006). Primary symptoms in woody plants after foliage contact with glyphosate include new narrow leaflets (strapping or witch's broom), distorted leaf shape, chlorosis of younger leaves, and drooping of stems and leaves. Glyphosate blocks the shikimate pathway through inhibition of 5-enolpyruvyl-shikimate-3-phosphate synthase (EPSPS). Inhibition of EPSPS results in reduced aromatic amino acids and deregulation of the shikimate pathway (Duke et al., 2003), which causes accumulations of high levels of shikimic acid and its derivatives. In several experiments, inhibition of growth caused by glyphosate has been reversed by the addition of various combinations of the three aromatic amino acids tyrosine, tryptophan, and phenylalanine (Haderlie et al., 1977).

Plant tissues such as shoot and root tips with high metabolic activity are sinks (sites of high accumulation) of foliar-applied glyphosate (Schultz et al., 1990, Hetherington et al., 1999, Feng et al., 2003). Feng et al. (2003) reported up to 80% of the glyphosate applied with foliar treatments was translocated into shoot and root tips. Even at low application rates, sink tissues accumulated glyphosate in high concentrations. Glyphosate accounted for up to 16% of the dry weight of sink tissues of tomato and spinach plants treated with glyphosate (Schulz et al 1990). In an experiment with 3-week-old soybean plants, Cakmak et al. (2009) showed that increasing rates of glyphosate on shoots significantly reduced the chlorophyll content of young leaves and shoot dry weight, particularly the young plant parts. Concentration of shikimate due to increasing glyphosate rates was nearly 2-fold for older leaves and 16-fold for younger leaves compared to non-treated plants.

After glyphosate application, plants continue to attempt to push carbon through the shikimate pathway, with a resulting accumulation of shikimate in sensitive plants in the days immediately after application (Mueller et al., 2008). Glyphosate is difficult to detect and quantify in plant tissue, while shikimate is easily detectable at normal and elevated levels after herbicide application. Elevated shikimate levels can be used as an early highly sensitive indicator of glyphosate effects on glyphosate-sensitive tissues (Harring et al., 1998). Henry et al. (2005) reported that shikimate levels were short-lived in 6-7-leaf corn and 2nd to 3rd trifoliolate soybean treated with 0, 0.0625, 0.25, and 0.50 times the recommended rate of glyphosate. Shikimate accumulation peaked between 4 and 7 days after treatment and then declined. Visual injury symptoms developed more slowly than shikimate accumulations. Therefore, it was necessary to take samples for

analysis within one week or at the first sign of crop injury to detect shikimate in the plants. Two methods for measuring shikimate are currently available: an HPLC assay and a spectrophotometric assay (Anderson et al., 2001; Cromartie and Polge, 2000). The HPLC assay is labor intensive and reagents and equipment are expensive (Anderson et al., 2001), while the spectrophotometric assay is relatively rapid and inexpensive (Cromartie and Polge, 2000).

Glyphosate and the role of cations

Hard water contains Ca, Mg, and/or Na cations which can form a complex with the anionic glyphosate molecule in spray solution, reducing its effectiveness (Zollinger, 2008). Reductions in herbicide toxicity by salts of zinc and iron have been observed, with trivalent iron and aluminum ions causing the most reduction (Stahlman and Phillips, 1979). The Roundup Pro[®] label (Monsanto) indicates that up to 17 lb. of ammonium sulfate can be added to 100 gallons of hard water used in the spray solution. With the addition of ammonium sulfate, glyphosate binds to the NH₄ ion and functions normally. The amount of ammonium sulfate needed (lb per 100 gal of water in spray solution) = 0.009 (ppm calcium) + 0.005 (ppm sodium) + 0.002 (ppm potassium) + 0.014 (ppm magnesium) (Zollinger 2008). The use of lower volumes of spray solution also reduces the effect of cations as there are fewer cations when using fewer gallons of water. Some plants contain high levels of Ca in their intracellular spaces. Velvetleaf (*Abutilon theophrasti*) releases Ca from within the leaf upon misting (Hall et al., 1999). Velvetleaf, lambsquarters, and a few other weeds have chalk glands on leaf surfaces that release Ca and other cations that interfere with glyphosate (Zollinger, 2008). Addition of ammonium sulfate enhances herbicide activity in these cases as well.

Accumulations of glyphosate in metabolic sinks may impair mineral nutrient divalent cations such as calcium (Ca), magnesium (Mg), manganese (Mn), and iron (Fe) by chelation (Lundager-Madsen et al., 1978; Motekaitis and Martell, 1985; Barja et al., 2001). These nutrients bind easily to the glyphosate molecule in spray solutions, forming poorly soluble or very stable complexes and reducing the effective of herbicide applications. Presence of monovalent cations in glyphosate spray solutions did not cause any change in efficacy (Stahlman and Phillips, 1999). This chelation occurs within plant tissues as well. The ‘yellow flashing’ commonly seen in glyphosate-resistant crops is due to immobilization of Fe and Mn (Franzen et al., 2003; Hansen et al., 2004; Jolley et al., 2004). Length of recovery time from ‘yellow flashing’ is dependent on the plant’s ability to absorb adequate amounts of the deficient elements. High tolerance of certain weeds has been attributed to divalent cation concentrations in leaf tissue. Velvetleaf tolerance has been attributed to high Ca concentrations (Nalewaja et al., 1992) and is related to high concentrations of Mg and Ca on the leaf surface and within the plant (Hall et al., 1999). Conversely, Cakmak et al. (2009) reported that leaf concentrations of potassium (K), phosphorus (P), copper (Cu) and zinc (Zn) were not affected or even increased significantly in case of P and Cu in young soybean leaves treated with glyphosate.

Over-the-top glyphosate applications to selectively control pest species

Control of field dodder (*Cuscuta campestris*) has been tested in various crops with glyphosate applications. Liu and Fer (1990) reported that glyphosate applied to host foliage accumulated in the apical portions of dodder in concentrations 26 times that in the apical bud and treated leaves of the host. No damage to alfalfa was observed when both host and parasite were growing vigorously and 40.5 g ai/A was applied (Dawson 1989).

In another study, Bewick et al. (1988) reported that about 162.0 g ai/A controlled dodder in carrots (*Daucus carota* L.). Hock et al. (2008) tested ornamentals with and without dodder infestations. While host plants had a wide range of sensitivities to glyphosate, the parasite was killed by the same dose regardless of host. The rates of glyphosate for a 10% reduction in visual quality of dodder-free plants were croton, 0.71 lb ai/A; allamanda (*Allamanda blanchetii* A. DC), 0.25 lb; hibiscus (*Hibiscus* L. spp.), 1.11 lb; paper gardenia [*Tabernaemontana divaricata* (L.) R. Br. ex Roemer & Schultes], 0.33 lb; ixora (*Ixora* L. spp.), 0.53 lb; duranta (*Duranta* L. spp.), 0.74 lb; schefflera [*Schefflera arboricola* (Hayata) Merr.], 0.59 lb; and king's mantle [*Thunbergia erecta* (Benth.) T. Anders], 0.15 lb. While dodder-infested plants were less tolerant to glyphosate due to stress from both the parasite and the herbicide, dodder infesting the plants could be controlled on all eight species with about 0.15 lb ai/A of glyphosate. Nadler-Hassar et al. (2004) reported that shikimate was detected in the parasite as early as 1 day after treatment with glyphosate. Shikimate was continuously accumulated in the parasite, but not in the host. At 3 DAT, apices of dodder had accumulated high shikimate levels, while very little had accumulated in the meristems of host plants.

Glyphosate has applications in regulating the growth of grassy and broadleaf plants. Roundup Pro® can be used to control or partially control many annual and perennial weeds in actively growing bermudagrass. No more than 0.5 lb ai/A are recommended in highly maintained turfgrass areas. However, 0.5 to 1.5 lb ai/A can be applied per acre of actively growing bermudagrass along roadsides where some plant injury can be tolerated (Monsanto). Walker and Belcher (2008) showed that dallisgrass could be controlled in hybrid bermudagrass turf (419) with 0.33 lb ai/A of glyphosate

applied in late September to late October. No difference in bermudagrass ground cover was observed the following spring, although addition nitrogen and irrigation may be needed for the slight reduction in grass cover the following spring.

The Roundup Pro[®] label (Monsanto) recommends 1.0 to 2.0 lb ai/A to control (kill) bahiagrass. However, along roadsides, 0.19 lb ai/A can be applied for suppression of vegetative bahia growth and seedhead inhibition for 45 days. The application must be made 1-2 weeks after full greenup or after mowing to a uniform height of 3 to 4 inches. For up to 120 days of suppression, 0.125 lb ai/A are applied, followed by an application of 0.063 to 0.125 lb ai/A about 45 days later. With virtually the same amount of herbicide used in a different way, almost 3 times the length control is achieved.

Chemical mowing is used in many applications to stunt or stop weed growth where temporary plant injury and discoloration can be tolerated, thereby reducing mechanical mowing along roadsides or other industrial areas. Roundup Pro[®] rates from 0.125 to 0.156 lb ai/A applied on active growth before the boot stage of development will suppress annual ryegrass, wild barley and wild oats. Applications of 0.19 lb ai/A can be used to suppress Kentucky bluegrass, and 0.25 lb ai/A will suppress tall fescue, fine fescue, orchardgrass, quackgrass, and reed canarygrass (Monsanto).

Chemical mowing has been studied for vegetation management in row middles in Florida citrus. The rate of herbicide applied varied according to the weed species present, with 0.28 to 0.59 and 0.59 to 0.86 lb ai/A respectively for bahiagrass (*Paspalum notatum*) and bermudagrass (*Cynodon dactylon*) (Futch and Singh, 2000). North Carolina Fraser fir growers employ chemical mowing to suppress weeds with applications of 0.25 lb ai/A of Roundup Original[®] from the dormant period until May 10, when shoot elongation

occurs. Applications at 0.125 lb ai/A are applied until the end of June, when trees are more tolerant; 0.25 lb ai/A is then applied until the end of August. Spot treatments are applied during the remainder of the year. Tree injury from spray contact was reported between May 10th and June 10th (Hundley and Owen, 2005). Sidebottom et al. (1998), also working with North Carolina Fraser fir, reported that under normal weather conditions, the growing height for perennial grass and some overwintering perennial broadleaves is allowed to reach the chemical mowing threshold of 6 to 18 inches and treated in April before bud break. In cool weather, the chemical mowing threshold may not be reached until mid-May, when summer annuals such as ragweed, lambsquarters, smartweed, and asters and perennials including pokeweed, bindweed, dock and others emerge. If the first chemical mowing can be delayed until June, a single treatment will control all weeds. In a separate report, Sidebottom (2003) states that generally two to three glyphosate treatments are required. The first treatment is usually before bud break, with the second about six weeks later. Excessive weed growth may require a third treatment in wet years.

Factors in plant tolerance to glyphosate

The required rate in a weed control situation is determined by the most tolerant species. Recommended glyphosate rates for weed control can vary from 0.5 to 5.0 lb ai/A. Annual and seedling grasses are most easily controlled, while broadleaves are more tolerant. Higher rates are usually required for perennials. According to label rates (Monsanto), annual weeds less than 6 inches tall are controlled with 1.0 lb ai/A of Roundup Pro[®]. Annual weeds taller than 6 inches are controlled with 1.5 lb ai/A. Perennial weeds are controlled by 1.0 to 5.0 lb ai/A, depending on the weed species.

Woody brush and trees are controlled by 2.0 to 5.0 lb ai/A, depending on species. Plant size, reproductive stage, and time of year are factors as well.

Susceptibility to glyphosate can vary among species. *Amaranthus retroflexus* L. is unusually susceptible to glyphosate. Effects can be observed only a few hours after spraying. Percent control of *Amaranthus retroflexus*, *albus*, *viridis*, *tamariscinus* and *hybridus* by glyphosate-trimesium (0.2 lb ai/A) 22 days after application was 94, 89, 77, 58, and 52% respectively (Baylis, 2000). Likewise, 'Blue Rug' juniper showed much lower injury, especially in the first half of the growing season, than 'Blue Pacific' juniper (Neal and Skroch, 1985).

Glyphosate tolerance and resistance can exist within a species as well. It was reported that a single population of field bindweed (*Convolvulus arvensis* L) was reported to contain 5 biotypes which differed in their susceptibility to glyphosate (DeGennaro and Weller, 1984).

A waxy cuticle provides defense against absorption of glyphosate of plant leaves. Ferreira and Reddy (2000) studied absorption and translocation in *Erythroxylum coca* and *E. novogranatense* with ¹⁴C-glyphosate. Results showed a higher rate of absorption as expected in younger plants, but the rates of translocation were higher for older *E. coca* plants and for younger *E. novogranatense* plants. When wax was removed from the cuticle, absorption was significantly higher and translocation was nearly doubled in *E. coca*. This indicates some of the resistance that the cuticle imparts against the absorption and translocation of glyphosate.

In a study of olive (*Olea europaea*) suckers, leaf absorption of ¹⁴C-glyphosate was limited to 1 to 4% of total applied glyphosate 10 days after treatment, attributed to a

thicker cuticle (Valera-Gil and Garcia-Torres, 1994). In a study of dogbane (*Apocynum cannabinum*), tolerance to glyphosate due to decreased absorption was attributed to a thicker and waxier cuticle when compared with milkweed (*Asclepias syriaca* L.), a more susceptible species (Wyrill and Burnside, 1976).

Considerable work has been done on coca plants, woody shrubs with a productive life of 10 to 15 years (Ferreira et al., 1997). In ¹⁴C-glyphosate studies, it was reported that at 6, 24, and 288 hours after application, *E. coca* absorbed 1.2, 4.2, and 59.6% of the glyphosate applied. *E. novogranatense* absorbed 1.8, 3.2, and 79.4% for the same time periods. However, *E. coca* had translocated 8.6% of what was applied after 288 hours, while *E. novogranatense* translocated only 1.8% (Ferreira and Reddy, 2000), yet Ferreira et al. (1997) reported that a twofold higher rate was required to kill *E. coca* versus *E. novogranatense*. This seems to indicate significant differences between species. Even though the foliage of both species had similar amounts of wax, *E. coca* translocated 4.78 times more glyphosate, yet double the amount was needed to kill it. However, both species absorbed very little glyphosate in the first 6 hours, which is within the rain-free period needed for any glyphosate product to effectively kill weeds.

Tolerance to glyphosate appears to involve other mechanisms as well. Work by Norsworthy et al (2001) showed that hemp sesbania [*Sesbania exaltata* (Raf.)] had the highest glyphosate uptake of all species tested with 52% absorption and 66% translocation, but it was not the most susceptible species. Pitted morningglory (*Ipomoea lacunosa* L.) had the lowest absorption rate at 6% and was the most tolerant with 51% controlled while barnyardgrass (*Echinochloa crus-galli* L.) absorbed 30% and was controlled 95%, yet both showed similar amounts of glyphosate translocation. Prickly

sida (*Sida spinosa* L.), which was almost completely controlled in the study, showed an average of 18% glyphosate absorption. Results suggested that the chemical composition of the cuticle may have a larger effect than the quantity of wax since hemp sesbania and barnyardgrass, species with the highest wax content, absorbed more glyphosate.

Glyphosate tolerance in woody plants

Glyphosate is considered to be nonselective, killing almost all species of plants on which it is applied at sufficient rates. However, many woody plants tolerate glyphosate to varying degrees. Neal (1998) reported that in general, conifers and broadleaf evergreen shrubs are most tolerant to glyphosate in late fall and winter, while low rates cause severe damage when applied in the spring. Conversely, deciduous plants are more tolerant in winter and spring, while significant damage results from glyphosate applications in late summer and early fall. It was reported that as few as 6 leaves on a 5-cm branch treated with a 1.0 % solution (4.0 lb ai per 100 gallons) can kill the entire branch.

Putnam (1976) applied glyphosate to selected areas on young apple (*Malus sylvestris* L.), pear (*Pyrus communis* L.), sour cherry (*Prunus cerasus* L.), and peach [*Prunus persica* (L.) Patsch] trees to observe tree response. Glyphosate killed suckers without damaging trees. When a lower branch of apple tree was sprayed, damage occurred to that limb the same year and the following year, but there were no injury symptoms in the rest of the tree. ¹⁴C-glyphosate was applied to the trunks, leaves, and suckers of 4-year-old apple and 5-year-old pear trees. No radioactivity was detected at harvest time in leaves, buds, or fruits following June trunk applications, indicating that the bark provided a barrier to the herbicide. Applications on suckers produced radioactivity only in treated and

adjacent sucker foliage, with none in other parts of the tree. Glyphosate moved from treated leaves of lower branches to other leaves, buds, and fruit on the same branch but was not detected in other parts of the trees.

When selected branches or entire 'MacSpur'/MM106 apple trees were sprayed in September after harvest, severe tree damage was observed in the following two growing seasons. When treated with 2.64 lb ai/100 gallons, trees produced sparse, stunted foliage and no flowers the following spring, with many dead terminal buds. Some deformed leaves and reduced flowering were observed the second season. When applications were made to selected single branches, the injury described for whole-tree treatments only occurred on treated branches. Basal trunk and lower branch applications were variable for peach trees, with 'Redhaven' showing good tolerance from July applications, while newly planted 'Shasta/Halford' trees suffered trunk splitting and death of terminal shoots as herbicide was absorbed through the trunk or lower branches and translocated throughout the tree. The fact that injury symptoms occurred one and two seasons after contact on lower limbs led to the conclusion that glyphosate is not rapidly degraded in apple and pear tissue.

McKloskey and Wright (1998) evaluated the effect of Roundup[®] sprayed on the bottom 20 to 24 inches of lemon (*Citrus x limon*) tree canopies. Citrus trees can be considered to be large evergreen shrubs and thus are similar to evergreen landscape plants. Treatments were applied over a three-year period at rates of 0.5, 0.75, 1.0, 1.25, and 1.5 lb ai/A on June 6 and September 1, 1995; March 6, July 31, and November 22, 1996; May 5, August 15, and November 19, 1997; and March 20, 1998. Significant injury occurred in the sprayed area of the trees and there was significant defoliation on

treated branches at higher rates, but there was little effect on the upper portion of the tree canopies. Glyphosate applications to the bottom of the canopy did not significantly affect lemon yields. The authors noted the possibility that repeated applications as indicated above may have injured tissue to the point that not all glyphosate was absorbed.

Curtis (1974) reported that glyphosate injured apple trees when applied to fresh pruning wounds, but not when applied to two-week-old wounds. Ahrens (1974) also reported localized injury from applications of glyphosate on pruning wounds on junipers, yew, and pines. Ahrens (1977) observed that injury from basal applications to crowns of woody plants occurred when the basal foliage constituted a large portion of the foliage of the tree or at high rates of application. No movement from basal sprouts to crown occurred at 3.0 lb ai/100 gallons, well above the rate required for control of perennial weeds. Bark injury was not noted on one-year-old trees tested, which included Norway maple (*Acer planatoides*), honeylocust (*Gleditsia triacanthos inermis*), London planetree (*Platanus orientalis*), European mountain ash (*Sorbus aucuparia*), pin oak (*Quercus palustris*), and littleleaf linden (*Tilia cordata*).

Kuhns (1992) applied glyphosate at 1.0 or 4.0 lb ai/A to the lower 6 inches of the trunk on both sides with the nozzle held about 12 inches away from the trunk. The same treatments were applied to the lower 18 inches of trunk on one side, with the nozzle held within 4 inches of the trunk. Applications were made on August 25, 1989 to Northwood red maple (*Acer rubrum* L. cv. Northwood), green ash (*Fraxinus pennsylvanica* Marsh.), thornless honeylocust (*Gleditsia triacanthos* L. var. *inermis* Willd.), Cortland apple (*Malus* cv. Cortland), Montmorency cherry (*Prunus* cv. Montmorency), M.A. Blake peach [*Prunus Persica* (L.) Batsch cv. M.A. Blake], Cleveland Select flowering pear

(*Pyrus calleryana* Decne cv. Cleveland Select), English oak (*Quercus robur* L.) and littleleaf linden (*Tilia cordata* Mill.). Forty-eight plots containing one of each of the species was planted. Treated trees were between 0.7 and 1.7 inches in diameter at 12 inches above the ground. Trees were evaluated for damage to foliage or bark in 1989, 1990, and 1991. No signs of foliar damage were observed with any of the treatments. None of the treatments damaged the bark of ash, honeylocust, maple, oak, pear, or apple. These trees tolerated limited amounts of glyphosate to thin and pigmented bark. Injury seen on one linden was attributed to glyphosate. Dead trees and bark splitting were scattered among cherries and peaches, but the researcher was uncertain whether the injury was caused by glyphosate treatments. Glyphosate applied at 4.0 lb ai/A with the nozzle close to the trunks of young trees was treatment most likely to cause injury.

Recent work by Mathers (2008) involves research on the possible role of glyphosate applications in bark splitting on trunks of thin-skinned trees. It is thought that surfactants in the formulation are to blame for bark splitting by enhancing uptake of glyphosate through the trunk. Woody plants most susceptible to glyphosate uptake include: *Pyrus* species, especially Callery pears; *Prunus* species, especially Yoshino cherry and Kwanzan cherry; crab apples; sycamore; serviceberry; hawthorn; mountain ash; black gum; paper bark maple; Japanese maples, especially ‘dissectum;’ Norway maple, especially ‘Emerald Queen’; red maples; dogwood, especially Kousa dogwood; magnolias, especially Magnolia ‘Elizabeth’ and the yellow magnolias such as Magnolia ‘Butterflies’, ‘Sawada’s Cream’, Magnolia ‘Yellow Bird’ and Magnolia ‘Yellow Lantern.’

It is suggested that glyphosate formulations with no adjuvant load be used as needed around sensitive trees. There are fourteen such products including: Backdraft, Campaign, Expert, Extreme, Fallowmaster, Fallow Star, FieldMaster, Glypro, Landmaster BW, Land Star, ReadyMaster ATZ, Rodeo[®], Roundup Custom[™], and RU SoluGran (Mathers, 2008). Of these, only Rodeo[®], Glypro, and Roundup Custom[™] (all glyphosate-ipa formulations) and RU SoluGran (glyphosate-NH₃) are glyphosate-only products.

Daniel and Mathers (2009) reported research on the effects of glyphosate and pelargonic acid on sucker removal and injury of field tree liners subjected to freezing temperatures. *Acer x freemanii* ‘Jeffersred (Autumn Blaze[™] red maple), *Malus* ‘Prairifire’ (Prairifire crabapple), *Cercis canadensis* (Eastern redbud), and *Quercus rubra* (red oak) liners were planted in the field in October, 2003 and allowed to grow for four seasons, when average calipers were 2.4, 1.5, 2.0, and 1.3 inches respectively. In June 2007 and 2008 suckers were removed with pruning shears. Trees that lacked suckers, such as oak, received an incision 1 inch wide and 2 inches long approximately 4 inches from the base of the tree. Sucker removal or one incision was performed on the north and south sides of each tree. Herbicide treatments of 5% solution were applied immediately afterward with treatments including Roundup Original Max[®] (48.7% glyphosate), Roundup Pro[®] (41% glyphosate), Kleen-up[®] Pro (41% glyphosate), and Scythe[®] (57% pelargonic acid) applied from a distance of 6 inches. Injury-only (no herbicide) and no-injury-or-herbicide treatments served as non-treated controls. Maple exhibited the greatest amount of cracking, with Roundup Original Max[®] producing the most, followed

by Roundup Pro[®], Scythe[®], Kleenup[®] Pro, and mechanical injury had statistically similar amounts of cracking, and noninjured trees had much lower numbers of cracks.

Roundup[®] over the top of nursery crops

Interest in the potential for use of glyphosate as an over-the-top weed control treatment in nursery crops received much attention beginning with the work of Neel and Burt (1973). They experimented with an over-the-top spray on 19 ornamental species with glyphosate rates of 0, 1.0, 2.0, 4.0, and 8.0 lb ai/A applied in July and repeated in December, 1972. Plants used in the study included *Aglaonema*, *Asparagus*, *Bougainvillea*, bromeliad, *Callistemon*, *Casuarinas*, *Chrysalidocarpus*, *Codiaeum*, *Dizygotheca*, *Hemigraphis*, *Hibiscus*, *Kalanchoe*, *Murraya*, *Podocarpus*, *Polyscias*, *Rhoeo*, *Setcreasea*, and *Swietenia*. Variable injury was noted from species to species. Fully developed symptoms appeared within 6 weeks. Rates > 2.0 lb ai/A usually killed plants in 3 weeks, with death of the growing point followed by death and /or necrosis of older leaves and portions of shoots. Sublethal symptoms from applications \leq 2.0 lb ai/A developed fully in about 6 weeks. It was concluded that foliar applications of glyphosate were not recommended, although directed sprays around woody stems could be feasible.

Ahrens (1974) reported that rate and the time of year of application were significant factors in the selectivity of glyphosate. Fall applications on dormant conifers at 1.0 lb ai/A to control perennial grasses and blackberries and 0.5 lb applied during the growing season to control annual weeds showed promise. Temporary growth suppression in certain woody plants was considered a benefit in landscape plantings, where maximal growth is often undesirable.

Neal and Skroch (1985) studied rates and timing of Roundup[®] applications on 13 species of ornamentals from March 12 to November 11, 1982. They applied Roundup[®] at 0.8, 1.5, and 3.0 kg ai/ha (0.71, 1.33, and 2.67 lb ai/A) at six different times throughout the season. They divided plants and their responses to Roundup[®] into 4 groups. Group 1 species: ajuga (*Ajuga reptans*), azalea [*Rhododendron* x 'Kirin' (syn. 'Coral Bells')], and variegated liriopse (*Liriope muscari* 'Variegata') were injured by all application times and rates. Group 2, 3, and 4 species showed tolerance to fall applications. Group 2; dwarf yaupon, English ivy (*Hedera helix*), 'Helleri' holly (*I. crenata* 'Helleri') and ligustrum (*L. japonicum*) sustained the most injury from spring applications. Group 3; Andorra Juniper (*Juniperus horizontalis* 'Plumosa'), compacta holly (*I. crenata* 'Compacta'), Fraser's photinia (*Photinia x fraseri*), and green liriopse (*Liriope spicata*) were most injured by summer applications. Group 4; 'Blue Pacific' juniper and 'Blue Rug' juniper (*Juniperus horizontalis* 'Wiltonii') tolerated all but the highest rates with acceptable damage, which was considered to be $\leq 15\%$. Results verified that the time of the herbicide application was as important as the amount of herbicide applied. As a general rule, treatments after August 5 resulted in minimal injury compared to treatments before that time of year. Plants were evaluated through the second season after treatment to determine latent effects that may have shown up in the spring flush; none were reported.

In a separate study, Neal et al. (1985) reported that ligustrum showed a linear decrease in susceptibility from March to November, while Blue Pacific juniper sustained only a temporary tip chlorosis from summer applications at high rates. Both species recovered by the end of the growing season. Neal stated that except for applications on young expanding ligustrum leaves, the time required for absorption of detectable levels

of ¹⁴C- glyphosate into ligustrum and juniper was slow when compared to absorption rates for herbaceous weeds, but the time was similar for absorption rates for other woody species.

Multiple applications of Roundup[®] applied over the top of nursery crops were also tested. Self (1978) applied Roundup[®] once, twice, or three times at 0.5, 0.75, 1.0, and 1.5 lb ai/A on 7, 14, and 21 April 1978 over the top of 18 ornamental species. Total amounts of glyphosate applied ranged from 0.5 to 4.5 lb ai/A. Of the 18 species tested, eight were not injured, including *Magnolia soulangeana*, *Juniperus conferta*, *Cupressus* sp., *Ilex cornuta* 'Burfordii Nana,' *I. cornuta* 'Yellow top,' *Photinia fraseri*, *Podocarpus*, and *Trachycarpus fortunei*. *Gardenia radicans* was injured only at 3 and 4.5 total lb ai/A. Of the remaining species, 'Hinodegiri' and 'Fashion' azaleas were the most sensitive, with injury occurring from as little as 2 applications of the 0.5 lb rate. Self concluded that there is a greater difference in sensitivity to glyphosate between species and cultivars than between light multiple applications and single heavy applications.

Perry and Knowles (1978) applied glyphosate on Aug 3, 1978 at 0.25, 0.5, 0.75, or 1.0 lb ai/A. The same rates were repeated over the same plants on Aug 17. Plants were evaluated at the end of Feb 1979, when no injury was reported on *Berberis mentorensis*, *Camellia japonica*, *Forsythia intermedia*, and *Ligustrum vicari*. Slight temporary yellowing of leaf tips was observed with higher rates on *B. juliana*, *Euonymus japonicas*, and *Ilex cornuta* 'Burfordi nana.' Yellowing of leaf tips was not observed following the second spray on dwarf burford. Injury was more severe at rates ≥ 0.75 lb ai/A on *Rhododendron obtusum japonicum* cv 'Hino,' *Ilex crenata* 'Helleri,' and *I.*

crenata ‘Hetzi.’ These plants showed cumulative effects of glyphosate damage, but the injury was not permanent and appeared to have a slight pruning effect on azalea. No phytotoxicity was observed on any species at any rate in the fall, and all overwintered well.

With variable results from glyphosate applications, growers feared plant damage. Self and Washington (1977) concluded from accumulated data in 1974, 1975, and 1977 that glyphosate had a place in all phases of weed control, including young rooted liners as well as older established container-grown crops. They reported that some species could be injured or killed, and that grower testing early in the season would be needed before weeds became a problem. However, subsequent research (Neal and Skroch, 1985) has shown that crops are most easily injured early in the season. With availability of inexpensive labor for hand weeding, widespread interest in the potential of glyphosate over nursery crops waned in the early 1980’s. However, research continued sporadically in the early 2000’s.

Altland et al. (2002) reported that Roundup[®] at 0.4 lb ai/A could be used as a cleanup treatment for effective control of spurge (96%) in *L. muscari* ‘Big Blue’ with no short-term or long-term injury to ‘Big Blue.’ In separate experiments, Roundup[®] at 1.6 lb ai/A, the maximum rate tested, was applied to recently divided liners of ‘Variegata’ and ‘Big Blue’ infested with mature and flowering spurge. Effective control of spurge (92.8% and 100% respectively) with no short-term or long-term injury to ‘Variegata’ was reported. ‘Big Blue’ showed slight initial injury which was outgrown by 60 DAT. Walsworth et al. (2006) reported that Roundup[®] applied on September 6, 2005 in a 1% solution (4.0 lb ai in 100 gallons) caused no injury on liriopie or Asiatic jasmine.

Early research was done with Roundup Original[®], a product which required 4 to 6 hours without rainfall or irrigation, applied at rates of 100 to 125 GPA. In 1997, Roundup Pro[®], with a new mix of surfactants, was introduced. Roundup Pro[®] requires only 1 to 2 hours without rainfall or irrigation to become rainfast (Monsanto literature, 1998). Therefore, research prior to 1997 was done with a slightly different product than the Roundup Pro[®] formulation used today. Ahrens (1986) in his work on Christmas trees noted that the addition of surfactants decreased the selectivity of glyphosate and reductions in spray volumes required greater attention to minimizing spray contact with conifer foliage. Reductions in total spray volumes resulted in increased surfactant concentration and activity.

Wagner (1999) reported that after the introduction of Roundup Original[®] in the late 1970's through the late 1980's, consistent vegetation control for conifer release in northeastern U.S. forests was achieved with minimal injury. Replacement of Roundup Original[®] with a significantly changed glyphosate formulation (Accord plus Entry) occurred in the late 1980's. While results were similar with the new product, noticeable increases in conifer injury were reported by Maine forest landowners. Similar changes in spruce injury with glyphosate were also noted in Canadian forests. Likewise, Neal (1998) reported that landscapers who learned to use Roundup Original[®] around and over conifers reported injury when Roundup Pro[®] was used in the same way.

A summary of past work done with glyphosate applied over the top of nursery crops is shown below for each species tested, detailing time of year, rate, and gallons per acre (GPA) of spray solution. All of these factors have been shown to be significant. Glyphosate was also tested over rooted cuttings, described as "cuttings, rooted."

Species tested

Abies balsamea (Balsam fir)

- June 1, June 22, July 13, Aug 3, Aug 24, Sep 21, or Oct 6. 2.0 lb ai/A applied by aircraft in 5 GPA. After early Aug, very slight injury. (Wagner, 1999)

Acer planatoides ‘Crimson King’ (Norway maple)

- One-year-old whips planted Apr 12, treated June 16, 1976. 3.0 or 6.0 lb ai/100 gal sprayed on lower 18 inches of bark and basal sprouts. Evaluated 1, 3, 7, and 14 weeks after treatment. 3.0 and 6.0 lb killed basal sprouts within 3 weeks. No bark or crown injury. (Ahrens, 1977)

Acer planatoides ‘Superform’ (Norway maple)

- One-year-old whips planted Apr 12, treated June 16, 1976. 3.0 or 6.0 lb ai/100 gal sprayed on lower 18 inches of bark and basal sprouts. Evaluated 1, 3, 7, and 14 weeks after treatment. 3.0 lb caused 30-50% necrosis on basal sprouts, some crown injury (necrotic leaf tips on isolated branches, symptoms gone after 7 weeks) from 6.0-lb rate. (Ahrens, 1977)

Acer rubrum L. (Red maple)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Trees were killed (After 2 years, no foliage or resprouting from base of dead stems.) GPA not noted. (Wendell and Kochenderfer, 1982)

Ajuga reptans

- Mar 12, Apr 30, Jun 23, Aug 5, Sep 30, or Nov 11, 1982. 0.70, 1.33, or 2.67 lb ai/A, 25 GPA. Significant injury at all rates and dates. (Neal and Skroch, 1985)

Allamanda blanchettii (Purple allamanda)

- Greenhouse (Guam). 0.21 lb ai/A, 9 GPA, resulted in 5% plant visual quality reduction. Time of application not noted. (Hock et al., 2008)

Amelanchier arborea (Michx. f.) Fern. (Downy serviceberry)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Trees were killed (After 2 years, no foliage or resprouting from base of dead stems.) GPA not noted. (Wendell and Kochenderfer, 1982)

Andropogon virginicus L. (Broom sedge)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Plants were killed (After 2 years, no foliage or resprouting from base of dead stems.) GPA not noted. (Wendell and Kochenderfer, 1982)

Berberis julianae (Wintergreen barberry)

- Aug 3 and 17, 1978. 0.25, 0.5, 0.75, or 1.0 lb ai/A sprayed twice. Evaluated at the end of Feb 1979. Temporary slight yellowing leaf tips at higher rates. GPA not noted; “complete coverage of weeds.” (Perry and Knowles, 1979)

Berberis mentoris (Barberry)

- Aug 3 and 17, 1978. 0.25, 0.5, 0.75, and 1.0 lb ai/A sprayed twice. Evaluated at the end of Feb 1979. No injury. GPA not noted; “complete coverage of weeds.” (Perry and Knowles, 1979)

Berberis thunbergii (Red barberry)

- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)

Berberis thunbergii atropureana (Crimson pygmy barberry)

- July 1, 1980. 0.5 lb ai/A. Severe stunting, stems killed. 15 GPA. (Pounders and Gilliam, 1981)

Betula lenta L. (Sweet birch)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Trees were killed (After 2 years, no foliage or resprouting from base of dead stems.) GPA not noted. (Wendell and Kochenderfer, 1982)

Buxus harlandii (Harland boxwood)

- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)

Buxus microphylla var. *japonica* (Japanese boxwood)

- Jun 19, 1978. 0.38 or 0.75 lb ai/A in 100 or 125 GPA. Observed five weeks later; apical chlorosis and some necrosis at both rates. (Cobb and Self, 1979)

Buxus microphylla var. *japonica* ‘Wintergreen’ (Wintergreen boxwood)

- June 15, 1978. No injury, cuttings rooted after 0.75 lb ai/A applied 3X one week apart. GPA not noted (Cobb and Self, 1979 a)

Buxus sempervirens (Common boxwood, American boxwood)

- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury at 2.0 lb. 80-90% weed control. GPA not noted. (Self and Pounders, 1975)
- July 6, 1979. 1.0, 2.0, 4.0, and 8.0 lb ai/A in 40 GPA. Evaluated 12 weeks later. Established liners in soil with heavy weed infestation. Slight or no injury at 1.0, 2.0, and 4.0 lb ai/A. (Harakami et al., 1980)

Camellia japonica

- Jun 19, 1978. 0.38 or 0.75 lb ai/A in 100 or 125 GPA. Observed five weeks later, no injury (Cobb and Self, 1979)
- 0.5, 0.75, 1.0, or 1.5 lb ai/A applied on Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21. Totals applied ranged from 0.5 lb ai (single application) to 4.5 lb ai/A (1.5 x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. Injury at 2 x 0.50 lb., 2 x 0.75 lb., 3 x .075 lb, 3 x 1.0 lb, and 3 x 1.5 lb. All injury rated moderate. (Self, 1978)

Citrus x limon 'Limoneira 8A' Lisbon lemon on *Citrus volkameriana* rootstock (Lemon)

- June 6 and Sep 1, 1995; Mar 6, July 31, and Nov 22, 1996; May 5, Aug 15, and Nov 19, 1997; and Mar 20, 1998. 0.5, 0.75, 1.0, 1.25, or 1.5 lb ai/A sprayed on a 20-24 inch band around the perimeter of the canopy. GPA not noted. Visual injury ratings were done on Apr 26, 1996; May 14, 1997; and Apr 18, 1998. Injury and defoliation were noted on treated leaves, but no translocation or injury, reduction in flower counts, or loss of fruitlet production was noted in the upper foliage. (McCloskey and Wright, 1998)

Cleyera japonica (Japanese cleyera)

- Aug 3 and 17, 1978. 0.25, 0.5, 0.75, or 1.0 lb ai/A sprayed twice. Evaluated at the end of Feb 1979. No injury. GPA not noted; "complete coverage of weeds." (Perry and Knowles, 1979)

Codiaeum variegatum (L.) Blume (Croton)

- Greenhouse (Guam). 0.45 lb ai/A in 9 GPA resulted in 5% plant visual quality reduction. Time of application not noted. (Hock et al., 2008)

Conocarpus erectus var. *sericeus* (Silver buttonwood tree)

- May 10, 1974. 1.2 or 2.4 lb ai/A. GPA not noted. Evaluated 14 DAT, injury on trunk suckers only. (Neel and Hull, 1974)

Cornus florida L. (Flowering dogwood)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Intermediate resistance (Crowns partially killed, second-year foliage deformed and sparse.) GPA not noted. (Wendell and Kochenderfer, 1982)

Cotoneaster apiculata REHD (Cranberry cotoneaster)

- July 6, 1979. 1.0, 2.0, 4.0, or 8.0 lb ai/A in 40 GPA. Evaluated 12 weeks later. Established liners in soil with heavy weed infestation. Showed injury whether treated or not, mostly dead at 4.0 and 8.0 lb ai/A. (Harakami et al., 1980)

Cotoneaster horizontalis (Rockspray cotoneaster)

- June 28, 1973. 0.5 lb ai/A. Evaluated on July 20 (40% injury) and Sept 12 (40% injury). Three one-gallon plants tested. GPA not noted (Ahrens, 1974)

Cupressus sp. (Cypress)

- 0.5, 0.75, 1.0, or 1.5 lb ai/ac applied on Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21. Totals applied ranged from 0.5 lb ai (single application) to 4.5 lb ai/A (1.5 x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. No injury at any rate. (Self, 1978)

Cuttings, rooted

- Jan 15, 1975. 0.25, 0.5, or 1.0 lb ai/A applied in 50 GPA. Azalea varieties: Coral Bell, Delaware White, Fashion, Glory, Hershey Red, Hinodegiri, Hino-Crimson, Prudence, Snow, and Christmas Cheer. Additional species: *Fatsyhedera lizei*, *Ilex vomitoria*, *I. vomitoria* nana, *Raphiolepis* sp., *Viburnum tinis*, *I. cornuta* 'Burfordi,' *Euonymus japonica* 'Gold Spot,' *E. japonica microphylla*, and *Ligustrum* sp. Rooted in peat:perlite:vermiculite 1x2-inch cell packs. Excessive stunting at all rates except for *Euonymus* 'Gold Spot' and *Rapheolepis*, which were safe at the 0.25 rate and moderately injured at the higher rates (Self, 1975).

Duranta L. spp. (*Duranta*)

- Greenhouse (Guam). 0.52 lb ai/A in 9 GPA resulted in 5% plant visual quality reduction. Time of application not noted. (Hock et al., 2008)

Eleagnus augustifolia (Russian olive)

- Liners planted in soil on May 9-11, 1973, treated on July 24. 1.0, 2.0, or 3.0 lb ai/A, 50 GPA. Evaluated on Sept 13, Oct 15. Fair growth with 1.0 and 2.0 lb, poor with 3.0 lb. (Bing, 1974)

Euonymus fortunei ‘Emerald Cushion’

- June 28, 1973. 0.5 lb ai/A. Evaluated on July 20 (30% injury) and Sept 12 (no injury). Three one-gallon plants tested. GPA not noted (Ahrens, 1974)

Euonymus fortunei (Wintercreeper)

- Liners planted in soil on May 9-11, 1973, treated on July 24. 1.0, 2.0, or 3.0 lb ai/A, 50 GPA. Evaluated on Sept 13, Oct 15. Vigorous growth with all rates. (Bing, 1974)
- Aug 1974 and 1975. 1.0, 2.0, or 3.0 lb ai/A, evaluated for 9 months, no injury. GPA not noted. (Whitcomb et al., 1976)

Euonymus japonica (Japanese euonymus)

- Aug 3 and 17, 1978. 0.25, 0.5, 0.75, or 1.0 lb ai/A sprayed twice. Evaluated at the end of Feb 1979. Temporary slight yellowing leaf tips at higher rates. GPA not noted; “complete coverage of weeds.” (Perry and Knowles, 1979)
- Jun 19, 1978. 0.375 or 0.75 lb ai/A in 100 or 125 GPA. Evaluated five weeks later, abnormal foliage near apexes and abnormal subapical breaks. (Cobb and Self, 1979)

Euonymus japonica ‘Gold Spot’

- 0.5, 0.75, 1.0, or 1.5 lb ai/A applied on Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. Injury at 1.5 lb ai/A applied 3 times. (Self, 1978)

- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury at 2.0 lb or less. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Euonymus 'Marble Queen'

- March 15, 1977 (dormant). 1.0 or 2.0 lb ai/A, 100 GPA, 2 to 25 plants in 4- to 10-inch pots. No injury. Date(s) of observation not noted. (Self and Washington, 1977)

Euonymus japonica 'Silver Queen'

- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury at 2.0 lb or less. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Euonymus microphylla (Littleleaf boxwood)

- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury at 2.0 lb or less, 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Euonymus variegated

- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)

Euphorbia triangularia

- Mar 15, 1977 (dormant), 0.25, 0.5 or 1.0 lb ai in 100 GPA, 2 plants in 6-inch pots. No injury; date(s) of observation not noted. (Self and Washington, 1977)

Fatshedera lizei (Bush ivy)

- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)

Ficus nitida (Indian laurel fig)

- May 10, 1974. 1.2 or 2.4 lb ai/A. Evaluated 14 DAT, no injury. GPA not noted. (Neel and Hull, 1974)

Forsythia intermedia (Showy forsythia)

- Liners planted in soil on May 9-11, 1973, treated on July 24. 1.0, 2.0, or 3.0 lb ai/A, 50 GPA. Evaluated on Sept 13, Oct 15. Vigorous growth with 1.0 lb, fair with 2.0 and 3.0-lb. rates. (Bing, 1974)
- June 28, 1973. 0.5 lb ai/A. Evaluated on July 20 (40% injury) and Sept 12 (50% injury). Three one-gallon plants tested. GPA not noted (Ahrens, 1974)
- Aug 3 and 17, 1978. 0.25, 0.5, 0.75, or 1.0 lb ai/A sprayed twice. Evaluated at the end of Feb 1979, no injury. GPA not noted; “complete coverage of weeds.” (Perry and Knowles, 1979)

Fraxinus americana L. (White ash)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Intermediate resistance (Crowns partially killed, second-year foliage deformed and sparse.) GPA not noted. (Wendell and Kochenderfer, 1982)

Gardenia radicans (Creeping gardenia)

- Jun, Aug 1980. 0.5, 1.0, or 2.0 lb ai/A directed at base of plants, some foliage contact, no injury. GPA not noted. (Gilliam and Crockett, 1981)
- 0.5, 0.75, 1.0, or 1.5 lb ai/A applied on Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 lb x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. Injury at 1.0 lb applied 3 times (1.0 x 3) and 1.5 lb applied 3 times (1.5 x 3). (Self, 1978)
- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Rated on Aug 20, 1974, no injury at 2.0 lb or less. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Gardenia radicans variegated (Variegated creeping gardenia)

- Jun 19, 1978 .375, or 0.75 lb in 100 or 125 GPA. Evaluated five weeks later, chlorotic, abnormal growth at tips. (Cobb and Self, 1979)

Gleditsia triacanthos inermis ‘Imperial’ (Imperial honeylocust)

- One-year-old whips planted Apr 12, treated June 16, 1976. 3.0 or 6.0 lb ai/100 gal sprayed on lower 18 inches of bark and basal sprouts. Evaluated 1, 3, 7, and 14 weeks after treatment. No bark or crown injury. (Ahrens, 1977)

Gleditsia triacanthos inermis ‘Sunburst’ (Sunburst honeylocust)

- One-year-old whips planted Apr 12, treated June 16, 1976. 3.0 or 6.0 lb ai/100 gal sprayed on lower 18 inches of bark and basal sprouts. Evaluated 1, 3, 7, and 14 weeks after treatment. 3.0 and 6.0 lb killed basal sprouts within 3 weeks. No bark or crown injury. (Ahrens, 1977)

Hedera helix (English ivy)

- Mar 12, Apr 30, Jun 23, Aug 5, Sep 30, or Nov 11, 1982. 0.70, 1.33, or 2.67 lb ai/A in 25 GPA, significant injury all rates and dates. (Neal and Skroch, 1985)
- Can be controlled by 2-3% solution of Roundup Pro[®] with 3-5 fully expanded leaves in early spring. GPA not noted (Neal, 1998)
- Date unknown, tolerated 0.5-1.5 lb of glyphosate in 40 GPA. (Bing, 1977)

Hibiscus L. spp. (Hibiscus)

- Greenhouse (Guam). 0.77 lb ai/A in 9 GPA resulted in 5% plant visual quality reduction. Time of application not noted. (Hock et al., 2008)

Hypericum hidcote (St. John's wort)

- June 28, 1973. 0.5 lb ai/A. Evaluated on July 20 (50% injury) and Sept 12 (70% injury). Three one-gallon plants tested. GPA not noted (Ahrens, 1974)

Ilex cornuta 'Burfordi nana' (Dwarf burford holly)

- 0.5, 0.75, 1.0, or 1.5 lb ai/A applied on Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21, 1978. 100 GPA, 1 or 2 plants per treatment, no injury, no DAT observed given. (Self, 1978)
- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury at 2.0 lb or less. 80-90% weed control. GPA not noted (Self and Pounders, 1975)
- Aug 3 and 17, 1978. 0.25, 0.5, 0.75, or 1.0 lb ai/A sprayed twice. Evaluated at the end of Feb 1979. Temporary slight yellowing leaf tips at higher rates. GPA not noted; "complete coverage of weeds." (Perry and Knowles, 1979)
- March 15, 1977 (dormant). 1.0 or 2.0 lb ai/A, 100 GPA, 2 to 25 plants in 4- to 10-inch pots, no injury. Date(s) of observation not noted. (Self and Washington, 1977)

Ilex cornuta 'Burfordi Yellow Top'

- Mar 15, 1977 (dormant). 0.25, 0.5 or 1.0 lb ai/A in 100 GPA, one cell pack of 48 plants. No injury, date(s) of observation not noted. (Self and Washington, 1977)
- 0.5, 0.75, 1.0, or 1.5 lb ai/A applied on Apr only, Apr 7 and 14, or Apr 7, 14, and 21. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. No injury at any rate. (Self, 1978)

Ilex cornuta 'Rotunda' (Rotunda Chinese holly)

- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)
- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)
- July 1, 1980. 0.5 lb ai/A. No injury. 15 GPA (Pounders and Gilliam, 1981)

Ilex crenata 'Compacta' (Compacta holly)

- 0.5, 0.75, 1.0, or 1.5 lb ai/A applied on Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. Injury at 1.5 lb x 3. (Self, 1978)
- Mar 12, Apr 30, Jun 23, Aug 5, Sep 30, or Nov 11, 1982. .70, 1.33, or 2.67 lb ai/A, 25 GPA. Significant injury at all rates and dates Mar-Aug, none in Sep and Nov. (Neal and Skroch, 1985)
- July 8, 1977, 9.36 lb ai/100 gallons, evaluated at 22 DAT, severe injury. GPA not noted (Jones and Fulmer, 1978)

Ilex crenata 'Helleri' (Helleri holly)

- Aug 3 and 17, 1978. 0.25, 0.5, 0.75, or 1.0 lb ai/A sprayed twice. Evaluated at the end of Feb 1979. Injury at rates of 0.75 and above. GPA not noted; "complete coverage of weeds." (Perry and Knowles, 1979)
- March 15, 1977 (dormant). 1.0 or 2.0 lb ai/A, 100 GPA, 2 to 25 plants in 4- to 10-inch pots, no injury. Date(s) of observation not noted. (Self and Washington, 1977)

- Mar 12, Apr 30, Jun 23, Aug 5, Sep 30, or Nov 11, 1982. 0.70, 1.33, or 2.67 lb ai/A, 25 GPA. No injury in Nov, slightly more in Sep, significant injury at all other times with all rates. (Neal and Skroch, 1985)

Ilex crenata 'Hetzii' (Hetz's Japanese holly)

- Aug 3 and 17, 1978. 0.25, 0.5, 0.75, or 1.0 lb. ai/A sprayed twice. Evaluated at the end of Feb 1979, injury at rates ≥ 0.75 lb ai/A. GPA not noted; "complete coverage of weeds." (Perry and Knowles, 1979)

Ilex crenata 'Littleleaf yaupon'

- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)

Ilex glabra (L) A. Gray (Inkberry)

- July 6, 1979. 1.0, 2.0, 4.0, or 8.0 lb ai/A in 40 GPA. Evaluated 12 weeks later. Established liners in soil with heavy weed infestation. Slight injury at 1.0 and 2.0 lb, moderate leaf necrosis at 4.0 lb, and severe injury at 8.0 lb ai/A. (Harakami et al., 1980)

Ilex vomitoria (Yaupon holly)

- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Ilex vomitoria 'Nana' (Dwarf yaupon)

- Mar 12, Apr 30, Jun 23, Aug 5, Sep 30, or Nov 11, 1982. 0.70, 1.33, or 2.67 lb ai/A, 25 GPA. Significant injury Mar-Aug, slight in Sep and Nov. (Neal and Skroch, 1985)
- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)
- Aug 1974 and 1975. 1.0, 2.0 or 3.0 lb ai/A, evaluated for 9 months, no injury. GPA not noted. (Whitcomb et al., 1976)
- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Ixora L. spp.

- Greenhouse (Guam). 0.29 lb ai/A in 9 GPA resulted in 5% plant visual quality reduction. Time of application not noted. (Hock et al., 2008)

Juniperus chinensis ‘Blue Vase’ (Blue Vase juniper)

- 0.5, 0.75, 1.0, or 1.5 lb ai/A applied on Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. Injury at 1.0 lb x 3, 1.5lb x 2. (Self, 1978)

Juniperus chinensis ‘Hetzi’

- Sep 1976. 4.0 lb ai/A. Evaluated the summer 1977, no injury. Field grown. GPA not noted (Woodiel, 1977)

Juniperus chinensis ‘Blue Vase’ (Blue Vase juniper)

- 0.5, 0.75, 1.0, or 1.5 lb ai/A applied on Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. Injury at 1.0 lb x 3, 1.5lb x 2. (Self, 1978)

Juniperus chinensis ‘Hetzi’

- Sep, 1976. 4.0 lb ai/A. Observed summer 1977, no injury. Field grown. GPA not noted (Woodiel, 1977)

Juniperus conferta ‘Blue Pacific’ (‘Blue Pacific’ juniper)

- Mar 15, 1977 (dormant). 0.25, 0.5 or 1.0 lb ai/A in 100 GPA, one cell pack 48 plants. No injury, date(s) of observation not noted. (Self and Washington, 1977)
- 0.5, 0.75, 1.0, or 1.5 lb ai/A applied on Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. No injury at any rate. (Self, 1978)
- May 29, 2004, May 13, 2005. 0.5, 1.0, 2.5, 5.0, or 10.0 lb ai/A, 20 GPA, less than 23% injury (significance threshold) at rates \leq 2.5 lb ai. (Czarnota, 2008)

- Mar 12, Apr 30, Jun 23, Aug 5, Sep 30, or Nov 11, 1982. 0.70, 1.33, or 2.67 lb ai/A, 25 GPA. Significant injury in Mar (all rates) and 3.0 lb rate in Apr and Aug. (Neal and Skroch, 1985)
- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Juniperus davurica ‘Parsoni’ (Parsoni juniper)

- May 29, 2004, May 13, 2005. 0.5, 1.0, 2.5, 5.0, or 10.0 lb ai/A, 20 GPA, tolerant up to 1.0 lb. (Czarnota, 2008)

Juniperus horizontalis ‘Wiltonii’ (Blue Rug juniper)

- Mar 12, Apr 30, Jun 23, Aug 5, Sep 30, or Nov 11, 1982. 0.70, 1.33, or 2.67 lb ai/A, 25 GPA. Significant injury from 3.0 lb. rate in Jun and Aug. (Neal and Skroch, 1985)
- July 1, 1980. 0.5 lb ai/A. No injury. 15 GPA (Pounders and Gilliam, 1981)

Juniperus horizontalis ‘Youngstown’ (Andorra juniper)

- Mar 12, Apr 30, Jun 23, Aug 5, Sep 30, or Nov 11, 1982. 0.70, 1.33, or 2.67 lb ai/A, 25 GPA. Significant injury in Mar, Jun and Aug at 3.0 lb. (Neal and Skroch, 1985)
- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)
- June 28, 1973. 0.5 lb ai/A. Evaluated on July 20 (10% injury) and Sept 12 (no injury). Three one-gallon plants tested. GPA not noted (Ahrens, 1974)
- Liners planted in soil on May 9-11, 1973, treated on July 24. 1.0, 2.0, or 3.0 lb ai/A, 50 GPA. Evaluated on Sept 13, Oct 15. Vigorous growth with all rates. (Bing, 1974)

Juniperus squamata ‘Blue Star’

- May 29, 2004, May 13, 2005. 0.5, 1.0, 2.5, 5.0, or 10.0 lb ai/A, 20 GPA, less than 23% injury (significance threshold) at rates \leq 2.5 lb ai. (Czarnota, 2008)

Lagerstroemia spp. (Crape myrtle)

- Very sensitive and readily injured by drift when new spring growth is developing. (Weatherspoon, 1980)

Leucophyllum frutescens (Texas sage)

- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Rated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Leucothoe axillaris (Coast leucothoe)

- June 28, 1973. 0.5 lb ai/A. Evaluated on July 20 (30% injury) and Sept 12 (30% injury). Three one-gallon plants tested. GPA not noted (Ahrens, 1974)

Ligustrum japonicum (Japanese privet)

- Mar 12, Apr 30, Jun 23, Aug 5, Sep 30, or Nov 11, 1982. 0.70, 1.33, or 2.67 lb ai/A, 25 GPA. Significant injury at all rates and dates except Sep 0.7 lb and all Nov rates. (Neal and Skroch, 1985)

Ligustrum japonicum 'Recurvifolia' (Wavy-leaf Japanese privet)

- 0.5, 0.75, 1.0, or 1.5 lb ai/A applied on Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. Injury at 0.5 lb x 3, 0.75 lb x 2, 0.75 lb x 3, 1.0 lb x 3, 1.5 lb x 1,2, and 3. (Self, 1978)
- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)

Ligustrum japonicum 'Variegatum' (Variegated Japanese privet)

- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)
- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Ligustrum ovalifolium (California privet)

- Liners planted in soil on May 9-11, 1973, treated on July 24. 1.0, 2.0, or 3.0 lb ai/A, 50 GPA. Evaluated on Sept 13, Oct 15. Fair growth with 1.0 lb, poor with 2.0 and 3.0 lb. (Bing, 1974)

Ligustrum sinense (Chinese privet)

- Apr 20, June 19, Aug 23, Oct 16, or Dec 2000. 0.7, 1.5, 3.0, 4.5, or 6.0 lb ai/A in 20 GPA. Privet control not influenced by changes in rate, 93 -100% control in Apr, Oct and Dec, 67-69 % in June and Aug. (Harrington and Miller, 2005)
- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)

Ligustrum vicaryi (Golden privet)

- Aug 3 and 17, 1978. 0.25, 0.5, 0.75, or 1.0 lb ai/A sprayed twice. Evaluated at the end of Feb 1979. No injury. GPA not noted; “complete coverage of weeds.” (Perry and Knowles, 1979)

Liriodendron tulipifera L. (Yellow poplar)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Trees killed (After 2 years, no foliage or resprouting from base of dead stems.) GPA not noted. (Wendell and Kochenderfer, 1982)

Liriope muscari (Lily turf)

- Mar 15, 1977 (dormant). 0.25, 0.5 or 1.0 lb ai/A in 100 GPA, 2 plants in 3.5 to 4-inch pots. No injury, date(s) of observation not noted. . (Self and Washington, 1977)
- Sep 6, 2005, 1% glyphosate solution (4.0 lb ai/100 gallons), no significant injury. (Walsworth et al., 2006)
- Mar 12, Apr 30, Jun 23, Aug 5, Sep 30, or Nov 11, 1982, 0.70, 1.33, or 2.67 lb ai/A, 25 GPA. Most injury in Mar, Jun, and at 3.0 lb in Apr. (Neal and Skroch, 1985)
- July 1, 1980. 0.5 lb ai/A. No injury. 15 GPA (Pounders and Gilliam, 1981)

Liriope muscari ‘Big Blue’

- Sep 6, 1997. 0.125, 0.25, or 0.5 lb ai/A, 20 GPA. June 1, June 28, or Aug 24, 2000. 1.6 lb ai/A in 40 GPA. Slight injury outgrown by 60 DAT. (Altland et al., 2002)

Liriope muscari ‘Variegata’

- Sep 6, 1997. 0.125, 0.25, or 0.5 lb ai/A, 20 GPA. June 1, June 28, or Aug 24, 2000. 1.6 lb ai/A in 40 GPA. No injury. (Altland et al., 2002)
- March 15, 1977, (dormant). 1.0 or 2.0 lb ai/A, 100 GPA, 2 to 25 plants in 4- to 10-inch pots, slight injury on youngest leaves at 2.0 lb rate. Date(s) of observation not noted. (Self and Washington, 1977)
- Mar 12, Apr 30, Jun 23, Aug 5, Sep 30, or Nov 11, 1982. 0.70, 1.33, or 2.67 lb ai/A, 25 GPA. Most injury in Mar at all rates, Apr and Jun at 3.0 lb. (Neal and Skroch, 1985)
- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)

Lonicera spp. (Honeysuckle)

- Can be controlled by 1.0 to 1.5% (4.0 to 6.0 lb ai/100 gallons) solution of Roundup Pro[®] at full bloom and up to one month after (early summer) (Neal, 1998)

Lonicera japonica 'purpurea' (Purple Japanese honeysuckle)

- Aug 1974 and 1975. 1.0, 2.0, or 3.0 lb ai/A, evaluated for 9 months, 40-50% defoliation. (Whitcomb et al., 1976)

Magnolia acuminata L. (Cucumbertree)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 ai/A airblast-applied Roundup[®]. Resistant (After 2 years, foliage appeared healthy and normal.) GPA not noted. (Wendell and Kochenderfer, 1982)

Magnolia x soulangeana (Saucer Magnolia)

- 0.5, 0.75, 1.0, or 1.5 lb ai/A applied on Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. No injury at any rate. (Self, 1978)

Mahonia aquifolia (Oregon grape)

- June 28, 1973. 0.5 lb ai/A. Evaluated on July 20 (30% injury) and Sept 12 (70% injury). Three one-gallon plants tested. GPA not noted (Ahrens, 1974)

Malus sieboldii (Toringo crabapple)

- Liners planted in soil on May 9-11, 1973, treated on July 24. 1.0, 2.0, or 3.0 lb ai/A, 50 GPA. Evaluated on Sept 13, Oct 15. Fair to poor growth with 1.0 lb, very poor with 2.0 and 3.0 lb. (Bing, 1974)

Mandevilla

- Mar 15, 1977 (dormant). 0.25, 0.5 or 1.0 lb ai/A in 100 GPA, 1 plant in 8-inch pot. No injury, date(s) of observation not noted. (Self and Washington, 1977)

Michelia fuscata (Banana shrub)

- Mar 15, 1977 (dormant). 0.25, 0.5 or 1.0 lb ai/A in 100 GPA, 2 plants in 3.5 to 4-inch pots. No injury, date(s) of observation not noted. (Self and Washington, 1977)

Nandina domestica (Heavenly bamboo)

- Jun, Aug 1980. 0.5, 1.0, or 2.0 lb ai/A directed at base of plants, some foliage contact, 2.0 lb rate suppressed height and width, 1.0 lb rate reduced width, not height. GPA not noted. (Gilliam and Crockett, 1981)
- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Rated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Nandina

- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)

Ophiopogon japonicus (Mondo grass)

- Sep 6, 2005. 1% glyphosate solution (4.0 lb ai/100 gallons), no significant injury. (Walsworth et al., 2006)
- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury up to 2.0 lb, 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Osmanthus heterophyllus (Hollyleaf osmanthus)

- March 15, 1977 (dormant). 1.0 to 2.0 lb ai/A, 100 GPA, 2 to 25 plants in 4 to 10-inch pots, no injury. Date(s) of observation not noted. (Self and Washington, 1977)

Oxydendron arboreum L. DC. (Sourwood)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Intermediate resistance (Crowns partially killed, second-year foliage deformed and sparse.) GPA not noted. (Wendell and Kochenderfer, 1982)

Pachysandra terminalis (Japanese spurge)

- Date unknown, tolerated 0.5 to 1.5 lb of glyphosate in 40 GPA. (Bing, 1977)

Phoenix robellini (Pygmy date palm)

- May 10, 1974. 1.2 or 2.4 lb ai/A. Evaluated 14 DAT, no injury. GPA not noted (Neel and Hull, 1974)

Photinia x fraseri (Fraser photinia)

- Jun, Aug 1980. 0.5, 1.0, or 2.0 lb ai/A directed at base of plants, some foliage contact, increasing injury with increasing rates, all plants rated “acceptable quality.” GPA not noted (Gilliam and Crockett, 1981)
- Jun 19, 1978. 0.38 or 0.75 lb in 100 or 125 GPA June 19, 1978. Evaluated five weeks later, dead shoot tips. (Cobb and Self, 1979)
- Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21. 0.5, 0.75, 1.0, or 1.5 lb ai/A. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. No injury at any rate. (Self, 1978)
- Mar 12, Apr 30, Jun 23, Aug 5, Sep 30, or Nov 11, 1982. 0.70, 1.33, or 2.67 lb ai/A, 25 GPA. Significant injury with all rates in Mar, Apr, Jun, and with 3.0 lb in Aug. (Neal and Skroch, 1985)
- July 1, 1980. 0.5 lb ai/A. Some stunting. 15 GPA (Pounders and Gilliam, 1981)

Photinia serrulata (Chinese photinia)

- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Picea abies L. Karst. (Norway spruce)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Resistant (After 2 years, foliage appeared healthy and normal.) GPA not noted. (Wendell and Kochenderfer, 1982)

Picea glauca (white spruce)

- Liners planted in soil on May 9-11, 1973, treated on July 24. 1.0, 2.0, or 3.0 lb ai/A, 50 GPA. Evaluated on Sept 13, Oct 15. Vigorous growth with 1.0 lb, fair growth with 2.0 and 3.0 lb. (Bing, 1974)

Picea mariana (Black Spruce)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Resistant (After 2 years, foliage appeared healthy and normal.) GPA not noted. (Wendell and Kochenderfer, 1982)

Picea Rubens (Red spruce)

- June 1, June 22, July 13, Aug 3, Aug 24, or Sep 21, Oct 6. 2.0 lb ai/A applied in 5 GPA. After early Aug, very slight injury. (Wagner, R.G. 1999)

Pieris floribunda (Mountain pieris)

- June 28, 1973. 0.5 lb ai/A. Evaluated on July 20 (50% injury) and Sept 12 (10% injury). Three one-gallon plants tested. GPA not noted (Ahrens, 1974)

Pieris japonica (Japanese pieris)

- June 28, 1973. 0.5 lb ai/A. Evaluated on July 20 (30% injury) and Sept 12 (10% injury). Three one-gallon plants tested. GPA not noted (Ahrens, 1974)

Pinus mugo mughus (Mugho pine)

- June 28, 1973. 0.5 lb ai/A. Evaluated on July 20 (no injury) and Sept 12 (no injury). Three one-gallon plants tested. GPA not noted (Ahrens, 1974)

Pinus palustris (Longleaf pine)

- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Pinus strobus (White pine)

- Liners planted in soil on May 9-11, 1973, treated on July 24. 1.0, 2.0, or 3.0 lb ai/A, 50 GPA. Evaluated on Sept 13, Oct 15. Fair growth with all rates. (Bing, 1974)

- Very sensitive and readily injured by drift when new spring growth is developing. (Weatherspoon, 1980)

Pinus sylvestris (Scots pine)

- Liners planted in soil on May 9-11, 1973, treated on July 24. 1.0, 2.0, or 3.0 lb ai/A, 50 GPA. Evaluated on Sept 13, Oct 15. Fair growth with all rates. (Bing, 1974)

Pittosporum tabora Var.

- Jun 19, 1978. 0.375 or 0.75 lb in 100 or 125 GPA June 19, 1978. Evaluated five weeks later, no injury. (Cobb and Self, 1979)
- Apr 7; Apr 7 and 14; or Apr 7, 14, and 21, 1978. 0.5, 0.75, 1.0, or 1.5 lb ai/A, 100 GPA. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3, 1 or 2 plants per treatment, no injury up to 4.5 lb ai/A, no DAT observed given. (Self, 1978)
- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Platanus orientalis (London planetree)

- One-year-old whips planted Apr 12, treated June 16, 1976. 3.0 or 6.0 lb ai/100 gal sprayed on lower 18 inches of bark and basal sprouts. Evaluated 1, 3, 7, and 14 weeks after treatment. 3.0 lb caused 30-50% necrosis on basal sprouts; injury to crown of one of three trees with 6.0 lb rate. Injured tree had small crown and sprouts were 40% of tree foliage. (Ahrens, 1977)

Platycladus orientalis (Arbor vitae)

- Jun 19, 1978. 0.375 or 0.75 lb in 100 or 125 GPA. Evaluated five weeks later, tip burn upper portions. (Cobb and Self, 1979)
- Apr 7; Apr 7 and 14; or Apr 7, 14, and 21, 1978. 0.5, 0.75, 1.0, or 1.5 lb ai/A, 100 GPA. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3. 1 or 2 plants per treatment, no injury up to 4.5 lb, no DAT observed given. (Self, 1978)

Podocarpus

- 0.5, 0.75, 1.0, or 1.5 lb ai/A applied on Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. No injury at any rate. (Self, 1978)
- Jul, Dec 1972. Rates of 2.0 lb ai/A or less not lethal, maximum symptoms 42 DAT, not recommended. GPA not noted (Neel and Burt, 1972)
- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)
- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Populus gradidentata Michx. (Bigtooth aspen)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Trees killed (After 2 years, no foliage or resprouting from base of dead stems.) GPA not noted. (Wendell and Kochenderfer, 1982)

Prunus pensylvanica L. f. (Pin cherry)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Trees killed (After 2 years, no foliage or resprouting from base of dead stems.) GPA not noted. (Wendell and Kochenderfer, 1982)

Prunus serotina Ehrh. (Black cherry)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Trees killed (After 2 years, no foliage or resprouting from base of dead stems.) GPA not noted. (Wendell and Kochenderfer, 1982)

Pseudotsuga taxifolia (Douglas fir)

- Liners planted in soil on May 9-11, 1973, treated on July 24. 1.0, 2.0, or 3.0 lb ai/A, 50 GPA. Evaluated on Sept 13, Oct 15. Fair growth with all rates. (Bing, 1974)

Pyracantha coccinea lalandi ROEM (Laland firethorn)

- July 6, 1979. 1.0, 2.0, 4.0, or 8.0 lb ai/A in 40 GPA. Evaluated 12 weeks later. Established liners in soil with heavy weed infestation. No injury at 1.0 lb,

moderate leaf necrosis and shoot tip dieback at 4.0 lb, and severe injury or death at 8.0 lb ai/A. (Harakami et al., 1980)

Quercus palustris (Pin oak)

- One-year-old whips planted Apr 12, treated June 16, 1976. 3.0 or 6.0 lb ai/100 gal sprayed on lower 18 inches of bark and basal sprouts. Evaluated 1, 3, 7, and 14 weeks after treatment. No bark or crown injury. (Ahrens, 1977)

Quercus prinus L. (Chestnut oak)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Trees killed (After 2 years, no foliage or resprouting from base of dead stems.) GPA not noted. (Wendell and Kochenderfer, 1982)

Quercus rubra L. (Northern red oak)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Trees killed (After 2 years, no foliage or resprouting from base of dead stems.) GPA not noted. (Wendell and Kochenderfer, 1982)

Raphiolepis (Indian hawthorn)

- Mar 15, 1977 (dormant). 0.25, 0.5 or 1.0 lb ai/A in 100 GPA, 2 plants in 3.5 to 4-inch pots. Tip dieback at 1.0 lb rate, Date(s) of observation not noted. (Self and Washington, 1977)

Rhododendron carolinianum (Carolina azalea)

- Very sensitive and readily injured by drift when new spring growth is developing. (Weatherspoon, 1980)

Rhododendron nudiflorum L. Torr. (Native deciduous azalea)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Plants killed (After 2 years, no foliage or resprouting from base of dead stems.) GPA not noted. (Wendell and Kochenderfer, 1982)

Rhododendron obtusum (Azalea)

- Liners planted in soil on May 9-11, 1973, treated on July 24. 1.0, 2.0, or 3.0 lb ai/A, 50 GPA. Evaluated on Sept 13, Oct 15. Vigorous growth with 1.0 lb, fair growth with 2.0 and 3.0 lb. (Bing, 1974)

Rhododendrum obtusum 'Coral Bells' azalea

- Mar 12, Apr 30, Jun 23, Aug 5, Sep 30, or Nov 11, 1982. 0.70, 1.33, or 2.67 lb ai/A in 25 GPA. Significant injury at all rates and dates, least in Nov. (Neal and Skroch, 1985)

Rhododendrum obtusum ‘Fashion’ azalea

- Apr 7; Apr 7 and 14; or Apr 7, 14, and 21, 1978. 0.5, 0.75, 1.0, or 1.5 lb ai/A, 100 GPA. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3). Slight injury with multiple applications of 0.5 lb ai/A, more injury with higher rates. 1 or 2 plants per treatment, very sensitive, no DAT observed given. (Self, 1978)

Rhododendrum obtusum ‘Hino’ azalea

- June 28, 1973. 0.5 lb ai/A. Evaluated on July 20 (40% injury) and Sept 12 (50% injury). Three one-gallon plants tested. GPA not noted (Ahrens, 1974)
- Jun 19, 1978. 0.375 or 0.75 lb in 100 or 125 GPA. Evaluated five weeks later, severe apical chlorosis and some necrosis. (Cobb and Self, 1979)
- 0.5, 0.75, 1.0, or 1.5 lb ai/A applied on Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. Injury at all rates from slight to severe; slight at 0.5lb x 3 and 0.75lb x 1 (Self, 1978)
- Aug 3 and 17, 1978. 0.25, 0.5, 0.75, or 1.0 lb ai/A sprayed twice. Evaluated at the end of Feb 1979. Injury at rates of 0.75 lb and above. GPA not noted; “complete coverage of weeds.” (Perry and Knowles, 1979)
- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)
- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Rated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Rhododendrum obtusum ‘Pride of Mobile’ azalea

- March 15, 1977 (dormant). 1.0 or 2.0 lb ai/A, 100 GPA, 2 to 25 plants in 4- to 10-inch pots, no injury. Date(s) of observation not noted. (Self and Washington, 1977)

Rhododendrum obtusum ‘Snow’ azalea

- 0.5, 0.75, 1.0, or 1.5 lb ai/A applied on Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. Injury at 1.5 lb x 2 and 1.5 lb x 3. (Self, 1978)

Rhododendron 'Linwood Pink Giant' azalea

- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Rhododendron 'Red Wing' azalea

- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Robinia pseudoacacia L. (Black locust)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Trees killed (After 2 years, no foliage or resprouting from base of dead stems.) GPA not noted. (Wendell and Kochenderfer, 1982)

Rosa alba (Old Garden rose variety)

- June 28, 1973. 0.5 lb ai/A. Evaluated on July 20 (40% injury) and Sept 12 (60% injury). Three one-gallon plants tested. GPA not noted (Ahrens, 1974)

Rosa 'Charlotte Armstrong' (Hybrid tea rose)

- Jun 19, 1978. 0.375 or 0.75 lb ai/A in 100 or 125 GPA. Evaluated five weeks later, most sensitive, abnormal shoot development in 12 inch subapical region. (Cobb and Self, 1979)

Rosa multiflora (Multiflora rose)

- Liners planted in soil on May 9-11, 1973, treated on July 24. 1.0, 2.0, or 3.0 lb ai/A, 50 GPA. Evaluated on Sept 13, Oct 15. Very poor growth with all rates. (Bing, 1974)

Rubus spp. (Blackberry)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Plants killed (After 2 years, no foliage or resprouting from base of dead stems.) GPA not noted. (Wendell and Kochenderfer, 1982)

Santolina chamaecyparissus (Lavender cotton)

- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Santolina virens (Green Santolina)

- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)
- June 29, 1974. 0.50, 1.0, 2.0, or 3.0 lb ai/A. Evaluated on Aug 20, 1974, no injury up to 2.0 lb. 80-90% weed control. GPA not noted (Self and Pounders, 1975)

Sassafras albidum (Nutt.) Nees (Sassafras)

- Aug 15, Sep 1, or Sep 15. 1.5 or 2.25 lb ai/A airblast-applied Roundup®. Trees killed (After 2 years, no foliage or resprouting from base of dead stems.) GPA not noted. (Wendell and Kochenderfer, 1982)

Schefflera arboricola (Hayata) Merr (Miniature schefflera)

- Greenhouse (Guam). 0.35 lb ai/A in 9 GPA resulted in 5% plant visual quality reduction. Time of application not noted. (Hock et al., 2008)

Sorbus aucuparia (European mountain ash)

- One-year-old whips planted Apr 12, treated June 16, 1976. 3.0 or 6.0 lb ai/100 gal sprayed on lower 18 inches of bark and basal sprouts. Evaluated 1, 3, 7, and 14 weeks after treatment. No bark or crown injury. (Ahrens, 1977)

Spirea nipponica (Snowmound spirea)

- June 28, 1973. 0.5 lb ai/A. Evaluated on July 20 (80% injury) and Sept 12 (80% injury). Three one-gallon plants tested. GPA not noted (Ahrens, 1974)

Taberaemontana divaricata (L.) R. Br. Ex Roemer & J.A. Schultes (Paper gardenia)

- Greenhouse (Guam). 0.23 lb ai/A in 9 GPA resulted in 5% plant visual quality reduction. Time of application not noted. (Hock et al., 2008)

Taxus spp. (Yew)

- Date unknown, rate of 2.0 to 3.0 lb of glyphosate in 40 GPA will kill tips of branches, but plants soon put on new growth that covers the damage. (Bing, 1977)

Taxus cuspidata hicksii (Hicks yew)

- Liners planted in soil on May 9-11, 1973, treated on July 24. 1.0, 2.0, or 3.0 lb ai/A, 50 GPA. Evaluated on Sept 13, Oct 15. Vigorous growth with all rates. (Bing, 1974)

Thunbergia erecta Benth. T. Anders (King's mantle)

- Greenhouse (Guam). 0.12 lb ai/A in 9 GPA resulted in 5% plant visual quality reduction. Time of application not noted. (Hock et al., 2008)

Tilia cordata 'Greenspire' (Greenspire littleleaf linden)

- One-year-old whips planted Apr 12, treated June 16, 1976. 3.0 or 6.0 lb ai/100 gal sprayed on lower 18 inches of bark and basal sprouts. Evaluated 1, 3, 7, and 14 weeks after treatment. No bark or crown injury (Ahrens, 1977)

Trachelospermum asiaticum (Asiatic jasmine)

- Sep 6, 2005. 1% solution (4.0 lb ai in 100 GPA). No injury.

Trachycarpus fortunei (Windmill palm)

- 0.5, 0.75, 1.0, or 1.5 lb ai/A applied on Apr 7 only, Apr 7 and 14, or Apr 7, 14, and 21. Totals applied ranged from 0.5 lb ai/A (single application) to 4.5 lb ai/A (1.5 x 3); 100 GPA. 1 or 2 plants per treatment in 6, 8, or 10-inch containers. No injury at any rate. (Self, 1978)
- March 15, 1977 (dormant). 1.0 or 2.0 lb ai/A, 100 GPA, 2 to 25 plants in 4- to 10-inch pots, no injury. Date(s) of observation not noted. (Self and Washington, 1977)

Tsuga canadensis (Canadian hemlock)

- Sep, 1976. 4.0 lb ai/A, evaluated summer 1977, no injury. Field grown, heavy grass cover at time of treatment. GPA not noted (Woodiel, 1977)
- Date unknown, rate of 2.0 to 3.0 lb of glyphosate in 40 GPA will kill tips of branches (burns easily), but plants soon put on new growth that covers the damage. (Bing, 1977)

Viburnum

- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)

Viburnum trilobum (Cranberry bush)

- Liners planted in soil on May 9-11, 1973, treated on July 24. 1.0, 2.0, or 3.0 lb ai/A, 50 GPA. Evaluated on Sept 13, Oct 15. Very poor growth with all rates. (Bing, 1974)

Wisteria

- Can be controlled with 1.5 to 2.0% solution of Roundup Pro[®] six to eight weeks after bloom (mid- to late summer (Neal, 1998)

Yucca filamentosa (Yucca)

- Aug 22, 1973, 0, 1.0, 2.0, or 3.0 lb ai/A, evaluated on Oct 15, 1973. 4 or 6-inch containers. No injury at 1.0 lb ai/A. GPA not noted. (Self, 1974)

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Chapter 2

Roundup Pro[®] Over the Top of Nursery Crops: Rates and Timing

Abstract. Nine species of container-grown plants were treated over-the-top with Roundup Pro[®] at four rates: 0.28, 0.56, 1.12, and 2.24 kg ai/ha (0.25, 0.5, 1.0 and 2.0 lb ai/A) once in June 2007, September 2007, or February 2008. A fourth group was treated on all three dates (JSF). The experiment was repeated on eight species in 2008-2009. Growth indices (GI) were taken before the spring growth flush in March 2008 and after the first growth flush in June. In experiment one, dwarf mondo grass (*Ophiopogon japonicus* 'Nana'), mondo grass (*O. japonicus*), lirioppe (*Liriope muscari* 'Cleopatra') variegated lirioppe (*L. muscari* 'Variegata'), and 'Blue Pacific' juniper (*Juniperus rigida* subsp. *conferta* 'Blue Pacific') were not affected by rates up to 1.12 kg ai/ha (1.0 lb ai/A) applied singly or JSF, except for temporary injury on 'Blue Pacific' from Feb applications. The remainder of the species had reduced growth as Roundup Pro[®] rates increased. 'Blue Rug' juniper (*J. horizontalis* 'Wiltonii') was tolerant in Feb but injured at ≥ 1.12 kg ai/ha (1.0 lb ai/A) in June and Sept (JS). Asiatic jasmine (*Trachelospermum asiaticum*) was tolerant of single applications at rates ≤ 1.12 kg ai/ha (1.0 lb ai/A) in JS, but showed stunting of new foliage from all Feb applications. Dwarf yaupon (*Ilex vomitoria* 'Stoke's Dwarf') showed injury at 74 DAT after June applications, no injury at rates ≤ 1.12 kg ai/ha (1.0 lb ai/A) in Sept, and stunting and delay of new foliage from all

Feb applications and rates ≥ 0.56 kg ai/ha (0.5 lb ai/A) in June. ‘Pink Gumpo’ azalea (*Rhododendron eriocarpum* ‘Gumpo Pink’) was injured by rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) applied in June, Feb, and JSF. In experiment two, dwarf mondo and mondo tolerated all single application rates up to 1.12 kg ai/ha (1.0 lb ai/A). Asiatic jasmine was injured by all Feb treatments and growth was reduced and stunted by ≥ 1.12 kg ai/ha (1.0 lb ai/A) in Feb and JSF. Dwarf yaupon GI were reduced by rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) in Feb, 2.24 kg ai/ha (2.0 lb ai/A) in June, and by all treatments in JSF. Feb treatments ≥ 0.28 kg ai/ha (0.25 lb ai/A) delayed shoot growth of dwarf yaupon for at least 6 weeks. ‘Hardy Daisy’ gardenia (*Gardenia jasminoides* ‘Hardy Daisy’) showed slight injury from Feb rates ≥ 1.12 kg ai/ha (1.0 lb ai/A), but growth was reduced at 2.24 kg ai/ha (2.0 lb ai/A) for June and JSF. Sky pencil holly (*Ilex crenata* ‘Sky Pencil’) showed stunting from all Feb applications, but was tolerant up to 2.24 kg ai/ha (2.0 lb ai/A) in June and Sept; GI were similar for all treatments. Purpleleaf wintercreeper euonymus (*Euonymus fortunei* ‘Coloratus’) was injured by rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) in June and JS, all Feb treatments, and stunted by two or three applications of 2.24 kg ai/ha (2.0 lb ai/A), but all other treatments had similar GI. Wintergreen boxwood (*Buxus sempervirens* ‘Wintergreen’) was injured at 2.24 kg ai/ha (2.0 lb ai/A) in June, ≥ 1.12 kg ai/ha (1.0 lb ai/A) in JS, and all Feb applications. Growth was reduced by rates of 2.24 kg ai/ha (2.0 lb ai/A) in Feb and ≥ 1.12 kg ai/ha (1.0 lb ai/A) in JSF.

Index words: Glyphosate, over the top, woody ornamentals, container production

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

Species used in this study: Experiment one: Dwarf mondo grass (*Ophiopogon japonicus* ‘Nana’), mondo grass (*O. japonicus*), lirioppe (*Liriope muscari* ‘Cleopatra’), variegated lirioppe (*L. muscari* ‘Variegata’), ‘Blue Pacific’ Juniper (*Juniperus rigida* subsp. *conferta* ‘Blue Pacific’), ‘Blue Rug’ Juniper (*J. horizontalis* ‘Blue Rug’), Asiatic jasmine (*Trachelospermum asiaticum*) and dwarf yaupon (*Ilex vomitoria* ‘Stoke’s Dwarf’), ‘Pink Gumpo’ azalea (*Rhododendron eriocarpum* ‘Gumpo Pink’). Experiment two: Dwarf mondo grass, mondo grass, Asiatic jasmine, dwarf yaupon. ‘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’).

Significance to the Industry

Current economic conditions have caused a significant slump in new home construction and sale of landscape plants. Many growers have lowered their prices to remain competitive. If weed populations exceed growers’ ability to control them, they may face the prospect of spending more on hand weeding than what the plant is worth.

Roundup Pro[®] over the top of woody ornamental nursery crops is showing promise as a postemergence weed control option. Our work indicates that some woody ornamentals are tolerant to Roundup Pro[®] applications. Several plants tested in this study were tolerant to glyphosate up to 2.24 kg ai/ha (2.0 lb ai/A) in June or September,

while most problem weeds are controlled at 1.12 kg ai/ha (1.0 lb ai/A). The hand-weeding cost for 3-gallon pots in early 2005 was 5.63 cents per pot, assuming labor costs of \$9.52 per hour (Florida Agricultural Statistics Service, 2005). If 3-gallon pots were jammed in 6-foot beds with 2-foot aisles, it would cost \$9225.70/ha (\$3733.59/A) to weed them. With a glyphosate rescue plan, growers can apply 1.12 kg ai/ha (1.0 lb ai/A) of Roundup Pro[®] for about \$31.50/ha (\$12.50/A). Barolli (2005) estimated that a backpack application requires 3.46 man hours and a high-clearance boom operated by 2 men requires 1.35 man hours/A. This would cost \$32.94 and \$12.85/A, respectively, at \$9.72 per hour.

Introduction

Postemergence weed control in container-grown nursery crops is becoming more critical for economic profitability in the nursery industry. Between 1975 and 1980, Roundup[®] was evaluated over the top of numerous container-grown crops. Self (1978) applied single, double, and triple treatments of Roundup[®] at 0.56, 0.84, 1.12, and 1.68 kg ai/ha (0.5, 0.75, 1.0, and 1.5 lb ai/A) on 7, 14, and 21 April 1978 over 18 ornamentals. Total amounts of glyphosate applied ranged from 0.56 – 5.04 kg ai/ha (0.5 to 4.5 lb ai/A). Of the 18 species tested, ‘Blue Pacific’ Juniper (*Juniperus rigida* subsp. *conferta* ‘Blue Pacific’), *Magnolia soulangeana*, *Cupressus* sp., *Photinia fraseri*, *Pittosporum tobira*, *Podocarpus* sp., *Ilex cornuta* ‘Burfordii Yellow Top’, and *Trachycarpus fortunei* were not injured.

Perry and Knowles (1979) applied Roundup[®] at 0.28, 0.84, and 1.12 kg ai/ha (0.25, 0.75, and 1.0 lb ai/A) over the top of 10 species, once on August 3 and again on

August 17, 1978. Following two applications, no phytotoxicity was observed on *Berberis x mentorensis*, *Camellia japonica*, *Forsythia x intermedia* and *Ligustrum* ‘vicaryi’ at all rates. Temporary slight yellowing was observed on *B. julianae*, *Euonymus japonicus* and *Ilex cornuta* ‘Dwarf Burford’ (syn ‘Burfordi Nana’) regardless of rate.

Neal and Skroch (1985) studied rates and timing of Roundup[®] applications on 13 species of ornamentals from March 12 to November 11, 1982. They applied Roundup[®] at 0.65, 1.3, and 2.6 kg ai/ha (0.73, 1.33, and 2.67 lb ai/A) at six different times throughout the season. They divided plants and their responses to Roundup[®] into 4 groups. Group 1 species: ajuga (*Ajuga reptans*), azalea [*Rhododendron* x ‘Kirin’ (syn. ‘Coral Bells’)], and variegated liriopse (*Liriope muscari* ‘Variegata’) were injured by all application times and rates. Group 2, 3, and 4 species showed tolerance to fall applications. Group 2; dwarf yaupon, English ivy (*Hedera helix*), ‘Helleri’ holly (*I. crenata* ‘Helleri’) and ligustrum (*L. japonicum*) sustained the most injury from spring applications. Group 3; Andorra Juniper (*Juniperus horizontalis* ‘Plumosa’), compacta holly (*I. crenata* ‘Compacta’), Fraser’s photinia (*Photinia x fraseri*), and green liriopse (*Liriope spicata*) were most injured by summer applications. Group 4; ‘Blue Pacific’ juniper and ‘Blue Rug’ juniper (*Juniperus horizontalis* ‘Wiltonii’) tolerated all but the highest rates with acceptable damage, which was considered to be $\leq 15\%$.

Neal et al. (1985) reported that ligustrum showed a linear decrease in susceptibility from March to November, while ‘Blue Pacific’ juniper sustained only temporary tip chlorosis from summer applications at high rates. Both species recovered by the end of the growing season. In a study with foliar droplet applications, it was

reported that except for ligustrum treated on young expanding leaves, the time required for absorption of detectable levels of ^{14}C - glyphosate into ligustrum and juniper was slow when compared to absorption rates for herbaceous weeds, but the time was similar for absorption rates for other woody species such as Norway spruce (*Picea abies*), white birch (*Betula verrucosa*), and European ash (*Fraxinus excelsior*). Research by Ferreira and Reddy (2000) on *Erythroxylum coca* and *E. novogranatense* demonstrated the role of the leaf cuticle in the slow uptake of glyphosate by woody plants. This indicates a degree of selectivity with glyphosate applied over woody ornamentals and weeds growing in beds or pots.

Altland et al. (2002) showed that Roundup Pro[®] at 1.8 kg ai/ha (1.6 lb ai/A) could be safely used as a cleanup treatment for control of spurge in *L. muscari* ‘Big Blue’ and ‘Variegata.’ Walsworth et al. (2006) reported that Roundup applied on September 6, 2005 in a 1% solution (8.8 kg ai / 378.5 liter, 4 lb ai / 100 gallons) caused no injury to lirioppe and Asiatic jasmine.

Recent work by Czarnota (2008) showed that ‘Blue Pacific’ juniper, ‘Blue Star’ juniper (*J. squamata* ‘Blue Star’), and ‘Parsoni’ juniper (*J. davurica* ‘Parsoni’) were tolerant of Roundup Pro[®] applications at rates up to 2.8 kg ai/ha (2.5 lb ai/A) on May 29, 2004 and May 13, 2005. Final dry weights for ‘Blue Pacific’ and ‘Blue Star’ juniper at 12 weeks after treatment were similar to controls with rates up to 11.2 kg ai/ha (10.0 lb ai/A). Injury did not exceed 27% for rates up to 5.6 kg ai/ha (5.0 lb ai/A) on ‘Blue Pacific.’

Monsanto (2007) recommends the use of 1.12 kg ai/ha (1.0 lb ai/A) of Roundup Pro[®] if weeds are less than 6 inches in height or runner length.

Recent declines in the economy have had severe effects on nursery crop production. Cost cutting by growers has resulted in less available labor. Reduced sales have caused carry-over of plants ready for market into another growing season. As a result, growers are increasingly interested in potential use of glyphosate over the top of nursery crops to stay economically viable. The objective of this research was to further evaluate the tolerances of individual container-grown species to various rates and application times of Roundup Pro[®] applied over the top.

Materials and Methods

In experiment 1, 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'), and 'Pink Gumpo' azalea (*Rhododendron eriocarpum* 'Gumpo Pink') were potted in 3:1 pinebark : peat moss (v:v) amended with 8.5 kg/m³ (14.0 lb/yd³) Osmocote 19-6-12 (N-P-K), 3.6 kg/m³ (6 lb/yd³) dolomitic limestone, 1.2 kg/m³ (2.0 lb/yd³) gypsum, and 0.9 kg/m³ (1.5 lb/yd³) Micromax/yd³ in 1-gallon containers on April 30, 2007. Roundup Pro[®] was applied at four rates: 0.28, 0.56, 1.12, and 2.24 kg ai/ha (0.25, 0.50, 1.0, and 2.0 lb ai/A) in 30 GPA with a CO₂ backpack sprayer at 25 psi with an 8004 flat fan nozzle and allowed to dry at least 4 hours before irrigation. Single treatments were applied on June 10, 2007,

September 1, 2007, and February 20, 2008 to separate groups of plants not previously treated. One group of plants was treated in June + September + February (JSF). There was one control group; 17 treatments in all. Plants were grouped by species in a completely randomized block design with eight single-pot replications. Snapshot was applied at 168.41 kg ai/ha (150 lb/A) to all species except mondo and dwarf mondo on May 8, 2007. Plants were observed at 15, 30, 60, and 90 DAT; injury and new growth were rated and recorded when differences from controls were noted. Growth indices were taken on March 3, before the start of spring growth, and June 13, 2008, after the first growth flush. Dwarf mondo, mondo, lirioppe 'Cleopatra' and lirioppe 'Variegata' were trimmed to one inch tall in May to simulate nursery production practices. Marketability was rated on October 11, 2008.

In experiment 2, dwarf mondo grass, mondo grass, Asiatic jasmine, dwarf yaupon, *Gardenia jasminoides* 'Hardy Daisy,' *Ilex crenata* 'Sky Pencil,' *Euonymus fortunei* 'Coloratus,' and *Buxus sempervirens* 'Wintergreen' were potted as in experiment 1 on May 12, 2008. Roundup Pro[®] was applied at four rates: 0.28, 0.56, 1.12, and 2.24 kg ai/ha (0.25, 0.50, 1.0, and 2.0 lb ai/A) in 30 GPA with a CO₂ backpack sprayer at 25 psi with an 8004 flat fan nozzle and allowed to dry at least 4 hours before irrigation. Single treatments were applied on June 24 and September 16, 2008, and February 20, 2009. One group of plants was treated on JSF. There was one control group; 17 treatments in all. Plants were grouped by species in a completely randomized block design with seven single-pot replications. Snapshot was applied to *Buxus* at 150 lb/A due to significant weed pressure in the pots. Plants were observed at 15, 30, 60, and 90 DAT; injury, bud break, and new growth were rated and recorded when differences from

controls were noted. Growth indices were taken on February 23, 2009, before the start of spring growth, and July 6, 2009, after the first growth flush. Marketability was rated on October 23, 2009. Dwarf mondo, mondo, Asiatic jasmine, and euonymus were trimmed on May 11, 2009 to simulate nursery practices.

Both experiments were conducted at the Ornamental Horticultural Research Center in Mobile, Alabama. Data collected was analyzed in a statistical software package (SAS Institute, Cary, North Carolina) using Least Significant Difference tests ($P \leq 0.05$). Data was analyzed separately for each sampling date.

Results and Discussion:

Dwarf mondo grass: In experiment 1, March injury ratings showed that slight injury (8%) occurred with 2.24 kg ai/ha (2.0 lb ai/A) applied in JSF (Table 2.1). All growth indices taken in March (Table 2.2), prior to the start of the spring growth flush, and June 2008 (Table 2.3), at the end of the first flush, and marketability ratings in October 2008 (Table 2.4) were similar to control plants. In experiment 2, injury ratings taken in April 2009 showed no injury from rates ≤ 1.12 kg ai/ha (1.0 lb ai/A) applied in February and JSF (Table 2.5). February growth indices were similar for all plants treated in June, September, and JS (Table 2.6), while JSF treatments at 2.24 kg ai/ha (2.0 lb ai/A) caused growth suppression (Table 2.7). All plants were rated marketable in October 2009 (Table 2.8).

Mondo grass: In experiment 1, injury ratings taken in March were similar to controls (Table 2.1). Growth indices taken in March (Table 2.2) and June 2008 (Table 2.3) were

similar to controls, except for plants treated with 2.24 kg ai/ha (2.0 lb ai/A) in February, JS, and in JSF. All treatments <1.12 kg ai/ha (1.0 lb ai/A) were marketable except JSF at 2.24 kg ai/ha (2.0 lb ai/A) rates, with February and June treatments smaller but marketable (Table 2.4). In experiment 2, injury ratings in April 2009 showed all treatments similar to controls except at rates \geq 1.12 kg ai/ha (1.0 lb ai/A) applied in February or JSF (Table 2.5). Growth indices taken in February for all June, September, and JS treatments were similar to controls (Table 2.6). Growth indices in July for all single treatments up to 2.24 kg ai/ha (2.0 lb ai/A) were similar to controls, while JSF treatments \geq 1.12 kg ai/ha (1.0 lb ai/A) showed growth reductions (Table 2.7). All plants were marketable in October, with February treatments of 2.24 kg ai/ha (2.0 lb ai/A) yielding significantly smaller but marketable plants (Table 2.8). Our data concurs with Self and Pounders (1975) who found *O. japonicus* tolerant of rates up to 2.24 kg ai/ha (2.0 lb ai/A) in June, and Walsworth et al (2006), who reported no injury with a 1% solution (8.8 kg ai / 378.5 liters, 4.0 lb ai in 100 gallons) applied in September.

Liriope ‘Cleopatra’: No injury was noted throughout the study (Table 2.1). Growth indices in March (Table 2.2) and June 2008 (Table 2.3) and marketability ratings in October 2008 (Table 2.4) were similar to controls. Injury has been reported by other researchers. Altland et al. (2002) observed slight injury to ‘Big Blue’ liriope on June 1, June 28, or August 24 at 1.8 kg ai/ha (1.6 lb ai/A) that was outgrown at 60 DAT. Walsworth et al (2006) reported no injury to liriope with a 1% solution (8.8 kg ai / 378.5 liters, 4.0 lb ai in 100 gallons) applied in September.

Liriope ‘Variegated’: No injury was noted throughout the study, and growth indices in March 2008 were similar to controls (Table 2.2). Growth indices in June 2008 showed that 2.24 kg ai/ha (2.0 lb ai/A) treatments applied in February and in JSF were smaller than the rest of the treatments and the controls (Table 2.3); however, all plants were similar to controls in marketability in October 2008 (Table 2.4). Altland et al. (2002) reported tolerance at 1.8 kg ai/ha (1.6 lb ai/A) applied June 1, June 28, or August 24 similar to our June and September treatments at 2.24 kg ai/ha (2.0 lb ai/A). Self (1978) reported no injury at 1.0 lb ai/A in August.

‘Blue Pacific’ juniper: Injury ratings in March 2008 indicated that rates ≥ 0.56 kg ai/ha (0.5 lb ai/A) applied in February had higher injury than all other treatments, including JSF treatments (Table 2.1). By 31 DAT, affected needles had recovered and all plants were similar to controls. Growth indices in March 2008 (Table 2.2) and June (Table 2.3) were similar to controls. All plants were similar and marketable in October 2008 (Table 2.4). Our data concurs with Neal and Skroch (1985), who reported the highest injury at 25 DAT from applications in mid-March, with tolerance increasing through the rest of the season after April 30 with injury not greater than 17% at 1.5 kg ai/ha (1.33 lb ai/A). Final injury ratings one year later reported injury $\leq 21\%$ with this rate for all treatment dates. Similarly, Czarnota (2008) reported tolerance up to 2.8 kg ai/ha (2.5 lb ai/A) with mid- to late-May applications with injury not exceeding 23%. Our results showed no long-term injury in February, June, or September or JSF for rates up to 2.24 kg ai/A (2.0 lb ai/A).

‘Blue Rug’ juniper: Injury from June applications was not seen in November, but plants treated in September were injured by rates ≥ 1.12 kg ai/ha (1.0 lb ai/A). JS applications

were not injured by rates ≤ 1.12 kg ai/ha (1.0 lb ai/A) (Table 2.1). Injury ratings in June 2008 showed no injury from September and JSF applications ≤ 1.12 kg ai/ha (1.0 lb ai/A) (Table 2.1). Growth indices recorded in March were reduced at rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) applied in September and JS, and at 2.24 kg ai/ha (2.0 lb ai/A) in June (Table 2.2). June growth indices were reduced at rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) when applied in June, September, or JSF (Table 2.3). There were no growth reductions from any February treatments. All plants were marketable in October 2008 except for 2.24 kg ai/ha (2.0 lb ai/A) treatments applied in September and JSF, with 2.24 kg ai/ha (2.0 lb ai/A) applied in June yielding smaller but marketable plants (Table 2.4). Neal and Skroch (1985) reported injury levels at 25 DAT of 11% or less when applied up to 3.0 kg ai/ha (2.67 lb ai/A) during the growing season, except for an increase in injury noted in late June and early August treatments. Final data taken one year later reported injury $\leq 15\%$ for rates up to 3.0 kg ai/ha (2.67 lb ai/A). Our data showed a similar trend in initial injury, but our final injury ratings indicated long-term effects from 2.24 kg ai/ha (2.0 lb ai/A) applied in early September and mid-June.

Asiatic jasmine: Experiment 1: Injury ratings in June 2008 indicated that all plants treated in June or September 2007 were similar to controls (Table 2.1). Slight to severe leaf stunting was observed on plants treated with ≥ 0.28 kg ai/ha (0.25 lb ai/A) February and JSF. Growth indices in March 2008 (Table 2.2) were similar to controls for all June treatments and up to 1.12 kg ai/ha (1.0 lb ai/A) in September. The 2.24 kg ai/ha (2.0 lb ai/A) rate applied in September and rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) applied in JSF resulted in growth reductions. Plants were trimmed in May to simulate common nursery practices. Growth indices in June 2008 were similar to controls for all June and

September treatments, while plants treated in February and JSF at rates ≥ 0.56 kg ai/ha (0.5 lb ai/A) showed 22-46 % reductions in growth (Table 2.3). Marketability ratings in October were lower for plants treated with rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) applied in February and JSF, while 2.24 kg ai/ha (2.0 lb ai/A) in June or September caused reductions in marketability (Table 2.4).

In experiment 2, April injury ratings from February and JSF applications indicated delayed flush from all rates, with suppression increasing with increased rates (Table 2.5). February growth indices were similar to controls for all rates except JS rates of 2.24 kg ai/ha (2.0 lb ai/A) (Table 2.6). July growth indices showed all treatments similar to controls except for JSF applications ≥ 1.12 kg ai/ha (1.0 lb ai/A) (Table 2.7). Plant marketability was similar to controls for all treatments except rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) in February and 2.24 kg ai/ha (2.0 lb ai/A) applied JSF (Table 2.8). Walsworth et al (2006) reported similar tolerance to September treatments with a 1% solution (8.8 kg ai / 378.5 liters, 4.0 lb ai in 100 gallons).

Dwarf yaupon: In experiment 1, significant injury was recorded at 71 DAT from single June 2007 applications ≥ 0.56 kg ai/ha (0.5 lb ai/A) (Table 2.1). Injury ratings in June 2008 showed that all June or September applications were similar to controls, while February applications caused slight to severe leaf distortion with increasing rates, with slight necrosis at the 2.24 kg ai/ha (2.0 lb ai/A) rates. Growth indices in early March before the spring flush showed growth reductions for rates ≥ 0.56 kg ai/ha (0.5 lb ai/A) in June and JS, and 2.24 kg ai/ha (2.0 lb ai/A) in September (Table 2.2). Growth indices taken in June 2008 showed growth reductions at rates ≥ 0.56 kg ai/ha (0.5 lb ai/A) from

June, February, and JSF treatments, and from 2.24 kg ai/ha (2.0 lb ai/A) rates in September (Table 2.3). Plants were marketable at treatment rates up to 0.56 kg ai/ha (0.5 lb ai/A) with February applications, 1.12 kg ai/ha (1.0 lb ai/A) with June and JSF applications and all September applications (Table 2.4).

In experiment 2, injury ratings in September 2008 (15 DAT from September applications) showed injury on plants treated in June from 2.24 kg ai/ha (2.0 lb ai/A) applications, while all other rates were similar to controls (Table 2.5). Injury ratings in April 2009 were similar to controls for June or September treatments, while rates ≥ 0.28 kg ai/ha (0.25 lb ai/A) applied in February showed increasing spring growth suppression with increasing rates from February and JSF treatments. Bud break was similar to controls for June and September treatments, but all February and JSF treatments saw virtually no bud break, with February treatments resulting in 26, 10, 3 and 0% new growth for 0.28, 0.56, 1.12, and 2.24 kg ai/ha (0.25, 0.5, 1.0 and 2.0 lb ai/A) respectively. JSF applications had 33, 19, 0, and 0% new growth respectively with increasing rates of Roundup Pro[®]. Growth indices in February 2009 showed that June, September, and JS treatments were all similar to controls except for 2.24 kg ai/ha (2.0 lb ai/A) in JS (Table 2.6). Growth indices in July 2009 were smaller than controls when treated in February at rates ≥ 1.12 kg ai/ha (1.0 lb ai/A), 2.24 kg ai/ha (2.0 lb ai/A) in June, and ≥ 0.28 kg ai/ha (0.25 lb ai/A) for JSF applications (Table 2.7). All September treatments were similar to controls. Plants treated with ≥ 1.12 kg ai/ha (1.0 lb ai/A) in February and 1.12 kg ai/ha (1.0 lb ai/A) in JSF were rated small but marketable, while JSF applications at 2.24 kg ai/ha (2.0 lb ai/A) were unmarketable due to stunting (Table 2.8). All other treatments were similar to controls. Neal and Skroch (1985) reported that 25-DAT evaluations

indicated great sensitivity to all mid-March treatments, and significant injury from April, June, and August treatments. However, applications at the end of September and the middle of November did not show injury above 16% for treatments up to 3.0 kg ai/ha (2.67 lb ai/A). Final evaluations one year later reported injury $\leq 18\%$ for treatments on or after April 30 at 1.5 kg ai/ha (1.33 lb ai/A). Our data likewise indicated significant effects early in the growing season on injury, growth indices and marketability with June and February treatments ≥ 0.56 kg ai/ha (0.5 lb ai/A) and tolerance to all treatments in September. Similarly, Whitcomb et al (1976) reported no injury from glyphosate up to 3 lb ai/A in August.

Azalea ‘Pink Gumpo’: Injury ratings at 74 DAT from June 2007 treatments showed significant injury at rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) (Table 2.1). June 2008 injury ratings showed all treatments similar to controls except for rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) applied in February and JSF. Growth indices in March 2008 showed growth reductions with June and JS treatments at rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) and with 2.24 kg ai/ha (2.0 lb ai/A) applied in September (Table 2.2). Growth indices in June 2008 showed growth reductions for rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) from February, June, and JSF applications, and growth reductions when 2.24 kg ai/ha (2.0 lb ai/A) was applied in September (Table 2.3). All azaleas were marketable and similar to controls in October 2008 except for 2.24 kg ai/ha (2.0 lb ai/A) in February and rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) for JSF applications (Table 2.4). Similarly, Cobb and Self (1979) reported severe apical chlorosis and some necrosis on ‘Hinodegiri’ from applications of 0.375 and 0.75 lb ai in mid-June, while Perry and Knowles (1979) reported August injury at rates above 0.75 lb ai on ‘Hino’ as well.

Gardenia ‘Hardy Daisy’: Injury ratings 14 DAT after June 2008 treatments showed injury at rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) (Table 2.5). No injury was noted later from these or any plants receiving September treatments. Injury ratings 18 DAT after the February 2009 treatments showed plant injury for rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) with February and JSF treatments. However, injury was slight (10%) and temporary. Growth indices in February 2009 indicated all treatments were similar to controls except plants treated with 2.24 kg ai/ha (2.0 lb ai/A) in June (Table 2.6). Growth indices in July 2009 showed all plants similar to controls except 2.24 kg ai/ha (2.0 lb ai/A) applied in June and JSF applications (Table 2.7). All plants were rated marketable and similar to controls in October 2009 (Table 2.8).

Ilex ‘Sky Pencil’: Bud break was rated in May 2009, with all treatments similar to controls with June and September treatments (Table 2.5). However, all rates applied in February and JSF caused delayed bud break and stunting increased with increasing rates of Roundup. Due to the growth habit of Sky Pencil holly, this injury was not particularly noticeable. All growth indices in February (Table 2.6) and July 2009 (Table 2.7) were similar to controls. All plants were similar and marketable in October 2009 (Table 2.8).

Euonymus ‘Coloratus’: September injury ratings 24 DAT after the September 2008 treatments indicated no injury from September treatments. Injury occurred at rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) with June and JS applications (Table 2.5). Spring growth ratings in April 2009 showed no growth suppression at rates up to 1.12 kg ai/ha (1.0 lb ai/A) from single applications in June or September, while all 2.24 kg ai/ha (2.0 lb ai/A) rates and all February and JSF treatments were significantly delayed compared to controls (Table 2.5). All growth indices in February 2009 were similar to controls except for JS treatments at

2.24 kg ai/ha (2.0 lb ai/A) (Table 2.6). Growth indices in July were all similar to controls except for JSF applications of 2.24 kg ai/ha (2.0 lb ai/A) (Table 2.7). Marketability ratings in October showed all plants marketable and similar to controls except for smaller but marketable ratings on plants treated with 0.56 and 1.12 kg ai/ha (0.5 and 1.0 lb ai/A) in February and 1.12 kg ai/ha (1.0 lb ai/A) in JSF. Plants were unmarketable at 2.24 kg ai/ha (2.0 lb ai/A) in February and with JSF applications (Table 2.8). Bing (1974) reported even greater tolerance over liners potted on May 9-11, 1973 and treated with 1.12, 2.24, and 3.36 kg ai/ha (1.0, 2.0, and 3.0 lb ai/A) on July 24, 1973. Vigorous growth at all rates was observed in September and October.

Wintergreen boxwood: No injury was observed until October 2008, when all treatments were similar to controls except for 2.24 kg ai/ha (2.0 lb ai/A) in June and JS treatments \geq 1.12 kg ai/ha (1.0 lb ai/A) (Table 2.5). Injury ratings in April 2009 showed all June and September treatments similar to controls, while all February and JSF applications caused injury (Table 2.5). All growth indices from June, September, and JS applications were similar to controls in February 2009 (Table 2.6). All growth indices were similar to controls in July except for rates \geq 1.12 kg ai/ha (1.0 lb ai/A) with JSF treatments and the 2.24 kg ai/ha (2.0 lb ai/A) in February (Table 2.7). All plants treated in June and September were marketable and similar to controls in October, while February and JSF treatments were unmarketable at all rates due to leaf distortion (Table 2.8). Cobb and Self (1979a) reported similar summer tolerance with no injury and normal rooting of cuttings treated with 0.75 lb ai/A three times applied one week apart in June, 1978.

Research indicates that windows of opportunity exist for the use of Roundup over the top of selected container-grown nursery crops with no injury or loss of growth, with

some species showing tolerance for accumulations of 6.72 kg ai/ha (6.0 lb ai/A) over the course a growing season. Most were tolerant to single applications beginning near the middle of June after the spring growth flush through September. Three applications generally caused stunting and/or leaf deformities on the majority of the species evaluated. However, 7 species exhibited no detrimental effects from 3 applications of Roundup provided the rate did not exceed 1.12 kg ai/ha (1.0 lb ai/A) per application. These species were dwarf mondo grass, mondo grass, liriopse ‘Cleopatra,’ variegated liriopse, ‘Blue Pacific’ juniper, gardenia ‘Hardy Daisy,’ and Sky Pencil holly, which experienced acceptable levels of stunting from February applications. Therefore, these species offer the greatest potential for Roundup-based weed control.

Our research indicates varied responses of individual species to applications of Roundup Pro[®]. Therefore, individual species should be tested for tolerance before large groups of plants are treated. Over time, tolerant plants outgrow symptoms of Roundup Pro[®] applications. Spring is the most susceptible time for plant injury; most species tested were very tolerant from the middle of June through the rest of the year. Symptoms seen in May were mostly gone by mid to late June. ‘Blue Rug’ juniper was the exception, with no injury in February but significant injury and growth reductions from June or September applications. Our research is intended to provide data for emergency measures for weed control when labor is unavailable or when it would cost more to weed the crop than it is worth. It should not replace a solid program of weed management consisting of monitoring, some hand weeding, and preemergence herbicides.

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Table 2.1. Injury ratings following applications of Roundup Pro® over the top of nine species, experiment 1.

Treatment		Ornamental species									
Roundup rate lb ai/A	Application timing	Dw. Mondo	Mondo grass	Blue Pacific	Blue Rug Juniper		Asiatic jasmine	Dwarf yaupon		Pink Gumpo azalea	
		Date recorded									
		3/7/08	3/7/08	3/7/08	11/15/07	6/23/08	6/23/08	8/20/07	6/23/08	8/23/07	6/23/08
Non-treated control		0.1 ^Z	1.6 ^Z	0.5	0	0	0	0	0	0	0
0.25	Once 6/10/07	0	1.1	0.7	0.1	0	0	0.7	0	0	1.1
0.5		0	2.1	1.4	0.3	0	0	5.5*	0	0	1.1
1.0		0	0.5	1.1	0	0	0	6.0*	0	4.1*	0
2.0		0.1	0	0	0	0	0	6.0*	0	5.2*	0
0.25	Once 9/1/07	0	1.5	0.5	0	0	0	-	0	-	0
0.5		0	1.5	1.9	0.1	0	0	-	0	-	0
1.0		0	3.1	1.6	1.1*	0	0	-	0	-	0
2.0		0	2.0	1.9	7.3*	9.5*	0.5	-	0	-	0.5
0.25	Once 2/20/08	0	0.5	1.4	-	0	1.0*	-	4.0*	-	0
0.5		0.5	0.5	3.2*	-	0	3.7*	-	4.0*	-	0
1.0		0.5	0.5	3.0*	-	0	5.8*	-	5.5*	-	2.3*
2.0		0.5	1.0	0.5	-	0	5.9*	-	7.0*	-	6.6*
0.25	Three times (repeated on all three dates)	0.3	0	0	0 ^Y	0	3.0*	0 ^X	4.0*	0 ^X	0
0.5		0.1	1.4	2.0	0	0	4.7*	3.6*	4.4*	0	1.0
1.0		0.3	1.5	0.5	0.4	0	5.4*	6.0*	5.5*	5.4*	6.4*
2.0		0.8*	2.0	0	3.4*	5.4*	6.0*	6.0*	8.7*	6.0*	10.0*
LSD _(0.05)		0.5	1.7	1.6	0.6	1.8	0.9	1.1	0.5	0.6	1.5

^Z Injury ratings (0 = no injury, 5 = 50% injury, 10 = dead plant)

^Y Only June + September treatments at this time

^X Only June treatments at this time

Liriope 'Cleopatra' and 'Variegata' exhibited no injury for all dates and treatments.

Table 2.2. Growth indices of nine species treated with Roundup Pro[®], experiment 1, recorded on 3/3/08.

Treatment		Ornamental species								
Roundup rate lb ai/A	Application timing	Dwarf Mondo grass	Mondo grass	Liriope 'Cleopatra'	Liriope var.	Blue Pacific Juniper	Blue Rug Juniper	Asiatic jasmine	Dwarf yaupon	Pink Gumpo azalea
Non-treated control		19.0 ^z	31.3	30.6	31.5	25.5	38.4	78.6	23.0	20.7
0.25	Once 6/10/07	18.4	32.5	35.4	34.4	31.6	41.5	77.0	22.2	21.7
0.5		18.2	33.1	27.9	33.5	41.6	41.9	72.0	18.3*	19.4
1.0		18.9	32.3	32.5	33.8	35.0	34.2	81.7	15.3*	18.3*
2.0		19.3	32.8	31.8	33.8	31.3	26.1*	78.8	13.8*	17.7*
0.25	Once 9/1/07	19.0	31.9	32.3	34.5	37.0	42.1	71.0	23.0	21.6
0.5		20.0	32.4	31.8	34.6	29.2	39.5	77.5	20.5	20.2
1.0		20.3	31.8	29.0	35.8	39.5	32.1*	73.0	22.3	20.7
2.0		19.7	32.6	30.5	32.8	37.5	31.6*	68.4*	19.2*	18.5*
0.25	Twice (both dates above)	19.0	31.2	33.2	32.1	20.1	38.7	72.7	23.3	20.4
0.5		19.2	32.8	28.6	33.8	28.1	38.8	71.8	19.1*	19.9
1.0		18.4	32.6	30.9	34.1	22.0	25.6*	69.0*	14.2*	15.7*
2.0		18.2	25.7*	26.3	31.5	20.7	17.9*	53.4*	9.4*	12.7*
LSD _(0.05)		1.2	2.1	7.0	3.4	9.8	5.1	8.9	2.7	1.9

^z Growth indices = [(height x width 1 x width 2)/ 3 in cm]

Table 2.3. Growth indices of nine species treated with Roundup Pro[®], experiment 1, recorded on 6/13/08.

Treatment		Ornamental species								
Roundup rate lb ai/A	Application timing	Dwarf Mondo grass	Mondo grass	Liriope 'Cleopatra'	Liriope var.	Blue Pacific Juniper	Blue Rug Juniper	Asiatic jasmine	Dwarf yaupon	Pink Gumpo azalea
Non-treated control		18.0 ^z	35.4	29.4	36.9	34.4	44.2	46.6	27.4	27.2
0.25	Once 6/10/07	17.6	35.3	35.2	34.1	38.3	44.4	47.4	27.0	27.9
0.5		17.8	36.5	27.5	37.5	46.2	45.7	51.6	21.8*	26.3
1.0		18.6	34.9	29.0	35.5	42.2	39.6*	46.1	20.6*	24.5*
2.0		17.8	34.7	33.0	37.6	38.4	35.4*	44.2	18.9*	23.4*
0.25	Once 9/1/07	19.0	35.0	30.6	36.4	42.5	48.8	42.0	27.2	28.0
0.5		19.5	36.0	20.7	35.3	38.2	44.5	45.0	24.9	27.8
1.0		19.5	35.6	32.7	34.1	42.7	36.2*	52.4	26.3	26.9
2.0		19.1	37.1	34.0	36.1	42.2	12.6*	46.5	22.7*	24.9*
0.25	Once 2/20/08	17.7	35.9	33.7	37.6	44.1	39.8	44.3	25.5	28.6
0.5		17.2	38.0	33.5	38.4	47.1	46.3	36.2*	24.5*	26.0
1.0		15.0	36.7	29.8	38.0	45.2	47.2	25.9*	22.0*	23.8*
2.0		18.5	32.7*	26.8	33.2*	46.6	45.4	26.0*	17.1*	22.0*
0.25	Three times (repeated on all three	18.3	34.0	31.0	35.4	30.5	46.0	45.1	27.4	27.6
0.5		18.7	36.6	26.4	35.3	36.0	44.0	35.6*	22.2*	25.1
1.0		18.0	34.9	29.3	34.5	32.3	31.0*	28.7*	16.1*	17.2*
2.0		17.0	16.6*	23.0	21.6*	28.4	22.4*	25.2*	7.2*	0*

LSD_(0.05)

1.9

2.6

4.2

2.9

8.3

5.6

4.7

2.7

2.1

^zGrowth indices = [(height x width 1 x width 2)/ 3 in cm]

Table 2.4. Marketability of nine species treated with Roundup Pro®, experiment 1, recorded on 10/11/08

		Ornamental species								
Roundup rate	Application timing	Dwarf Mondo grass	Mondo grass	Liriope 'Cleopatra'	Liriope var.	Blue Pacific Juniper	Blue Rug Juniper	Asiatic jasmine	Dwarf yaupon	Pink Gumpo azalea
Non-treated control		1 ^z	1	1	1	1	1	1	1	1
0.25	Once 6/10/07	1	1	1	1	1	1	1	1	1
0.5		1	1	1	1	1	1	1	1	1
1.0		1	1	1	1	1	1	1	2*	1
2.0		1	1	1	1	1	2*	2*	3*	1
0.25	Once 9/1/07	1	1	1	1	1	1	1	1	1
0.5		1	1	1	1	1	1	1	1	1
1.0		1	1	1	1	1	1	1	1	1
2.0		1	1	1	1	1	3*	3*	2*	1
0.25	Once 2/20/08	1	1	1	1	1	1	1	1	1
0.5		1	1	1	1	1	1	1	2*	1
1.0		1	1	1	1	1	1	1.5*	3*	1
2.0		1	2*	1	1	1	1	2*	3*	2.5*
0.25	Three times (repeated on all three	1	1	1	1	1	1	1	1	1
0.5		1	1	1	1	1	1	1	1	1
1.0		1	1	1	1	1	1	1.5*	2*	2.5*
2.0		1	3*	1	1	1	1	3*	2*	3*

LSD_(0.05) 0 0 0 0 1.6 1.8 0.3 0 0.3

^z Marketability rating (1 = marketable, 2 = small but marketable, 3 = unmarketable)

Table 2.5. Effects of Roundup Pro® applications over the top of eight species, experiment 2.

Treatment		Ornamental species											
Roundup rate	Application timing	Dw. Mondo grass	Mondo grass	Asiatic jasmine	Dwarf yaupon	Gardenia 'Hardy Daisy'	Sky Pencil' holly	Euonymus 'Colorata'	Boxwood				
lb ai/A		Date recorded											
		4/8/09	4/8/09	4/8/09	9/25/08	4/8/09	7/8/08	3/10/09	5/8/09	9/25/08	4/8/09	10/2/08	4/8/09
Non-treated control		0.9 ^z	1.0 ^z	3.7 ^y	0 ^z	10.0 ^x	0 ^z	0.3 ^z	5.0 ^y	0 ^z	4.9 ^y	0 ^z	1.0 ^z
0.25	Once 6/24/08	1.0	0.4	3.6	0	10.0	0	0.6	5.0	0	4.7	0	1.3
0.5		1.0	1.0	3.6	0	10.0	0	0	5.0	0	4.9	0	1.0
1.0		1.0	1.0	3.4	0	10.0	0.6*	0.1	5.0	3.4*	4.9	0.7	1.0
2.0		0.7	1.0	3.7	2.7*	10.0	2.3*	0.1	5.0	6.7*	4.3*	3.9*	1.7
0.25	Once 9/16/08	0.7	1.0	3.9	0	10.0	-	0.3	5.0	0	4.6	0	1.1
0.5		1.0	1.0	3.7	0	9.9	-	0.1	5.0	0	4.7	0	1.4
1.0		0.7	1.0	3.9	0	10.0	-	0	5.0	0	4.7	0	1.4
2.0		1.0	1.0	3.9	0	9.9	-	0.1	4.9	0	4.3*	0	1.4
0.25	Once 2/20/09	1.1	0.7	3.1*	-	2.6*	-	0.7	4.4*	-	3.9*	-	5.5*
0.5		0.9	1.6	2.3*	-	1.0*	-	0.4	3.4*	-	2.9*	-	3.6*
1.0		1.0	2.1*	1.6*	-	0.3*	-	1.0*	1.9*	-	2.1*	-	6.9*
2.0		1.4*	3.3*	1.0*	-	0*	-	1.0*	1.4*	-	2.3*	-	7.3*
0.25	Three times (repeated on all three	1.1	1.3	2.9*	0	3.3*	0 ^w	0.9	4.6*	0 ^v	4.0*	0 ^v	2.7*
0.5		1.3	1.6	1.9*	0	1.9*	0	0.3	3.1*	0	3.0*	0.3	5.9*
1.0		1.3	3.4*	1.4*	0	0*	0	1.0*	2.4*	1.9*	2.1*	1.4*	8.0*
2.0		4.1*	2.3*	1.0*	2.2*	0*	2.1*	0.7	1.3*	7.3*	2.0*	2.7*	8.4*
LSD _(0.05)		0.6	0.8	0.5	1.7	0.9	0.2	0.6	0.4	1.2	0.5	1.3	1.0

^z Injury ratings (0 = no injury, 5 = 50% injury, 10 = dead plant)

^y Spring growth rating scale: 1-5 (1 = no new flush, 2 = buds but no leaves, 3 = new leaves beginning to unfurl, 4 = 50% leaves unfurled, 5 = full of new growth.)

^x New shoot rating scale: 0-10 (0 = no new shoots, 1 = 10%, 5 = 50%, 10 = 100% of new buds/tips flushing out)

^w Only June treatments at this time

^v Only June + September treatments at this time

Table 2.6. Growth indices of eight species treated with Roundup Pro[®], experiment 2, recorded on 2/23/09.

Treatment		Ornamental species							
Roundup rate lb ai/A	Application timing	Dwarf Mondo grass	Mondo grass	Asiatic jasmine	Dwarf yaupon	Gardenia 'Hardy Daisy'	Sky Pencil' holly	Euonymus 'Colorata'	Boxwood
Non-treated control		17.8 ^z	26.2	121.7	26.0	54.0	27.6	49.8	27.8
0.25	Once 6/24/07	18.1	26.8	132.6	27.6	55.6	30.7	54.8	30.8
0.5		18.3	28.0	109.1	27.2	54.4	30.5	54.4	29.5
1.0		19.2	25.5	140.4	27.5	55.9	29.2	46.8	28.8
2.0		17.7	25.1	119.6	20.7*	49.6*	26.2	45.6	29.4
0.25	Once 9/16/07	16.4	26.3	118.3	26.6	56.9	31.2	59.2	30.4
0.5		17.9	27.5	123.0	28.7	53.8	31.2	54.0	29.7
1.0		17.3	26.9	116.6	27.6	55.6	30.8	53.0	28.5
2.0		16.9	25.9	104.0	27.6	55.6	29.1	49.2	30.2
0.25	Twice (both dates above)	18.3	26.1	105.8	26.2	57.2	32.2	48.5	29.5
0.5		18.4	26.6	127.3	26.7	54.0	31.2	58.8	30.0
1.0		18.7	23.8	105.0	25.3	53.9	31.5	49.2	28.4
2.0		18.1	27.2	90.3*	21.4*	51.3	28.6	29.9*	26.1
LSD _(0.05)		1.6	3.1	20.1	3.0	3.1	4.2	9.2	2.7

^z Growth indices = [(height x width 1 x width 2)/ 3 in cm]

Table 2.7. Growth indices of eight species treated with Roundup Pro[®], experiment 2, recorded on 7/6/09.

Treatment		Ornamental species							
Roundup rate lb ai/A	Application timing	Dw. Mondo	Mondo grass	Asiatic jasmine	Dwarf yaupon	Gardenia 'Hardy Daisy'	Sky pencil' holly	Euonymus 'Colorata'	Boxwood
Non-treated control		15.6 ^z	20.8	32.5	33.3	60.7	79.1	28.0	32.8
0.25	Once 6/24/07	15.7	21.1	34.5	34.8	62.1	92.3	30.3	35.3
0.5		16.1	21.2	33.3	34.0	62.5	87.4	32.7	36.1
1.0		15.6	20.5	32.5	35.0	62.6	88.3	26.1	34.8
2.0		15.4	20.7	28.1	29.3*	56.8*	83.1	30.6	35.2
0.25	Once 9/16/07	15.6	19.6	34.2	33.0	62.4	95.1	30.9	37.8
0.5		14.9	20.0	33.9	35.1	61.3	90.1	28.4	36.4
1.0		15.2	20.8	33.0	34.1	62.2	87.0	30.9	35.2
2.0		15.0	20.0	34.7	33.5	63.3	87.7	26.1	35.9
0.25	Once 2/20/08	15.0	20.5	34.8	31.7	61.4	84.9	28.9	33.3
0.5		15.1	20.7	32.0	30.8	63.5	85.3	31.5	32.3
1.0		15.0	27.6	28.6	29.8*	61.3	83.3	27.6	32.0
2.0		15.4	25.1	28.5	26.9*	60.9	75.4	25.1	30.1*
0.25	Three times (repeated on all three	15.6	20.6	33.2	30.1*	64.7	91.9	33.5	33.2
0.5		16.4	21.5	32.4	29.6*	59.0	90.4	30.4	32.3
1.0		16.1	17.0*	25.6*	26.8*	61.7	81.0	24.1	28.7*
2.0		12.8*	17.9*	22.8*	24.2*	56.8*	76.1	17.0*	26.3*

LSD_(0.05) 1.0 2.1 5.6 3.0 3.2 12.9 6.4 2.7

^zGrowth indices = [(height x width 1 x width 2)/ 3 in cm]

Table 2.8. Marketability of eight species treated with Roundup Pro®, experiment 2, recorded on 10/23/09

Treatment		Ornamental species							
Roundup rate lb ai/A	Application timing	Dwarf Mondo grass	Mondo grass	Asiatic jasmine	Dwarf yaupon	Gardenia 'Hardy Daisy'	Sky Pencil' holly	Euonymus 'Colorata'	Boxwood
Non-treated control		1 ^Z	1	1	1	1	1	1	1
0.25	Once 6/24/08	1	1	1	1	1	1	1	1
0.5		1	1	1	1	1	1	1	1
1.0		1	1	1	1	1	1	1	1
2.0		1	1	1	1	1	1	1	1
0.25	Once 9/16/08	1.3	1	1	1	1	1	1	1
0.5		1	1	1	1	1	1	1	1
1.0		1	1	1	1	1	1	1	1
2.0		1	1	1	1	1	1	1	1
0.25	Once 2/20/09	1.3	1.3	1.3	1.3	1	1	1.3*	2.3*
0.5		1.3	1	1	1	1	1	1.3*	2.7*
1.0		1	1.7	2.3*	1.7*	1	1	2*	3*
2.0		1	2*	3*	2*	1	1	3*	3*
0.25	Three times (repeated on all three	1	1	1	1	1	1	1	2*
0.5		1	1	1	1	1	1	1	2.3*
1.0		1	1.3	1	2*	1	1	2*	3*
2.0		1.3	1.3	2.3*	3*	1	1	3*	3*

LSD_(0.05) 0.5 0.8 0.8 0.5 0 0 0.3 0.8

^ZMarketability ratings 1 = marketable, 2 = small but marketable, 3 = unmarketable

Chapter Three
Effects of Repeated Applications of Roundup Pro[®] over the Top
of Container-Grown Nursery Crops

Abstract

Three experiments studying the effects of repeated applications of Roundup Pro[®] over-the-top of container-grown nursery crops were conducted. Plants in 3.8 liter (one-gallon) containers were treated with single applications of Roundup Pro[®] at 1.12 kg ai/ha (1.0 lb ai/A) in July, August, September, or October, 2008 or 2009. Other plants were treated in July and August (JA); July, August, and September (JAS); July, August, September, and October (JASO); or July and September (JS). Injury ratings were taken at multiple times after treatments. Growth indices 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. Experiment 1 (2008): *Liriope muscari* ‘Big Blue,’ *Camellia sasanqua* ‘Shishigashira,’ and *Gardenia jasminoides* ‘Radicans’ were evaluated. ‘Big Blue’ liriope showed minor injury from two or more applications with reduced growth from 3 or 4 applications, but all plants were marketable in June of the following season. *Camellia* exhibited no injury from any Roundup application and all parameters were similar to controls. ‘Radicans’ gardenia showed fall chlorosis and stunting through early spring from multiple applications, but all plants were marketable, with those treated 3 or 4 times

rated small but marketable. Experiment 2 (2009, Auburn): ‘Big Blue’ lirioppe, ‘Radicans’ gardenia, *C. sasanqua* ‘Martha Simms,’ and *Juniperus conferta* ‘Blue Pacific,’ showed no injury from any treatment and growth indices in January and June were similar to controls. *Ilex cornuta* ‘Dwarf Burfordii’ growth indices were similar to controls with occasional chlorosis observed after July treatments. *Ternstroemia gymnanthera* (cleyera) exhibited chlorosis, necrosis, and stunting of shoot tips for all treatments. Cleyera growth indices in January and June indicated that JAS, JASO, and JS-treated plants were smaller than controls, but regrowth was similar to controls for all treatments the following spring. All plants were vigorous and marketable. Experiment 3 (2009, Mobile, AL): ‘Big Blue’ lirioppe, ‘Radicans’ gardenia, ‘Blue Pacific juniper, *I. cornuta* ‘Carissa,’ and cleyera growth indices were similar to controls 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.

Introduction

Between 1975 and 1980, Roundup was evaluated over the top of numerous container-grown crops, with many exhibiting some degree of tolerance. Roundup was applied once, twice, or three times at 0.56, 0.84, 1.12 and 1.68 kg ai/ha (0.5, 0.75, 1.0, and 1.5 lb ai/A) on April 7, 14, and 21, 1978, over 18 ornamental cultivars (Self, 1978). Total amounts of glyphosate applied ranged from 0.56 to 5.0 kg ai/ha (0.5 to 4.5 lb ai/A). Of the 18 species tested, nine were not injured, including *Magnolia soulangeana*, *Juniperus conferta*, *Cupressus sp.*, *Ilex cornuta* ‘Burfordii,’ *I. cornuta* ‘Yellow top,’ *Photinia fraseri*, *Pittosporum tobira*, *Podocarpus*, and *Trachycarpus fortunei*.

Gardenia jasminoides ‘Radicans’ was injured at 3.36 and 5.04 kg ai/ha (3 and 4.5 total lb ai/A). Of the remaining species, *Rhododendron obtusum* ‘Hinodegiri’ and ‘Fashion’ azaleas were the most sensitive, with injury occurring from as little as 2 applications of the 0.56 kg ai (0.5 lb) rate. In another study, glyphosate was applied at 0.28, 0.84, and 1.12 kg ai/ha (0.25, 0.75, and 1.0 lb ai/A) over the top of 10 species, once on August 3 and again on August 17, 1978 (Perry and Knowles, 1979). Following two applications, no phytotoxicity was observed on *Berberis x mentorensis*, *Camellia japonica*, *Forsythia x intermedia*, and *Ligustrum* ‘vicaryi’ at any rate. Temporary slight yellowing was observed on *B. julianae*, *Euonymus japonicus* and *I. cornuta* ‘Dwarf Burfordi’ at higher rates. Damage was more severe on ‘Hinodegiri’ azalea, *I. crenata* ‘Helleri,’ and *I. crenata* ‘Hetzi’ at rates ≥ 0.84 kg ai/ha (0.75 lb ai/A). 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 (1.0 lb ai/A).

Ligustrum has shown a linear decrease in susceptibility from March to November (Neal et al., 1985). *J. conferta* ‘Blue Pacific’ juniper sustained tip necrosis on young elongating tips from early summer applications, but applications at other growth stages resulted in no significant absorption of glyphosate.

Roundup at 0.45 kg ai/ha (0.4 lb ai/A) can be used as a cleanup treatment for effective control of spurge (96%) in ‘Big Blue’ liriope with no short-term or long-term injury (Altland et al., 2002). In separate experiments, Roundup at 1.79 kg ai/ha (1.6 lb ai/A), the maximum rate tested, was applied to recently divided liners of ‘Variegata’ and ‘Big Blue’ liriope infested with mature and flowering spurge. Effective control of

spurge (92.8% and 100% respectively) with no short-term or long-term injury to 'Variegata' was reported. 'Big Blue' showed slight initial injury which was outgrown 60 DAT. In another study, Roundup applied on September 6, 2005 in a 1% solution of 1.82 kg ai in 378 liters (4.0 lb ai in 100 gallons) caused no injury on liriopse or Asiatic jasmine (Walsworth et al., 2006).

Minimal injury has been reported on 'Blue Pacific' juniper, 'Blue Star' juniper (*J. squamata*), and 'Parsoni' juniper (*J. davurica*) when Roundup Pro[®] was applied at rates up to 2.8 kg ai/ha (2.5 lb ai/A) on May 29, 2004 and May 13, 2005 (Czarnota, 2008). 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 (1.0 lb ai/A) was applied.

Nine species of ornamentals in containers were treated over-the-top with Roundup Pro[®] at 4 rates 0.28, 0.56, 1.12 and 2.24 kg ai/ha (0.25, 0.5, 1.0 and 2.0 lb ai/A) once in June 2007, August 2007, or February 2008 (Neal and Skroch, 1985). A fourth group was treated on all three dates. Dwarf mondo grass (*Ophiopogon japonicus* 'Nana'), Mondo grass (*O. japonicus*), liriopse 'Cleopatra', and liriopse 'Variegata' were tolerant to all rates and application dates. 'Blue Pacific' juniper was slightly injured by February applications but recovered quickly. Asiatic jasmine (*Trachelospermum asiaticum*) and dwarf yaupon (*I. vomitoria* 'Stoke's Dwarf') suffered significant injury after February applications. Blue rug juniper (*J. horizontalis*) was tolerant in August but injured at ≥ 1.12 kg ai/ha (≥ 1 lb ai/A) 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, liriopse 'Cleopatra' and 'Variegata' and 'Blue Pacific' juniper were not affected by over-the-top Roundup Pro[®] applications

except at 2.24 kg ai/ha (2.0 lb ai/A) applied 3 times. The remainder of the species had reduced growth as Roundup Pro[®] rates increased.

As growers have increased use of over-the-top Roundup applications, they are asking how often they can apply Roundup over the top. The objective of the experiment was to determine crop tolerance of container-grown nursery crops to repeated glyphosate applications at 1.12 kg ai/ha (1.0 lb ai/A), a rate found to be adequate for control of most weeds found in container production (Van Hoogmoed et al., 2009).

Materials and Methods

Three separate experiments were conducted, one in 2008-2009 and two in 2009-2010. Experiment 1 was initiated in July, 2008, in Auburn, AL (Hardiness zone 7b). 'Big Blue' liriope, 'Radicans' gardenia, and *C. sasanqua* 'Shishigashira' were evaluated. Plants in 3.8 liter (one-gallon) containers in pinebark/sand substrate were obtained from local nurseries and treated with single applications of Roundup Pro[®] at 1.12 kg ai/ha (1.0 lb ai/A) in July, August, September, or October 2008 or 2009 with a CO₂-powered backpack sprayer at 25 psi and 280 L/ha (30 GPA). Multiple applications were applied in July and August; July, August, and September; July, August, September, and October; or July and September. There was one non-treated control group; nine treatments in all. Plants received 0.4 inches of daily overhead irrigation and were allowed to dry for at least 6 hours after Roundup applications. Plants were grouped by species in a completely randomized block design with 8 single-pot replications. Plant injury ratings (1 = no injury, 10 = dead) were taken at 11-19-day intervals after test initiation until the end of the growing season. Growth indices were collected in January and June 2009 after the

end of the spring growth flush. Plant vigor (1 = healthy, 5 = chlorotic) and marketability (1 = marketable, 3 = not marketable) was rated in May, 2009. Data was analyzed in a statistical software package (SAS Institute, Cary, North Carolina) using Waller-Duncan k ratio t tests ($P \leq 0.05$). Data was analyzed separately for each sampling date.

Experiment 2 was initiated in July 2009 in Auburn, AL, and the following plants were used: 'Big Blue' lirioppe, 'Radicans' gardenia, *C. sasanqua* 'Martha Sims,' 'Blue Pacific' juniper, dwarf burford holly, and *Ternstroemia gymnathera* (cleyera) with all parameters similar to experiment 1. Plant injury ratings were recorded every 14-16 days. Growth indices were taken in January and June 2010. Plant vigor and marketability were rated in June 2010.

Experiment 3 was initiated in July 2009 in Mobile, AL (Hardiness zone 8b). 'Big Blue' lirioppe, 'Radicans' gardenia, 'Blue Pacific' juniper, *I. cornuta* 'Carissa,' *C. japonica* seedlings, and cleyera were evaluated. Growth indices were collected in early February and late May 2010, with all parameters similar to experiment 1. Plant injury ratings were recorded when noted every 14 to 16 days. Plant vigor and marketability were rated in late May 2010.

Results and Discussion

Experiment 1:

Injury ratings for 'Big Blue' lirioppe treated in July, September, or July and September were similar to controls through the end of October (Table 3.1), concurring with other research (Altland et al., 2002; Van Hoogmoed et al., 2009; Walsworth et al.,

2006). However, at the end of October slight injury was observed characterized by 1-4 yellow leaf blades per plant. All treatments with an August application had the highest percentage of plants with a few yellow leaf blades. Plants were rated for vigor on May 14, 2009 and no differences were observed. Growth indices taken on January 21, 2009 showed that single treatments in September and October and successive treatments in July + August were similar to non-treated controls. Single treatments in July and August and successive treatments in July + August and July + September were smaller than control plants. 'Big Blue' liriope receiving three or more treatments tended to be smallest. Growth indices on June 9, 2009 followed a similar trend to the January 21 ratings. Comparison of the differences in growth indices between January 21 and June 9 showed no significant difference in spring growth from the non-treated controls for any single or multiple treatments except for the July + August treatment and the four successive applications (data not shown). Although some treatments received up to 1.82 kg ai/ha (4.0 lb ai/A) total, regrowth was similar to the controls. All plants were similar to controls in plant vigor ratings on May 14, 2009. Plants were rated for marketability on June 6, 2009. All treatments except those treated four times from July to October or in August were similar to the controls; however, all plants were marketable.

No injury was noted on 'Shishigashira' camellia in any treatment (Table 3.1). Growth indices were similar in camellia for all treatments and controls on January 21 and June 9, 2009. There was no difference in plant vigor or color on May 14, 2009. Differences in growth between January and June were similar as well except for the July, August, and September multiple treatment. Plant vigor for all treatments was similar to the control. All camellias were marketable. Our data concurs with previous research

where no phytotoxicity was reported when 1.12 kg ai/ha (1.0 lb ai/A) was applied once on August 3 and again on August 17 (Perry and Knowles, 1979).

Injury on 'Radicans' gardenia from single treatments appeared as chlorotic leaves about 7 days after treatment (Table 3.2). However, within three weeks, treated plants were similar to the controls. As multiple treatments were applied, chlorosis and stunting became more evident. Treatments applied on July 28 were significantly different from the controls on August 8. Within one month all plants recovered from the July treatment and were visually similar to the controls. On September 12, the July treatment was similar to the control. Three July + August 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 treatment, all 'Radicans' gardenia treated in July and August had the most injury while plants treated in July only were similar to non-treated plants. Plants treated only in August exhibited slight injury. October ratings were similar to September ratings, with all plants that received July + August applications exhibiting the most injury. Injury among all other treatments was minimal, with the August-only treatment having slightly greater injury than the non-treated plants. September-only treatments were similar to controls.

Growth indices for 'Radicans' gardenia on January 21, 2009 were similar for non-treated control plants and plants treated only in August, September, and October (single applications). All 'Radicans' gardenia treated in July were smaller than non-treated controls. Those receiving two Roundup applications were smaller than all other plants. Growth indices taken after the spring flush on June 9, 2009 indicated that the non-treated

control and single applications in August, September, and October were similar. All ‘Radicans’ gardenia receiving multiple applications were smaller than non-treated control plants. As previously noted, ‘Radicans’ 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 non-treated control, while ‘Radicans’ gardenias receiving multiple treatments were rated lower due to slight leaf stunting. Marketability ratings showed that all single treatments were similar to the non-treated controls, while plants receiving multiple treatments had slightly higher ratings due to smaller leaf size; however, all plants were marketable.

Experiment 2:

All growth indices before and after the spring flush the following year were similar to non-treated controls for ‘Big Blue’ lirioppe, ‘Radicans’ gardenia, ‘Martha Simms’ camellia, ‘Blue Pacific’ juniper, and dwarf burford holly (Table 3.3, 3.4). Temporary foliar injury on ‘Blue Pacific’ as reported by Neal et al. (1985) and Perry and Knowles (1979) was not seen. Our results concurred with Czarnota (2008), who reported no significant injury at the 1.12 kg ai/ha (1.0 lb ai/A) rate. Occasional slight chlorosis from July treatments was seen on dwarf burford holly, similar to temporary symptoms reported by Perry and Knowles (1979). Cleyera exhibited chlorosis, necrosis, and stunting of shoot tips for all treatments. January and June growth indices showed that cleyera treated JAS, JASO, and JS was significantly smaller than controls. Cleyera injury ratings for single applications indicated less injury as plants were treated later in the growing season (Figure 3.1). Multiple applications began with a July treatment and

thus showed similar patterns of injury and stunting for each treatment of two, three, or four applications (Figure 3.2). For JS treatments, there was some recovery in August from the July application. 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 non-treated controls and much more desirable in appearance (Figure 3.3). All plants were vigorous and marketable.

Experiment 3:

‘Big Blue’ lirioppe, ‘Radicans’ gardenia, ‘Blue Pacific’ juniper, carissa holly, and cleyera growth indices were similar to controls in February (Table 3.5) and June (Table 3.6). Spring growth was similar or larger than controls for all species. All plants were vigorous and marketable. Camellia growth indices indicated no effect from Roundup Pro[®] treatments. The tolerance of ‘Big Blue’ lirioppe to single Roundup Pro[®] applications concurs with data in experiment 2 and previous research (Altland et al., 2002; Van Hoogmoed et al., 2009; Walsworth et al., 2006). No injury on ‘Blue Pacific’ juniper was seen in this study, similar to a report of no significant injury at the 1.12 kg ai/ha (1.0 lb ai/A) rate (Czarnota, 2008), but contrary to other reports (Neal et al., 1985; Van Hoogmoed et al., 2009). Injury on cleyera was much lower in experiment 3 than in experiment 2. Experiment 2 cleyera grew constantly throughout the test period,

presenting new tissue which was affected by glyphosate applications. Experiment 3 cleyera did not grow as much, thus presenting less new tissue.

Research demonstrates that multiple applications of Roundup are relatively safe when applied over the top of some ornamentals. Our research shows that several ornamentals are very tolerant, especially when treatments 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 controls. However, regrowth was similar for all treatments except some plants treated four times in successive months.

Our research shows that 'Big Blue' liriopse, 'Radicans' gardenia, *C. sasanqua* 'Shishigashira' and 'Martha Simms', 'Blue Pacific' juniper, Carissa holly, and dwarf burford holly are tolerant to repeated applications 28 days apart starting in July. Plants that are not affected by fall treatments have normal spring growth and marketability similar to non-treated plants. 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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Table 3.1. Liriope and camellia responses to repeated Roundup Pro® applications at 1.0 lb ai/A, expt. 1.

Treatment	Liriope					Camellia ¹			
	10/16/08	5/14/09	1/21	6/9	6/9	5/14	1/21	6/9	6/9
	IR ^Z	Plant vigor ^Y	Growth indices ^X	Growth indices	Mkt ^W	Plant vigor	Growth indices	Growth indices	Mkt
Control	1.1cd ^V	1.0a	32.0a	44.4a	1.1b	1.0a	23.6a	30.8a	1.0a
28-Jul	1.5bc	1.0a	28.5cd	40.2c	1.1b	1.0a	22.7a	28.7a	1.0a
28-Aug	1.9ab	1.0a	30.2bc	40.8bc	1.4a	1.3a	21.1a	27.4a	1.7a
29-Sep	1.0d	1.0a	33.2a	43.6ab	1.2b	1.4a	24.7a	30.3a	1.9a
29-Oct	.	1.0a	32.2ab	44.9a	1.0b	1.0a	22.9a	32.0a	1.0a
Jul, Aug	1.9ab	1.0a	30.7abc	44.9a	1.0b	1.7a	20.2a	24.9a	2.3a
Jul, Aug, Sep	1.9ab	1.0a	26.7d	38.1cd	1.2b	1.4a	23.0a	26.0a	2.0a
Jul, Aug, Sep, Oct	2.0a	1.0a	27.0d	35.9d	1.7a	1.0a	24.5a	29.1a	1.0a
Jul, Sep	1.3 bc	1.0a	29.7bc	40.0c	1.2b	1.0a	22.9a	31.5a	1.0a

^ZInjury ratings 1 = no injury, 10 = dead plant

^YPlant vigor 1 = healthy, 5 = chlorotic

^XGrowth indices = [(height x width1 x width 2)/3] in cm

^WMarketability 1 = marketable, 2 = small but marketable, 3 = unmarketable

^VDuncan's Multiple Range test $\alpha = 0.05$

¹No injury was recorded for camellia

Table 3.2. Gardenia responses to repeated Roundup Pro® applications at 1.0 lb ai/A, expt. 1.

Treatment	8/8/08 IR ^Z	8/27 IR	9/12 IR	9/29 IR	10/16 IR	5/14 Plant vigor ^Y	1/21/09 Growth indices ^X	6/9/09 Growth indices	6/9/09 Mkt ^W
Control	1.0d ^V	1.0a	1.0c	1.0c	1.0d	1.0d	40.5a	45.7a	1.0c
28-Jul	2.5ab	1.0a	1.5c	1.6b	2.0bc	1.2d	35.6bc	38.9c	1.0c
28-Aug	.	.	2.0b	2.0b	2.4b	1.0d	38.7ab	43.5abc	1.0c
29-Sep	.	.	.	1.0c	1.1d	1.0d	41.2a	44.1ab	1.1c
29-Oct	1.0d	42.1a	42.8abc	1.1c
Jul, Aug	2.9a	1.0a	5.0a	4.5a	4.1a	2.0c	30.2d	33.0d	1.7ab
Jul, Aug, Sep	2.7ab	1.0a	4.7a	4.9a	4.7a	2.4b	29.7d	33.1d	2.0ab
Jul, Aug, Sep, Oct	2.4b	1.0a	4.7a	4.9a	4.7a	2.9a	28.5d	31.7d	2.1a
Jul, Sep	1.9c	1.0a	1.2c	1.1c	1.5bcd	1.0d	32.7cd	39.8bc	1.6b

^ZInjury ratings 1 = no injury, 10 = dead plant

^YPlant vigor 1 = healthy, 5 = chlorotic

^XGrowth indices = [(height x width1 x width 2)/3] in cm

^WMarketability 1 = marketable, 2 = small but marketable, 3 = unmarketable

^VDuncan's Multiple Range test $\alpha = 0.05$

Table 3.3. Growth indices^Z of six species treated with Roundup Pro® at 1.0 lb ai/A recorded on 1/25/10, expt. 2.

Treatment	Ornamental species					
	Liriope	Gardenia	Camellia	Blue Pacific	Dwarf Burford	Cleyera
Non-treated control	39.0a ^Y	55.0a	65.5ab	29.0a	38.5a	57.0bc
July	41.6a	55.6a	61.1ab	28.5a	40.6a	55.8bcd
August	41.1a	54.6a	62.6ab	28.0a	38.1a	56.8bcd
September	40.3a	55.6a	65.8ab	28.0a	38.8a	62.1a
October	40.6a	53.4a	67.7a	28.2a	38.0a	59.3ab
July+August	39.2a	52.6a	61.6ab	27.4a	37.6a	54.0cde
Jul+Aug+Sept	40.0a	55.3a	60.3ab	27.8a	35.1a	49.9ef
Jul+Aug+Sept+Oct	40.0a	52.2a	59.6b	29.4a	34.8a	47.2f
Jul + Sept	40.2a	54.1a	58.4b	29.3a	40.0a	51.8def

^Z Growth indices = [(height x width 1 x width 2)/ 3] in centimeters

^Y Duncan's Multiple Range Test, $\alpha = 0.05$

Table 3.4. Growth indices^Z of six species treated with Roundup Pro® at 1.0 lb ai/A recorded on 6/2/10, expt. 2.

Treatment	Ornamental species					
	Liriope	Gardenia	Camellia	Blue Pacific	Dwarf Burford	Cleyera
Non-treated control	60.0a ^Y	62.9a	77.4ab	32.9a	50.8ab	69.8abc
July	63.0a	64.3a	73.8ab	32.8a	55.8a	67.8bcd
August	62.5a	62.7a	77.0ab	33.3a	53.6ab	72.5ab
September	60.8a	65.6a	77.0ab	33.1a	53.5ab	73.8a
October	57.8a	63.5a	79.2a	31.0a	53.6ab	70.9ab
July+August	58.7a	62.9a	76.6ab	33.6a	53.5ab	65.1cd
Jul+Aug+Sept	58.3a	64.3a	69.1b	31.3a	53.0ab	64.5d
Jul+Aug+Sept+Oct	58.6a	65.2a	70.6b	34.1a	48.7b	63.2d
Jul + Sept	60.0a	63.0a	71.1ab	31.9a	54.4ab	63.7d

^Z Growth indices = [(height x width 1 x width 2)/ 3] in centimeters

^Y Duncan's Multiple Range Test, $\alpha = 0.05$

Table 3.5. Growth indices^Z of six species treated with Roundup Pro® at 1.0 lb ai/A recorded on 2/8/10, expt. 3.

Treatment	Ornamental species					
	Liriope	Gardenia	Camellia	Blue Pacific	Carissa	Cleyera
Non-treated control	29.8a ^Y	38.1a	30.2a	46.8a	25.7ab	44.5ab
July	31.5a	35.3a	30.0a	43.0a	24.2ab	44.6ab
August	28.8a	38.8a	28.4a	47.3a	26.6a	43.7ab
September	28.1a	35.7a	30.3a	49.0a	26.2ab	43.7ab
October	27.9a	39.6a	30.0a	46.8a	24.5ab	46.5a
July+August	31.0a	38.6a	29.9a	50.1a	23.6b	41.8b
Jul+Aug+Sept	30.8a	38.7a	27.2a	46.3a	24.8ab	45.2ab
Jul+Aug+Sept+Oct	27.9a	36.9a	30.6a	48.4a	25.0ab	43.9ab
Jul + Sept	29.2a	36.8a	30.0a	45.7a	25.9ab	42.8ab

^Z Growth indices = [(height x width 1 x width 2)/ 3] in centimeters

^Y Duncan's Multiple Range Test, $\alpha = 0.05$

Table 3.6. Growth indices^Z of six species treated with Roundup Pro® at 1.0 lb ai/A recorded on 5/28/10, expt. 3.

Treatment	Ornamental species					
	Liriope	Gardenia	Camellia	Blue Pacific	Carissa	Cleyera
Non-treated control	47.3abc ^Y	46.3ab	23.4ab	51.5a	33.8a	50.1b
July	49.3a	40.8c	23.7ab	47.5a	32.8a	52.7ab
August	47.1abc	47.3a	30.9a	49.5a	33.8a	51.9ab
September	45.0bcd	42.2cd	31.8a	51.0a	33.2a	51.8ab
October	48.0ab	46.4ab	24.8ab	51.9a	32.8a	51.8ab
July+August	44.2c	46.0ab	27.5a	49.9a	32.2ab	52.7ab
Jul+Aug+Sept	44.0c	45.0abc	17.0b	48.3a	29.8b	53.3a
Jul+Aug+Sept+Oct	44.3c	43.0abc	22.0ab	50.2a	31.3ab	51.9ab
Jul + Sept	43.8c	40.5c	24.2ab	50.3a	32.6a	54.3a

^Z Growth indices = [(height x width 1 x width 2)/ 3] in centimeters

^Y Duncan's Multiple Range Test, $\alpha = 0.05$

Fig. 3.1: Injury ratings from single applications of Roundup (1.0 lb ai/A) over the top of clevera, expt. 2.

110

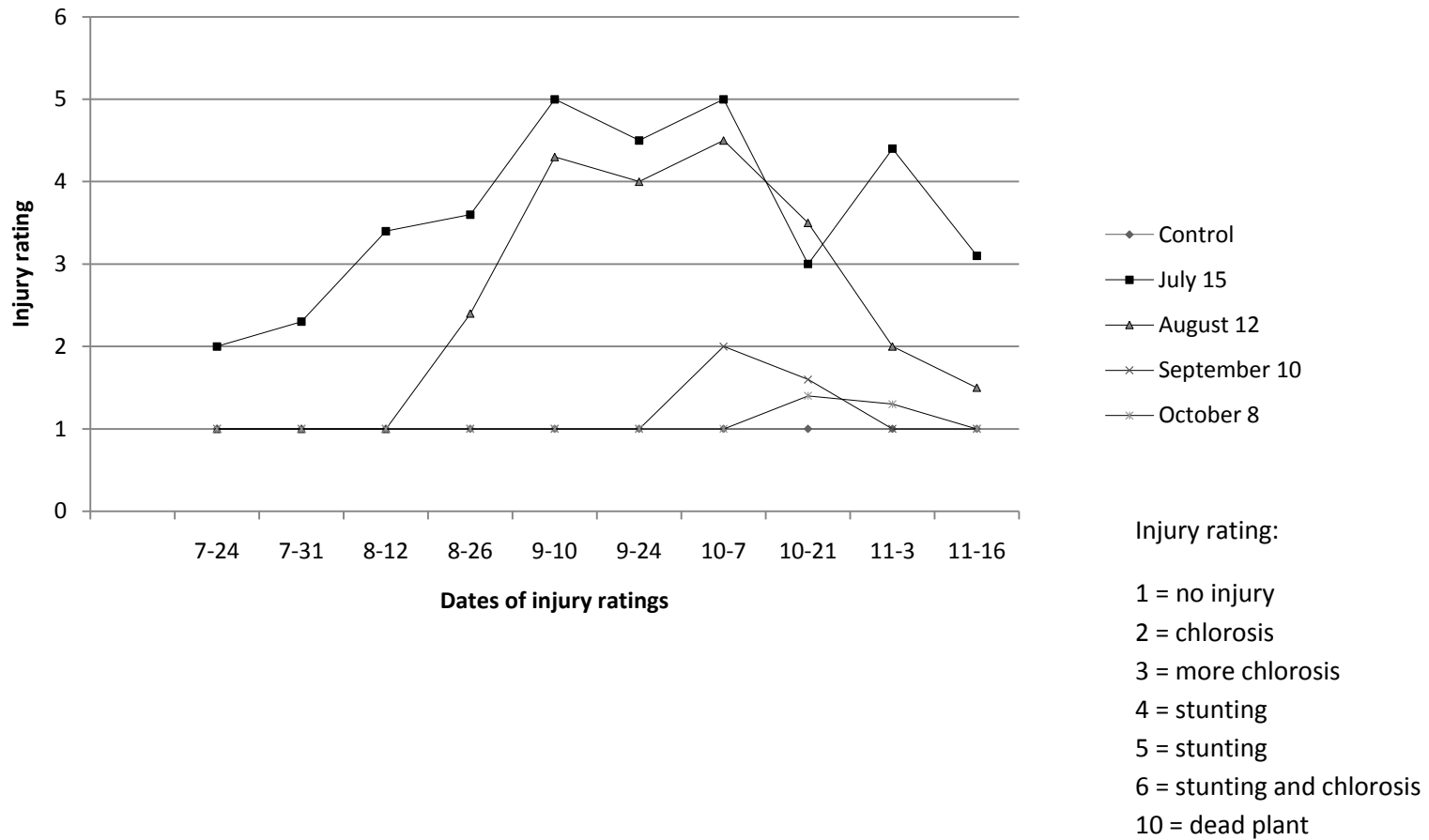


Fig. 3.2: Injury ratings from multiple applications of Roundup (1.0 lb ai/A) over the top of cleyera, expt. 2.

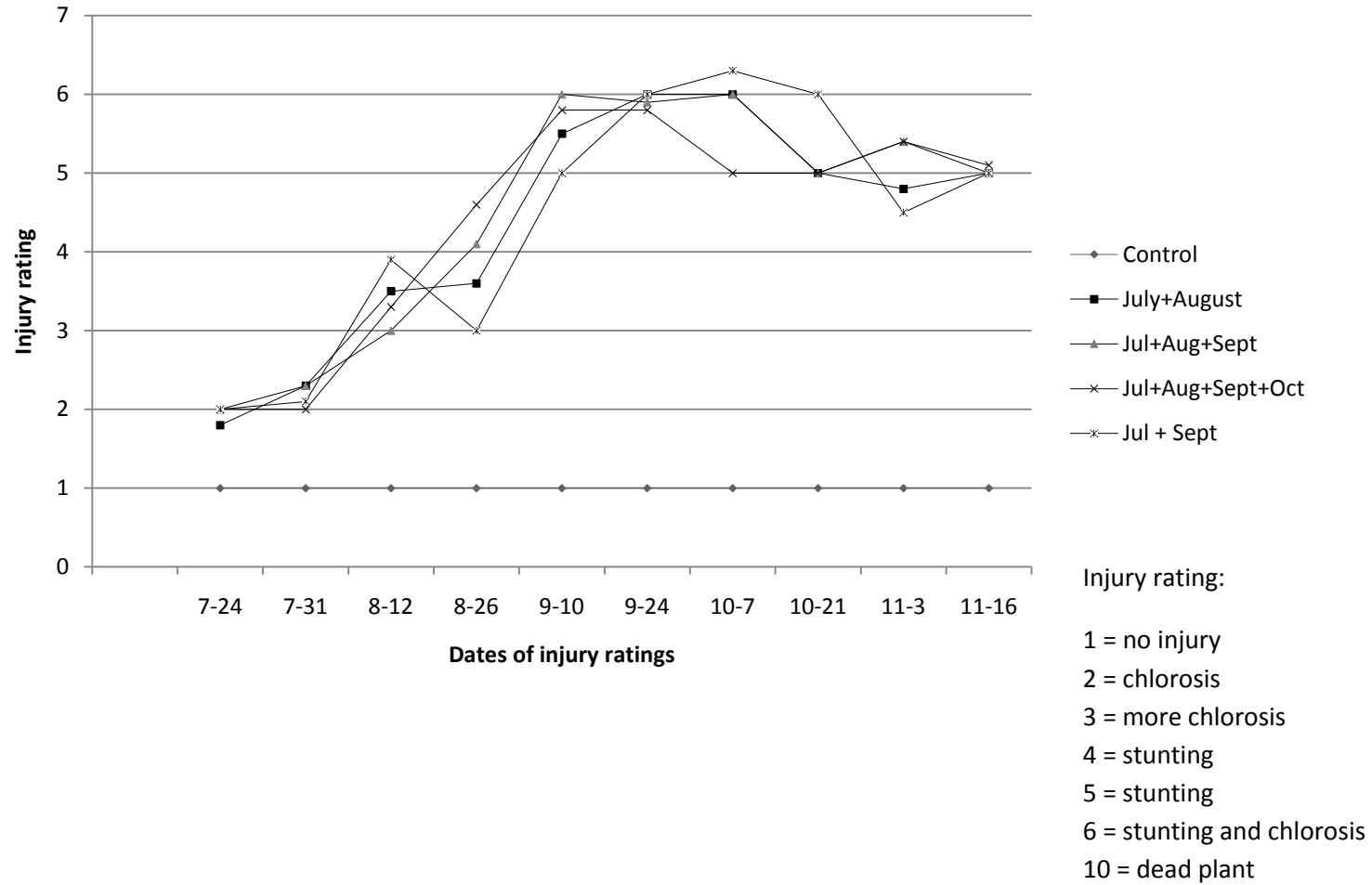


Figure 3.3
*Ternstroemia
gymnathera*
Roundup Pro®
@ 1.0 lb ai/A

Single
applications



Multiple
applications



Photo: 4/27/10

Chapter 4

Final Discussion

Hand weeding is very expensive. Due to unfavorable economic conditions, growers are seeking cost-effective practices to remain profitable. Some are tempted to apply rates of preemergent herbicide below recommended rates. Busy times may cause delayed or missed applications which may result in large outbreaks of weeds. Others may reduce manpower to the bare minimum, with no extra labor to control weed outbreaks that may arise. An explosion of weeds can make the crop worthless because it can be more expensive to weed it than what it is worth. In addition, slow sales may make it necessary to carry plants over to the following spring.

When Roundup Pro[®] was applied in June, September, or February, or on all 3 dates (Chapter 2), many plants were not affected by rates or timing, while others were most sensitive in the spring, some to very low rates, but became more tolerant through the growing season (Table 4.1, 4.2). Timing appears to be of greater importance than rate applied, although both are significant. Dwarf mondo, liriopse ‘Cleopatra’ and ‘Variegata,’ and ‘Blue Pacific’ juniper were tolerant to single or multiple rates up to 2 lb ai/A and were not affected by time of year, except for ‘Blue Pacific,’ which was temporarily injured by spring applications at rates ≥ 0.56 kg ai/ha (0.5 lb ai/A) but recovered quickly.

Mondo was tolerant of all single applications up to 2.24 kg ai/ha (2.0 lb ai/A) in June and September, but showed sensitivity to rates ≥ 1.12 kg ai/ha (1.0 lb ai/A) rates in February in separate experiments. 'Blue Rug' juniper was the only species that was more tolerant to spring applications and less tolerant in early summer. Asiatic jasmine was tolerant to summer applications but less tolerant in the spring, showing the effects of increasing rates. Dwarf yaupon spring growth, a sensitive species, was significantly delayed into mid-May by rates ≥ 0.28 kg ai/ha (0.25 lb ai/A) applied in February 2008. At the same time, applications in September 2007 up to 1.12 kg ai/ha (1.0 lb ai/A) did not reduce growth indices the following spring. When the experiment was repeated in 2008, June applications up to 1.12 kg ai/ha (1.0 lb ai/A), September applications up to 2.24 ka ai/ha (2.0 lb ai/A), and June + September up to 1.12 kg ai/ha (1.0 lb ai/A) did not suppress growth. The 2008 applications were made 14 days later than the 2007 applications, which may have given plants extra time to harden off sufficiently. A difference in early summer temperatures may have been a factor as well.

These two experiments also demonstrated that dwarf mondo, mondo (experiment 2 only), liriope 'Cleopatra' and 'Variegata,' 'Blue Pacific' juniper, 'Hardy Daisy' gardenia, 'Sky Pencil' holly, and 'Wintergreen' boxwood tolerated multiple treatments up to 2.24 kg ai/ha (2.0 lb ai/A) and that Asiatic jasmine, dwarf yaupon holly, and euonymus 'Colorata' tolerated rates up to 1.12 kg ai/ha) 1.0 lb ai/A as shown in growth indices for June + September treatments.

Three experiments with repeated applications (Chapter 3) further demonstrated plant tolerance to summer and fall applications. In 2008, single and multiple monthly applications resulted in growth reductions on liriope, injury and stunting on gardenia, and

no injury or stunting on camellia except for those treated 3 times. However, all plants were marketable after the spring growth flush the following season. In two experiments in 2009, single or multiple treatments at 1.12 kg ai/ha (1.0 lb ai/A) did not injure or reduce the growth of 'Big Blue' liriope, 'Radicans' gardenia, 'Martha Simms' camellia, dwarf burford holly, Carissa holly, or 'Blue Pacific' juniper. Cleyera exhibited chlorosis, necrosis, and stunting of shoot tips for all treatments. Cleyera injury ratings for single applications indicated less injury as plants were treated later in the growing season. Multiple applications began with a July treatment and thus showed similar patterns of injury and stunting for each treatment of two, three, or four applications. For JS treatments, there was some recovery in August from the July applications. 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.

Regardless of injury or stunting in the fall, however, spring regrowth of all plants was similar to non-treated controls. 'Big Blue' liriope, with smaller growth indices for single and multiple treatments, had the same amount of spring growth for all treatments. This pattern of spring growth was the same for all species tested. Cleyera receiving single treatments were similar to non-treated controls, while those receiving multiple treatments had smaller growth indices. However, multiple-treated cleyera were much bushier and desirable in appearance than controls and singly-treated plants.

Many plants in these studies showed no effects from the spray treatments. Plants that did experience injury did so on new tissue only. Cleyera, for example, saw new stems and leaves wither and die, while mature tissue was completely unaffected.

Likewise, 'Blue Pacific' juniper needles in shoot tips were injured with spring applications, but injury was not seen 3 to 4 weeks later.

All of our studies described in this thesis demonstrate the safety of summer and fall-applied Roundup treatments. Unlike deciduous plants, which can show severe injury in the spring from late summer and fall treatments, some container-grown nursery plants that are not affected by fall treatments have normal spring growth and marketability similar to non-treated plants. 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.

Table 4.1. Roundup Pro[®] rates up to 1.0 lb ai/A causing differences from controls in selected ornamentals, 2008

Growth indices (GI), marketability (Mkt), and injury (Inj) different from controls at:												
	February 08			June 07			September 07			All three dates		
	GI	Mkt	Inj	GI	Mkt	Inj	GI	Mkt	Inj	GI	Mkt	Inj
Dwarf mondo												
Mondo												
Liriope 'Cleopatra'												
Liriope var.												
Blue Pacific' juniper ^z			0.5 ^y									0.5
Blue Rug' juniper				1.0		1.0	1.0			1.0		1.0
Asiatic jasmine	0.5		0.25			1.0				0.5		0.25
Dwarf yaupon	0.5	1.0	0.25	0.5		0.5				0.5	1.0	0.25
Pink Gumpo'	1.0		0.5	1.0		1.0				1.0	1.0	0.5
^z 'Blue Pacific' juniper recovered quickly after initial injury												
^y Lb ai/A of Roundup Pro [®] causing difference from control												

Table 4.2. Roundup Pro[®] rates up to 1.0 lb ai/A causing differences from controls in selected ornamentals, 2009

Growth indices (GI), marketability (Mkt), and injury (Inj) different from controls at:												
	February 09			June 08			September 08			All three dates		
	GI	Mkt	Inj	GI	Mkt	Inj	GI	Mkt	Inj	GI	Mkt	Inj
Dwarf mondo												
Mondo			1.0 ^Z							1.0		1.0
Asiatic jasmine		1.0	0.25			1.0				1.0		0.25
Dwarf yaupon	1.0		0.25									0.25
Gardenia 'H. Daisy'			1.0 ^Y			1.0						0.5
Sky Pencil' holly			0.25 ^X									0.25
Euonymus 'Colorata'			0.25			1.0						0.25
Boxwood		0.25	0.25			0.5				1.0	0.25	0.25

^Z Lb ai/A of Roundup Pro[®] causing difference from control
^Y Gardenia recovered quickly from this injury
^X Stunting was not noticeable due to growth habit of this plant