Evaluation of Container Ornamental Species Tolerance to Three *p*-hydroxyphenylpyruvate Dioxygenase-inhibiting Herbicides

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SUMMARY. Selective weed control in ornamental plant production can be difficult as many herbicides can cause unacceptable injury. Research was conducted to evaluate the tolerance of several ornamental species to applications of *p*-hydroxyphenylpyruvate dioxygenase (HPPD)-inhibiting herbicides for the control of problematic weeds in ornamental production. Mesotrione (0.09, 0.18, and 0.36 lb/acre), tembotrione (0.08, 0.16, and 0.32 lb/acre), and topramezone (0.016, 0.032, and 0.064 lb/acre) were applied alone postemergence (POST) in comparison with the photosystem II-inhibiting herbicide, bentazon (0.5 lb/acre). All herbicide treatments, with the exception of the two highest rates of tembotrione, caused less than 8% injury to 'Noble Upright' Japanese holly (*Ilex crenata*) and 'Compactus' burning bush (*Euonymus alatus*). Similarly, no herbicide treatment caused greater than 12% injury to 'Girard's Rose' azalea (*Azalea*). Conversely, all herbicides injured flowering dogwood (*Cornus florida*) 10% to 23%. Mesotrione- and tembotrione-injured 'Radrazz' rose (*Rosa*) 18% to 55%, compared with only 5% to 18% with topramezone. 'Silosam June Bug' daylily (*Hemerocallis*) injury with topramezone and tembotrione was less than 10%. Topramezone was the only herbicide evaluated that provided at least 93% control of redroot pigweed (*Amaranthus retroflexus*) with all application rates by 4 weeks after treatment (WAT). Redroot pigweed was controlled 67% to 100% with mesotrione and tembotrione by 4 WAT, but this activity was variable among application rates. Spotted spurge (*Chamaesyce maculata*) was only adequately controlled by mesotrione applications at 0.18 and 0.36 lb/acre, whereas chamberbitter (*Phyllanthus urinaria*) was not controlled sufficiently with any herbicide evaluated in these studies. Yellow nutsedge (*Cyperus esculentus*) was suppressed 72% to 87% with mesotrione applications at 0.18 lb/acre or higher and with bentazon at 0.5 lb/acre by 4 WAT. All other herbicide treatments provided less than 58% control of yellow nutsedge. In the second study, 'Patriot' hosta (*Hosta*), 'Green Sheen' pachysandra (*Pachysandra terminalis*), autumn fern (*Dryopteris erythrosora*), 'Little Princess' spirea (*Spiraea japonica*), 'Green Giant' arborvitae (*Thuja plicata*), and 'Rosea' weigela (*Weigela florida*) displayed no response to topramezone when applied at 0.024 and 0.095 lb/acre. Since 10 ornamental species in our studies exhibited less than 10% herbicidal response with all rates of at least one HPPD-inhibiting herbicide then it is possible that these herbicides may provide selective POST weed control in ornamental production systems.

Controlling weed contamination in nursery stock is difficult in ornamental production. Although cultural practices for weed control in nurseries include mulching and the use of fabrics to impede the development of emerging weeds, these techniques are not completely effective in the absence of a chemical control (Case et al., 2005; Mathers and Ozkan, 2001). Acetyl-CoA carboxylase inhibitors are effective at remedially managing grasses in dicotyledonous nursery stock (Senesac, 2002); however, selective control of broadleaf weeds in

ornamental systems is more difficult. In part, challenges derive in that both broadleaf weeds and many desirable ornamentals are both dicotyledonous species with variable sensitivity to postemergence herbicides (Case et al., 2005; Derr, 1994).

To date, there are few POST herbicides registered for selective broadleaf control in ornamental plants. These herbicides do not provide broad-spectrum broadleaf weed control in ornamental production and/or are not registered for use over the top of many ornamental species.

Mesotrione, topramezone, and tembotrione are herbicides that inhibit the HPPD enzyme. These herbicides impede the production of plastoquinone in susceptible species, ultimately preventing the production of photoprotective carotenoid compounds. As a result, the plant's ability to sequester singlet- and triplet-state oxygen and dissipate excess photosynthetic active radiation is compromised (Niyogi, 1999). Eventually foliar plant tissue becomes bleached, necrotic, and photosynthetically inactive resulting in plant death. Mesotrione, topramezone, and tembotrione are labeled for weed control in corn (*Zea mays*) and multiple turfgrass species (Elmore et al., 2011; Gettys and Haller, 2009). Weeds controlled by these herbicides include (but are not limited to) common cocklebur (*Xanthium strumarium*), common lambsquarters (*Chenopodium album*), smartweed species (*Polygonum* sp.), common ragweed (*Ambrosia artemisiifolia*), yellow nutsedge, nimblewill (*Muhlenbergia schreberi*), and crabgrass (*Digitaria* sp.) (Beam et al., 2006; Giese et al., 2005; Jones and Christians, 2007; Senseman, 2007; Willis et al., 2006).

Several researchers have reported moderate injury (<45%) to burning bush, vinca (*Vinca* sp.), and loblolly pine (*Pinus taeda*) with mesotrione applications (Jackson et al., 2009; Little et al., 2004; Senesac and Tsontakis-Bradley, 2007). Other researchers (Vea and Palmer, 2010) showed that mesotrione applications caused unacceptable phytotoxicity to over 20 ornamental plant species. However, data describing ornamental tolerance to topramezone and tembotrione are minimal. Thus, our objective was to determine ornamental tolerance and weed control efficacy with applications of the HPPD-inhibiting herbicides mesotrione, tembotrione, and topramezone compared with bentazon, an important ornamental herbicide on common ornamental plant and weed species in Tennessee.

Materials and methods

SITE DESCRIPTION. Two studies were conducted in a shadehouse structure at the University of Tennessee (Knoxville, lat. 35.9465°N, long. 83.9386°W) evaluating ornamental tolerance and weed control efficacy with mesotrione, tembotrione, and

topramezone compared with the commercial standard bentazon. Study 1 was conducted from 3 July 2008 until 3 Aug. and then repeated from 4 Aug. until 4 Sept. Maximum/minimum air temperature during this period averaged 88/66 °F and accumulated growing degree days during this time was 848 (base temperature 50 °F). Study 2 was conducted from 2 Aug. 2009 until 16 Sept. 2009 and repeated from 9 Aug. until 23 Sept. Maximum/minimum air temperature during this time was 84/64 °F and accumulated growing degree days during this time was 866 (base temperature 50 °F).

STUDY 1. The ornamental species were chosen for these studies based on their value to the nursery industry in Tennessee (Jackson et al., 2008; Johnson et al., 1976; Smith and McConnel, 1978). For the first study, ornamental species included trade-grown ‘Siloam June Bug’ daylily, ‘Girard’s Rose’ azalea, and Knock Out™ ‘Radrazz’ rose, as well as plants propagated on campus including flowering dogwood seedlings, ‘Compactus’ burning bush and ‘Noble Upright’ japanese holly from rooted cuttings. Redroot pigweed, chamberbitter, spotted spurge, and yellow nutsedge were also included in this study as they are problematic weeds of ornamental production (Atland et al., 2003; Gilliam et al., 1990; Norcini and Stamps, 1994). A 1/4-teaspoon was filled with weed seeds of a specific species and the seeds were dispersed

equidistant from one another. All weed species in this first study were established from seed in 1-gal blow-molded containers (Nursery Supplies, Chambersburg, PA). Weeds were treated with herbicides 6 weeks after seeding.

All ornamental and weed species were treated with the HPPD-inhibitors mesotrione (Tenacity®; Syngenta Professional Products, Greensboro, NC), tembotrione (Laudis®; Bayer Crop Science, Research Triangle Park, NC), and topramezone (Impact®; Amvac Chemical Corp., Los Angeles, CA). Three rates of mesotrione (0.09, 0.18, and 0.36 lb/acre), tembotrione (0.08, 0.16, and 0.32 lb/acre), and topramezone (0.016, 0.032, and 0.064 lb/acre) were applied. These rates encompassed the labeled rate ranges in pounds of active ingredient per acre for topramezone, tembotrione, and mesotrione in corn and fine turf. For comparison, bentazon was also applied at 0.5 lb/acre a.i. In all studies, herbicide treatments included crop oil concentrate (Agridex; Helena Chemical Corp., Memphis, TN) at 1% v/v. Treatments were applied with a water carrier using a carbon dioxide-powered backpack sprayer calibrated to deliver 23 gal/acre. A four-nozzle boom with 8002 flat fan nozzles (TeeJet; Spraying Systems Corp., Wheaton, IL) spaced 18 inches apart was pressurized at 60 psi to deliver the spray solution. Irrigation was withheld for 24 h following all herbicide treatments.

STUDY 2. Topramezone is the first pyrazolone herbicide that has the potential to be labeled in ornamental production (Senseman, 2007). Thus, a second study was conducted to generate additional data on ornamental tolerance to topramezone applications. Ornamental species in the second study consisted of kousa dogwood (*Cornus kousa*) seedlings and ‘Lynwood Gold’ border forsythia (*Forsythia × intermedia*), ‘Scarlet Curls’ hankow willow (*Salix matsudana*),

‘Dark Knight’ butterfly bush (*Buddleia davidii*), and ‘Green Sheen’ pachysandra plants that were propagated on campus from rooted cuttings, as well as trade-grown, 1-gal containerized ‘Patriot’ hosta, autumn fern, ‘May Night’ salvia (*Salvia officinalis*), ‘Little Princess’ spirea, ‘Green Giant’ arborvitae, and ‘Rosea’ weigela in 3-gal nursery containers.

The application equipment used in Study 2 was the same as was used in Study 1. In the second study, topramezone was evaluated POST at 0.024 and 0.095 lb/acre alone in comparison with bentazon at 1.0 lb/acre. To better characterize topramezone tolerance for ornamental plant production, a larger number of species were accessed in the second experiment with a higher rate of topramezone than was applied in the first experiment.

PLANT PROPGATION. For both studies, propagated plant materials were maintained in a greenhouse during Spring 2008 and 2009. Mean greenhouse air temperatures during the 1-month propagation period was 68 °F. Irrigation was supplied by mist at 8 s on duration with 10-min intervals from 0800 to 2000 HR. Once rooted, ornamental plants were transplanted from propagation trays and grown in a shadehouse for an additional 2 months in separate 1-gal blow-molded containers (Nursery Supplies) filled with 100% aged pine bark media with fines (Smith Garden Products, Cumming, GA). Particle size distribution of the soilless substrate was not recorded. No sand or micronutrients were added at time of transplanting, but 1 week before herbicide treatment, all containers were fertilized with the low label rate (8 g per 1-gal container, 23 g per 3-gal container) of 14N–6.1P–11.6K controlled-release fertilizer (Osmocote Classic 14–14–14, 3 to 4-month release rate; Everris International, Geldermalsen, The Netherlands). Overhead irrigation to container plants was supplied to

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To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg·ha ⁻¹	0.8922
28.3495	oz	g	0.0353
6.8948	psi	kPa	0.1450
4.9289	teaspoon	cm ³	0.2029
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

maintain active growth by hand during the duration of the study.

Ornamental plant injury was visually assessed 2 and 4 WAT. Injury was visually assessed in both studies using a 0% (i.e., no injury) to 100% (i.e., no healthy tissue visible/complete necrosis) scale relative to a nontreated control. Greater than 10% injury to the ornamental plant may be undesirable for immediate sale of the plant and would be considered undesirable injury in an ornamental landscape. Weed control for each species was assessed at 4 WAT using a similar 0% to 100% scale relative to a nontreated control. Greater than 80% weed control may be considered acceptable. At 4 WAT all above-ground vegetation for each weed species was removed from the pine bark and oven-dried at 262 °F for 48 h then weighed in Study 1.

All studies were designed as randomized complete blocks with three replications and repeated in time. Arcsine transformations were performed on visual ratings before analysis of variance using mixed model methodology in SAS (version 9.2; SAS Institute, Cary, NC). Herbicide treatment was considered a fixed effect, while replication was considered random. The Shapiro-Wilk diagnostic value of normality assessments of nontransformed means was acceptable and interpretations of arcsine and nontransformed data did not differ. Therefore, nontransformed means are presented for clarity. Treatment means in each study were separated

using Fisher's protected least significant difference test ($\alpha = 0.05$). Data were pooled across experimental runs when no run-by-treatment interactions occurred.

Results and discussion

STUDY 1. Ornamental plant injury varied because of herbicide treatment in the first study (Table 1). Mesotrione injured daylily 3% to 27% by 2 WAT with up to 10% injury still visible by 4 WAT. Azalea and burning bush were injured 2% to 8% from mesotrione applications by 2 WAT, but this response was not visible by 4 WAT. Japanese holly was never injured greater than 5% by any mesotrione treatment. Applications of mesotrione resulted in unacceptable injury to flowering dogwood and rose. Applying mesotrione at 0.36 lb/acre resulted in 55% injury to rose, which was the most observed on any ornamental species in these studies. Veal and Palmer (2010) had previously reported that applications of mesotrione was injurious to many ornamental plants evaluated in their study, thus the injury observed to rose in this study was not surprising.

With the exception of flowering dogwood and rose, application of tembotrione at 0.08 lb/acre resulted in minimal injury (0% to 8%) to all ornamentals in the first experiment (Table 1). Flowering dogwood and rose injury ranged from 10% to 33% regardless of tembotrione rate. Few differences in injury were detected by increasing the application rate of

tembotrione to 0.32 lb/acre; however, this increase in application rate did result in 10% to 20% injury to burning bush, azalea, and daylily by 4 WAT.

Topramezone at all rates resulted in less than 8% injury to daylily, burning bush, and Japanese holly in the first study (Table 1). No differences in azalea injury were detected between topramezone rates; injury ranged from 5% to 12% by 4 WAT. Topramezone was the safest HPPD-inhibiting herbicide evaluated on flowering dogwood and roses; however, 17% to 20% injury was still observed with the highest rate evaluated by 4 WAT. Topramezone is in the pyrazolone family, whereas mesotrione and tembotrione are in the triketone family. Structural differences between pyrazolone and triketone herbicides likely impact uptake, translocation, metabolism, or binding at the herbicide target site differently for multiple species. Previous research indicates that tolerance to HPPD-inhibiting herbicides is a function of both herbicide metabolism and a decreased affinity of the herbicide to the HPPD enzymes in tolerant plants (Grossman and Ehrhardt, 2007). Therefore, a different spectrum of ornamental plants might be more tolerant to topramezone than was observed with mesotrione and tembotrione.

STUDY 2. In the second topramezone specific study, hosta, pachysandra, autumn fern, spirea, arborvitae, and weigela displayed no response to topramezone when applied at 0.024 and 0.095 lb/acre by 4 WAT (Table 2).

Table 1. Effects of herbicide treatment on tolerance to six ornamental plant species in a shadehouse study at Knoxville, TN in 2008.

		Ornamental injury (%) ^y											
		Daylily		Burning bush		Azalea		Japanese holly		Flowering dogwood		Rose	
Treatment	Rate (lb/acre) ^z	Weeks after treatment											
		2	4	2	4	2	4	2	4	2	4	2	4
Mesotrione	0.090	12	3	2	0	8	0	3	0	13	17	37	23
Mesotrione	0.180	27	10	2	0	3	0	5	3	10	18	37	35
Mesotrione	0.360	3	2	2	0	2	0	3	5	10	8	23	55
Topramezone	0.016	0	2	3	7	7	5	3	0	10	20	15	5
Topramezone	0.032	3	0	5	7	5	10	3	0	13	17	8	7
Topramezone	0.064	7	2	0	7	3	12	5	0	18	20	18	17
Tembotrione	0.080	2	0	0	5	2	8	0	0	15	10	32	20
Tembotrione	0.160	0	0	2	15	3	5	5	0	10	17	23	18
Tembotrione	0.320	10	0	8	20	5	12	3	5	18	13	20	33
Bentazon	0.500	0	0	5	8	0	0	0	0	10	10	42	3
LSD _{0.05} ^x		7	6	6	9	5	7	6	3	8	13	11	13

^z1 lb/acre = 1.1209 kg/ha⁻¹.

^yInjury was evaluated visually on a 0% (no injury) to 100% (complete necrosis) scale relative to a nontreated control for each species.

^xFisher's least significant difference (LSD) at $\alpha = 0.05$.

Table 2. Effects of herbicide treatment on tolerance to 11 ornamental plant species 4 weeks after treatment in a shadehouse study at Knoxville, TN in 2009.

Treatment	Rate (lb/acre) ^y	Ornamental injury (%) ^y									
		Border forsythia	Hankow willow	Butterfly bush	Hosta	Pachysandra	Autumn fern	Salvia	Kousa dogwood	Spiraea	Arborvitae
Topramezone	0.024	13	39	40	0	0	0	29	12	0	0
Topramezone	0.095	17	36	56	0	0	0	52	20	0	0
Bentazon	1.000	8	60	45	0	0	0	20	14	0	0
LSD ^x	9		19	20	0	0	0	15	19	0	0

^x1 lb/acre = 1.1209 kg·ha⁻¹.^yInjury was evaluated visually on a 0% (no injury) to 100% (complete necrosis) scale relative to the nontreated control.^zFisher's least significant difference (LSD) at $\alpha = 0.05$.

Salvia, hankow willow, and butterfly bush were all substantially injured (29% to 56%) by these topramezone treatments 4 WAT. Border forsythia and kousa dogwoods treated with topramezone at 0.024 and 0.095 lb/acre were injured $\approx$ 12% to 20% with no differences detected between application rates. Across all species evaluated in the second study, injury with topramezone at 0.024 lb/acre was less than the commercial standard bentazon at 1.0 lb/acre. Similarly, Gettys and Haller (2009) reported that 'Cocktail Whiskey' begonia (*Begonia semperflorens*), 'Sun Devil Extreme' vinca (*Catharanthus roseus*), 'Million Gold' melampodium (*Melampodium paludosum*), and 'Super Elfin' impatiens (*Impatiens walleriana*) exhibited only modest response when treated with topramezone contaminated irrigation water. In their studies, begonia was the most tolerant species followed by impatiens with the greatest response observed on vinca and melampodium.

Weed control and dry weight varied because of herbicide treatment (Table 3) in Study 1. Mesotrione and tembotrione provided 67% to 100% control of redroot pigweed across the three application rates tested (Table 3). All rates of topramezone controlled redroot pigweed 93% or greater. Responses in the current study are similar to those reported by other researchers studying mesotrione, tembotrione, and topramezone efficacy for redroot pigweed control in agronomic crops (Bollman et al., 2008; Lamore et al.,

2006; Zollinger and Ries, 2006). All rates of tembotrione, topramezone, and mesotrione at 0.09 lb/acre provided only 8% to 60% control of spotted spurge; however, when mesotrione rates were increased to 0.18 lb/acre or higher, spotted spurge was controlled at least 93%. Neither mesotrione nor tembotrione effectively controlled chamberbitter in this study and while topramezone exhibited the most activity on chamberbitter, control never exceeded 60%. Bentazon did not provide adequate control of spotted spurge, redroot pigweed, or chamberbitter but did control yellow nutsedge 78%. Similarly, mesotrione applied at 0.18 lb/acre to 0.36 lb/acre controlled yellow nutsedge 72% to 87%. This response has been reported by other researchers following bentazon or mesotrione applications for yellow nutsedge control (Armel et al., 2008; Derr and Wilcut, 1993; Fretz and Sheppard, 1979; Pereira et al., 1987; Stoller et al., 1979).

In general, dry weights of weed biomass confirmed visual weed control ratings (Table 4). Mesotrione and bentazon were the only herbicides that reduced yellow nutsedge dry weight to less than 10 g, which was 50 g less than the nontreated control. The dry weights of spotted spurge treated with mesotrione were significantly less than the nontreated spotted spurge; however, no other herbicide treatments significantly reduced the dry weight of spotted spurge. Generally, topramezone treatments reduced dry weights of redroot

Table 3. Effects of herbicide treatment on weed control in a container shadehouse study by 4 weeks after treatment at Knoxville, TN in 2008.

Treatment	Rate (lb/acre) ^z	Weed control (%) ^y			
		Yellow nutsedge	Spotted spurge	Redroot pigweed	Chamberbitter
Mesotrione	0.090	33	60	67	12
Mesotrione	0.180	87	100	100	7
Mesotrione	0.360	72	93	78	23
Topramezone	0.016	18	25	93	42
Topramezone	0.032	30	33	100	27
Topramezone	0.064	12	58	98	63
Tembotrione	0.080	10	23	78	15
Tembotrione	0.160	23	10	80	40
Tembotrione	0.320	57	8	100	17
Bentazon	0.500	78	0	0	0
LSD _{0.05} ^x		16	47	31	13

^x1 lb/acre = 1.1209 kg·ha⁻¹.^yControl was evaluated visually on a 0% (no control) to 100% (complete necrosis) scale relative to the nontreated control.^zFisher's least significant difference (LSD) at $\alpha = 0.05$.

Table 4. Effects of herbicide treatment on weed dry weight in a shadehouse study at Knoxville, TN in 2008.

Treatment	Rate (lb/acre) ^z	Weed dry wt (gram/container) ^z			
		Yellow nutsedge	Spotted spurge	Redroot pigweed	Chamberbitter
Mesotrione	0.090	43.60	0.53	1.94	0.84
Mesotrione	0.180	4.20	0	0	1.22
Mesotrione	0.360	21.44	0.11	0.45	1.48
Topramezone	0.016	67.86	1.92	0	0.55
Topramezone	0.032	39.30	1.21	0	0.33
Topramezone	0.064	78.47	1.32	0	0.75
Tembotrione	0.080	50.76	2.41	0.60	1.07
Tembotrione	0.160	46.90	2.83	0.67	1.16
Tembotrione	0.320	14.34	2.48	0	0.61
Bentazon	0.500	8.88	4.51	5.16	3.34
Non-treated control		61.95	2.01	12.45	1.96
LSD _{0.05} ^y		18.7	1.45	3.65	0.9

^z1 lb/acre = 1.1209 kg·ha⁻¹, 1 g = 0.0353 oz.

^yFisher's least significant difference (LSD) at $\alpha = 0.05$.

pigweed and chamberbitter more than the other herbicide treatments, particularly when comparing the lowest herbicide rate applications.

Conclusion

Japanese holly and daylily were tolerant to all rates of mesotrione, topramezone, and tembotrione evaluated in this study. In addition, burning bush, hosta, pachysandra, autumn fern, spirea, arborvitae, and weigela were tolerant to topramezone at rates as high as 0.095 lb/acre. Flowering dogwood, hankow willow, butterfly bush, salvia, and rose were injured by all HPPD-inhibiting herbicides evaluated in these studies. Topramezone was the only herbicide evaluated that provided at least 93% control of redroot pigweed across all rates evaluated. All HPPD-inhibitors provided poor control of chamberbitter ($\leq 63\%$) and only mesotrione applied at 0.09 lb/acre or higher provided significant activity on spotted spurge or yellow nutsedge. The commercial standard bentazon provided acceptable control of yellow nutsedge. Similar to responses reported by other researchers (Bachman et al., 1995; Derr and Appleton, 1987), bentazon was also safe (0% to 10% injury) to all ornamental plants evaluated in the first experiment with the exception of rose and was found to be safe to six additional ornamental plant species in the second study.

The damage that untreated weed infestations inflict on nurseries can exceed \$7100 per acre annually (Hall et al., 2006). Therefore, it is important

to incorporate new herbicide active ingredient in ornamental plant systems. Future research should include additional evaluations of tembotrione and topramezone on other ornamental plants and weeds of importance to the nursery and landscape industries. In addition, studies should be undertaken to understand the differential tolerance of ornamentals and weeds to HPPD-inhibitors applied in these environments.

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