Paclobutrazol, Uniconazole, or Flurprimidol Applied at Various Concentrations as a Substrate Drench or Through Subirrigation Have Little Effect on Bee Balm Growth

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SUMMARY. Summer and fall studies investigated the control of growth of bee balm (*Monarda didyma* ‘Marshall’s Delight’) by paclobutrazol, uniconazole, or flurprimidol applied to the substrate as a surface drench or through subirrigation. Flurprimidol and uniconazole were applied at 0, 0.5, 1.0, 1.5, or 2.0 ppm (0, 0.09, 0.18, 0.27, or 2.0 mg/pot), while paclobutrazol was applied at 0, 2, 4, 6, or 8 ppm (0, 0.6, 1.2, 1.8, or 2.4 mg/pot). Substrate drench applications were more effective than applications through subirrigation at reducing plant growth. Few trends in application concentrations within plant growth regulator occurred for the plant parameters measured. Based on inconsistent plant responses between the two studies and few differences among application concentrations, we do not recommend any of these plant growth regulators for controlling plant size of bee balm during production without further testing in production environments specific to bee balm.

Several plant growth regulators are labeled for use on ornamental crops; however, their effectiveness is often species- or cultivar-dependent (Barrett, 2001; Chamberlayne and Banko, 2003; Keever and Olive, 1994; Kim et al., 1999; Latimer et al., 2001). In addition to the variety of plant growth regulators available, alternative application methods are being developed and added to product labels. Subirrigation occurs when water is applied to plants by ebb-and-flood irrigation or by adding the solution to a saucer under the plant. Plant growth regulators can be added to a tank mix of water and fertilizer and then delivered to the plants using subirrigation. Effectiveness of the plant growth

regulator in reducing plant growth might be increased with subirrigation compared with foliar applications, since most plant growth regulators are absorbed by plant roots more readily than by leaves. For example, Wang et al. (1986) showed that root-applied paclobutrazol was translocated throughout apple (*Malus* sp.) seedlings grown in a continuously aerated nutrient solution, but foliar-applied paclobutrazol did not translocate to the stems or roots. Translocation of paclobutrazol from root uptake has been assumed to occur primarily through the xylem and appears to be less mobile in the phloem (Dalziel and Lawrence, 1984; Sterrett, 1985).

Chemical application concentrations are important in determining monetary costs of a given application. Less active ingredient is required

with subirrigation to achieve similar growth suppression compared with applying plant growth regulators to the foliage (Cox, 2003). Million et al. (2002) noted that plant size was reduced more when paclobutrazol was applied continuously through an ebb-and-flood system than when applied as a single application. For begonia (*Begonia* $\times$ *semperflorens-cultorum* hybrids ‘Cocktail Gin’), impatiens (*Impatiens wallerana* ‘Super Elfin White’), chrysanthemum (*Dendranthema* $\times$ *grandiflorum* ‘Tara’), and petunia (*Petunia* $\times$ *hybrida* ‘Plum Crazy’), 2.1, 4.0, 5.4, and 3.0 times higher application concentrations, respectively, were required with a single application than the cumulative amount applied by continuous application (Million et al., 2002).

The volume of solution absorbed by the plant is important in determining the appropriate application concentration of plant growth regulators. Million et al. (2002) noted that nonuniform uptake of growth regulator solution volume by the substrate can result in the need for greater application rates with a single growth regulator application to achieve the desired growth reduction compared with when growth regulators are applied in continuous applications. A small amount of leaching through the pot may occur when drenching, resulting in loss of growth regulator active ingredient. Uniconazole and paclobutrazol have limited redistribution in plants once deposited from the xylem (Early and Martin, 1988). In the same study, paclobutrazol remained in lower regions of peach (*Prunus persica*) stems after being absorbed by roots. Flurprimidol chemical structure and mode of action are similar to paclobutrazol and uniconazole, and it is effective as a substrate drench (Rademacher, 2000).

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
6.4516	inch ²	cm ²	0.1550
16.3871	inch ³	cm ³	0.0610
28.3495	oz	g	0.0353
28,350	oz	mg	3.5274 $\times 10^{-5}$
1	ppm	mg·L ⁻¹	1
3.9063	tablespoon(s)/gal	cm ³ ·L ⁻¹	0.2559
(°F - 32) $\div$ 1.8	°F	°C	(°C $\times$ 1.8) + 32

However, we found no information on flurprimidol applied through subirrigation.

Bee balm is an herbaceous perennial plant that produces scarlet-red 2- to 3-inch flowers in single or double whorls (Still, 1994). Bee balm is desired by consumers because it is colorful and attracts bees (*Apis* sp.) and hummingbirds (Trochilidae) to the landscape. Nursery producers have noted that bee balm plants tend to lack uniformity because of variable stem lengths with some being very tall and others very short (L. Marquez and L. Steffy, personal communication). Tall stems are easily broken during shipping and as plants are moved in the market, resulting in less salable plants. Application of plant growth regulators might improve plant uniformity and result in less stem breakage, resulting in a more desirable plant for consumers. Takahiro et al. (2001) treated bee balm with ethephon three times at 1000 mg·L⁻¹. Plant height was reduced by 40% in ethephon-treated plants. No other plant growth regulator research on bee balm was found.

The objectives of this research were to determine 1) the effects of substrate drench application vs. application through subirrigation of paclobutrazol, uniconazole, or flurprimidol on plant growth, and 2) the effect of amount of active ingredient applied on plant growth for each application method and growth regulator.

Materials and methods

SUMMER 2010 OUTDOOR STUDY. Commercially produced (Greenleaf Nursery Co., Park Hill, OK) rooted cuttings of bee balm were planted in 1-gal containers (173 inch³, ITML Elite 300; New Christie Ventures, Naugatuck, CT) with peat-based substrate (LC1; Sun Gro Horticulture, Bellevue, WA). Plants were allowed to establish for 4 weeks outdoors under full sun [average photosynthetic photon flux (*PPF*) of 1890 μmol·m⁻²·s⁻¹] at Claremore, OK. Daily high temperatures averaged 97 °F. The experiment began on 14 May 2010 and was ended on 18 Aug. 2010.

Paclobutrazol, uniconazole, or flurprimidol was applied as a substrate drench or through subsurface irrigation once every 2 weeks with a total of seven applications. Subsurface applications were poured into an 8-inch-

diameter plastic saucer placed under each container. Paclobutrazol was applied at 0 (control), 2, 4, 6, or 8 ppm (0, 0.6, 1.2, 1.8, or 2.4 mg/pot). Flurprimidol and uniconazole were applied at 0 (control), 0.5, 1.0, 1.5, or 2.0 ppm (0, 0.09, 0.18, 0.27, or 2.0 mg/pot). Paclobutrazol and tap water (control) were applied in aliquots of 296 mL, while flurprimidol and uniconazole were applied in aliquots of 177 mL based on suggested drench solution volumes on the product labels. On days when no plant growth regulators were applied, 300 mL of tap water was applied to all plants as a substrate drench or through subirrigation depending on application treatment. About a 10% leaching fraction occurred with substrate drench applications of tap water.

Soluble fertilizer was applied every other week at 1/2 tablespoon/gal 22N-2.2P-13.3K (Jack's Professional 22-5-16; J.R. Peters, Allentown, PA). Soluble trace elements mix (STEM; Everris International, Geldermalsen, The Netherlands) was applied monthly at 1/2 tablespoon/gal of water. All plants received 300 mL of fertilizer solution at each application. Acephate (Bonide Systemic Granules Insect Control; Bonide Products, Oriskany, NY) was applied 22 June 2010 at three tablespoons/pot for grasshopper (*Caelifera* sp.) control.

Plant height was measured from the substrate surface to the top of the tallest stem and canopy width (an average of two perpendicular measurements) was measured at initiation of the project and at harvest. Plant quality was rated on a scale of 1 to 4. A plant with a rating of 1 was considered poor quality, asymmetrical (mix of very tall and very short stems), and generally these plants were too tall for the container. A plant with a rating of 4 was considered high quality, symmetrical with dark green, healthy foliage, and a salable plant 2 weeks before market date (4 Aug. 2010). At harvest, total plant leaf area (LI-3100 area meter; LI-COR, Lincoln, NE) and stem, leaf, and root dry weights were determined.

A randomized complete block design with three growth regulators at five application concentrations and two methods of application with 10 single-pot replications was used. Data were analyzed using the GLM procedure in SAS (version 9.1; SAS Institute, Cary, NC) by plant growth regulator. Trend analyses were performed using orthogonal contrasts within each growth regulator and application method.

FALL 2010 GREENHOUSE STUDY. A study similar to the Summer 2010 study was conducted except plants were grown in a polycarbonate-covered

Table 1. Growth in height, stem, and leaf dry weight at harvest in Summer 2010 of bee balm treated with paclobutrazol as a substrate drench or subirrigation application at several concentrations (*n* = 10).

Application method	Application concn (ppm) ^z	Growth in ht (cm) ^y	Dry wt (g) ^z	
			Stem	Leaf
Substrate drench	0	22.2	4.2	4.7
	2	20.6	3.4	4.7
	4	15.0	2.2	3.7
	6	14.3	2.1	4.3
	8	9.5	1.3	2.7
	Linear	**	**	*
	Quadratic	NS	NS	NS
Subirrigation	0	21.9	4.3	5.9
	2	17.0	3.0	4.8
	4	21.8	3.0	3.8
	6	19.8	3.5	4.4
	8	22.5	4.4	5.9
	Linear	NS	NS	NS
	Quadratic	NS	**	**

NS, *, **Not significant or significant at *P* ≤ 0.05, 0.01, respectively.

^z1 ppm = 1 mg·L⁻¹, 1 g = 0.0353 oz.

^yPlant growth in height between measurement dates was calculated as *G* = *M*_H - *M*_O, where *G* = growth in height, *M*_H = measurement at harvest, and *M*_O = measurement at the beginning of the measurement interval; 1 cm = 0.3937 inch.

greenhouse (Oklahoma State University Research Greenhouses, Stillwater) with an average daily high/low temperature of 70/59 °F and average *PPF* of 1450 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. Supplemental lighting (lamps with 400-W high-pressure sodium bulbs) was added on 22 Oct. 2010 to extend the daylength from 1800 to 2200 HR. The experiment began on 1 Oct. 2010 and was ended on 31 Jan. 2011.

In addition to the plant measurements described above, number of leaves per plant was counted at harvest. Leaf area per leaf was calculated as leaf area/leaf = (total plant leaf area)/(number of leaves/plant).

Results

PACLOBUTRAZOL. Application method interacted with application

concentration for growth in height, stem, and leaf dry weight ($P \leq 0.001$, $P = 0.002$, and $P = 0.0175$, respectively) at harvest during Summer 2010. Growth in height, stem, and leaf dry weight of plants receiving paclobutrazol as a substrate drench decreased linearly as application concentration increased (Table 1). In contrast, growth in height was unaffected by paclobutrazol applied in subirrigation. Stem and leaf dry weight decreased as application concentration increased to 4 ppm then increased at higher application concentrations when paclobutrazol was applied in subirrigation in Summer 2010.

In contrast, application method did not interact with application concentration for growth in width during

Summer or Fall 2010 or for stem dry weight, number of leaves, or total plant leaf area at harvest during Fall 2010. Plants receiving a substrate drench of paclobutrazol grew less in width during both years than those receiving paclobutrazol in subirrigation (Table 2). Likewise, at harvest, stem dry weight, number of leaves, and total plant leaf area were smaller with the substrate drench than with subirrigation. Growth in width decreased linearly as paclobutrazol application concentration increased in both summer and fall.

UNICONAZOLE. No interaction occurred between application method and application concentration for any parameter measured. Plants receiving uniconazole as a substrate drench grew less in width in summer and fall

Table 2. Growth in width in Summer 2010 and growth in width, stem dry weight, number of leaves per plant, and total plant leaf area at harvest in Fall 2010 of bee balm treated with paclobutrazol as a substrate drench or subirrigation application in Summer 2010 ($n = 50$ for the application method main effect, $n = 20$ for the application concentration main effect).

Variable	Summer 2010	Fall 2010			
	Growth in plant width (cm) ^z	Growth in plant width (cm)	Stem dry wt (g) ^y	Leaves (no.)	Leaf area (cm ²) ^y
<i>Application method main effect</i>					
Substrate drench	6.5	11.4	0.3	125	115.1
Subirrigation	10.4	13.4	0.5	177	221.0
Significance (F-test)	**	*	**	*	***
<i>Application concentration (ppm) main effect^y</i>					
0	10.8	14.8	0.4	148	211.8
2	8.5	12.5	0.5	165	202.0
4	9.6	12.4	0.4	153	163.5
6	7.0	11.1	0.3	133	116.0
8	6.4	11.2	0.4	164	159.2
Linear	*	*	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS

NS, *, **Not significant or significant at $P \leq 0.05$, 0.01, respectively.

^zPlant growth in width between measurement dates was calculated as $G = M_H - M_O$, where G = growth in width, M_H = measurement at harvest, and M_O = measurement at the beginning of the measurement interval; 1 cm = 0.3937 inch.

^y1 g = 0.0353 oz, 1 cm² = 0.1550 inch², 1 ppm = 1 mg·L⁻¹.

Table 3. Growth in plant width in Summer and Fall 2010, stem and leaf dry weight, number of leaves, total plant leaf area, and visual ratings at harvest in Fall 2010 of bee balm plants treated with uniconazole as a substrate drench or subirrigation application ($n = 50$).

	Summer 2010	Fall 2010				
Application method	Growth in plant width (cm) ^z	Growth in plant width (cm)	Leaf dry wt (g) ^y	Leaves (no.)	Leaf area (cm ²) ^y	Visual rating (1–4 scale) ^x
<i>Application method main effect</i>						
Substrate drench	7.9	12.4	0.8	123	146.4	1.6
Subirrigation	11.4	15.0	1.3	206	259.2	2.0
Significance (F-test)	**	*	**	***	**	**

NS, *, **, ***Not significant or significant at $P \leq 0.05$, 0.01, 0.001, respectively.

^zPlant growth in height and width between measurement dates was calculated as $G = M_H - M_O$, where G = growth, M_H = measurement at harvest, and M_O = measurement at the beginning of the measurement interval for height or plant width; 1 cm = 0.3937 inch.

^y1 g = 0.0353 oz, 1 cm² = 0.1550 inch².

^xPlant quality was rated on a scale of 1 to 4 with 4 being a symmetrical plant in good proportion to the pot size and with dark green, healthy foliage; whereas, a plant with a rating of 1 was considered poor quality because the plant was asymmetrical due to some very tall stems and other very short stems.

than plants receiving uniconazole in subirrigation (Table 3). At harvest in the fall, leaf dry weight, number of leaves, and leaf area were lower when uniconazole was applied as a substrate drench than when it was applied in subirrigation. Plants receiving uniconazole as a substrate drench had

a lower visual rating compared with plants receiving uniconazole through subirrigation. Uniconazole application concentration did not affect any parameter measured (data not presented).

FLURPRIMIDOL. Application method interacted with application

concentration for plant growth in height ($P = 0.0018$) and stem dry weight at harvest ($P = 0.0186$) in the summer. Plants receiving flurprimidol as a substrate drench decreased linearly in growth in height and stem dry weight at harvest; whereas, no trends occurred for growth in height or stem dry weight at harvest when flurprimidol was applied in subirrigation (Table 4). No interaction between application method and concentration occurred for growth in plant width or leaf dry weight at harvest during the summer or for plant growth in width, stem or leaf dry weight, number of leaves, total plant leaf area, or visual rating in the fall. Plants receiving flurprimidol as a substrate drench grew less in width and had a lower leaf dry weight than those receiving flurprimidol in subirrigation in summer (Table 5). Likewise, in the fall, growth in plant width, stem and leaf dry weight, number of leaves, and plant leaf area were lower for plants receiving flurprimidol as a substrate drench than those that were subirrigated. The visual rating of plants receiving a substrate drench were lower than those of plants receiving subirrigation. No phytotoxicity symptoms were noted on plants treated with any plant growth regulator. Growth in plant width in summer and fall and leaf

Table 4. Growth in height and stem dry weight at harvest of bee balm treated with flurprimidol as a substrate drench or subirrigation application at several concentrations in Summer 2010 ($n = 10$).

Application method	Application concn (ppm) ^z	Growth in ht (cm) ^y	Stem dry wt (g) ^z
Substrate drench	0	22.2	4.2
	0.5	18.1	2.7
	1.0	13.6	2.1
	1.5	12.1	1.5
	2.0	7.5	1.3
	Linear	**	**
	Quadratic	NS	NS
Subirrigation	0	21.9	4.3
	0.5	24.6	4.3
	1.0	19.5	3.7
	1.5	20.6	4.0
	2.0	19.2	3.4
	Linear	NS	NS
	Quadratic	NS	NS

NS, **Not significant or significant at $P \leq 0.01$, respectively.

^z1 ppm = 1 mg·L⁻¹, 1 g = 0.0353 oz.

^yPlant growth in height between measurement dates was calculated as $G = M_H - M_O$, where G = growth in height, M_H = measurement at harvest, and M_O = measurement at the beginning of the measurement interval; 1 cm = 0.3937 inch.

Table 5. Growth in plant width and leaf dry weight at harvest in Summer 2010 and growth in plant width, and stem and leaf dry weight, number of leaves, total plant leaf area, and visual ratings at harvest in Fall 2010 of bee balm plants treated with flurprimidol as a substrate drench or subirrigation application ($n = 50$ for the application method main effect, $n = 20$ for the application concentration main effect).

	Summer 2010		Fall 2010					
Variable	Growth in plant width (cm) ^z	Leaf dry wt (g) ^y	Growth in plant width (cm)	Dry wt (g) ^y		Leaves (no.)	Leaf area (cm ²) ^y	Visual rating (1–4 scale) ^x
				Stem	Leaf			
<i>Application method main effect</i>								
Substrate drench	5.9	3.8	0.7	0.3	0.6	110	106.8	1.5
Subirrigation	8.6	5.3	3.9	0.4	1.2	184	212.4	1.9
Significance (F-test)	**	**	**	*	***	**	***	**
<i>Application concentration (ppm) main effect^z</i>								
0	10.8	5.3	4.8	0.4	1.0	148	211.8	1.8
0.5	8.2	5.1	4.5	0.4	0.9	136	156.3	1.7
1.0	7.9	4.4	0.0	0.4	0.9	132	163.3	1.9
1.5	5.9	4.4	2.3	0.5	1.2	193	195.3	1.7
2.0	3.3	3.4	0.4	0.3	0.6	145	103.1	1.4
Linear	***	*	**	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS

NS, *, **, ***Not significant or significant at $P \leq 0.05$, 0.01, 0.001, respectively.

^zPlant growth in height and width between measurement dates was calculated as $G = M_H - M_O$, where G = growth, M_H = measurement at harvest, and M_O = measurement at the beginning of the measurement interval for height or plant width; 1 cm = 0.3937 inch.

^y1 g = 0.0353 oz, 1 cm² = 0.1550 inch², 1 ppm = 1 mg·L⁻¹.

^xPlant quality was rated on a scale of 1 to 4 with 4 being a symmetrical plant in good proportion to the pot size and with dark green, healthy foliage; whereas, a plant with a rating of 1 was considered poor quality because the plant was asymmetrical due to some very tall stems and other very short stems.

dry weight at harvest in the summer decreased linearly as application concentration increased. No other measurement parameters were affected by application concentration of flurprimidol.

Discussion

Surface drench applications were more effective at reducing several plant growth parameters measured than application through subirrigation for all of the plant growth regulators tested. Though unlikely, this may be explained by the potential for surface applications to compact the substrate due to the impact of water droplets on the substrate surface. Compaction of the substrate reduces air space (Milks et al., 1989) and may result in reduced plant growth. In contrast, subirrigation eliminates the impact of water droplets on the substrate surface by allowing the substrate to absorb moisture from below the container. A second, more likely explanation for greater growth reduction with substrate drenches is that the plant growth regulators may be more evenly distributed through the substrate and readily available for root uptake than with subsurface irrigation because it is applied to the top of the substrate and flows through the substrate due to gravity. It is possible that with subirrigation, the plant growth regulators carried by the water remained at the bottom of the substrate rather than being distributed throughout the substrate, thus limiting root exposure and uptake.

Plant growth regulators tested in this study reduced some measured plant parameters, but none of the plant growth regulators consistently reduced plant growth. Plant quality ratings were low regardless of treatment suggesting that none of the plant growth regulators improved plant quality by improving plant uniformity. Paclobutrazol and flurprimidol were more consistently effective

than uniconazole at controlling growth of bee balm. Substrate drench generally was more effective than subirrigation application of growth regulators. However, plant quality for plants treated with uniconazole or flurprimidol was slightly better when subirrigated than drenched. Slight differences in results between the two experiments may be attributed to different environmental conditions such as shorter daylengths and cooler temperatures in the fall experiment. Based on inconsistent plant responses between the two studies and few differences among application concentrations, we do not recommend any of these plant growth regulators for controlling plant size of bee balm during production without further testing under the specific growing conditions of the producer.

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