Efficacy of Plant Growth Regulators on the Growth of Vigorous *Osteospermum* Cultivars

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SUMMARY. Vigorous *osteospermum* (*Osteospermum ecklonis*) cultivars Congo and Wildside received foliar sprays of daminozide or daminozide + chlormequat (Expt. 1). Both cultivars responded similarly to the plant growth regulator (PGR) treatments. Only a limited amount of plant height control occurred using 5,000 mg·L⁻¹ (ppm) daminozide + 1,500 mg·L⁻¹ chlormequat or 5,000 mg·L⁻¹ daminozide + 3,000 mg·L⁻¹ chlormequat. Flowering was delayed, phytotoxicity was observed, while peduncle length increased, suggesting that higher concentrations of daminozide or chlormequat may or not be effective at any concentration and may result in increased phytotoxicity. In Expt. 2, 'Lusaka' received foliar sprays or substrate drenches of paclobutrazol or uniconazole. Foliar sprays ≤80 mg·L⁻¹ paclobutrazol or ≤24 mg·L⁻¹ uniconazole were ineffective in controlling plant growth. Substrate drenches of paclobutrazol (a.i.) at 8 to 16 mg/pot (28,350 mg = 1.0 oz) produced compact plants, but at a cost of \$0.23 and \$0.46/pot, respectively, would not be economi-

cally feasible for wholesale producers to use. Uniconazole drenches were effective in producing compact 'Lusaka' *osteospermum* plants. Uniconazole drench concentrations of 0.125 to 0.25 mg/pot were recommended for retail growers, while wholesale growers that desire more compact plants should apply a 0.25 to 0.5 mg/pot drench. Applying uniconazole would cost \$0.06 for a 0.25 mg drench or \$0.12 for a 0.5 mg drench.

Vegetative *osteospermum* cultivars have significant potential for southeastern U.S. ornamental plant growers. Because of its ability to perform well under cool temperatures, *osteospermum* can be marketed as a late winter and early spring annual in the southern U.S. Because they grow vigorously, vegetative *osteospermum* present a challenge to growers in maintaining short and robust plants.

Plant growth regulators (PGRs) are commonly applied to container-grown plants to limit stem elongation and produce compact plants (Tayama et al., 1992). Current PGR recommendations for height control of *osteospermum* include two or more chlormequat (Cycocel; Olympic Horticultural Products, Mainland, Pa.) foliar sprays of 750 mg·L⁻¹ or a single substrate drench between 1,500 to 3,000 mg·L⁻¹ (D. Hartley, personal communication). Olsen and Anderson (1995a) reported foliar applications of uniconazole (Sumagic; Valent, USA, Marysville, Ohio) at 8 mg·L⁻¹ or flurprimidol (Cutless; Dow AgroSciences, Indianapolis, Ind.) at 45 mg·L⁻¹ were the most effective at controlling growth of the prostrate-growing cultivar Calypso. They also reported that paclobutrazol (Bonzi; Uniroyal Chemical, Middlebury, Conn.) was ineffective at controlling *osteospermum* growth at concentrations as high as 32 mg·L⁻¹. Daminozide (B-Nine; Uniroyal Chemical) was ineffective at rates as high as 4,180 mg·L⁻¹, which also produced phytotoxic symptoms.

While PGR effects were determined on the prostrate-growing 'Calypso' (Olsen and Anderson, 1995a), many vegetatively propagated *osteospermum* cultivars have vigorous, upright growth habits that require multiple foliar PGR sprays. Sub-

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strate drenches are alternatives to foliar sprays and have shown greater control of plant growth on chrysanthemum (*Dendranthema × grandiflorum*), easter lily (*Lilium longiflorum*), and poinsettia (*Euphorbia pulcherrima*) (Tayama et al., 1992). The objective was to determine optimal foliar spray and substrate drench concentrations for upright-growing osteospermum plants.

Materials and methods

EXPT. 1. Osteospermum ‘Congo’ and ‘Wildside’ rooted cuttings from 3.5 × 3.8 cm (1.4 × 1.5 inch) cells were transplanted two per pot into 2.54-L (0.671-gal) (19.0-cm [7.5-inch-diameter]) round plastic containers on 9 Jan. 1999. The root substrate was Fafard 4-P (Fafard, Anderson, S.C.), which contained 4 sphagnum peat : 2 pine bark : 2 vermiculite : 1 perlite (by volume). Plants were fertilized at each irrigation with 100 mg·L⁻¹ nitrogen (N) using 20N-4.4P-16.6K (Peters 20-10-20; Scotts, Marysville, Ohio). After 14 d plant roots reached the edge of the container and fertility was increased to 200 mg·L⁻¹ N with each irrigation. Osteospermum plants were grown under natural daylengths for 2 weeks with greenhouse day/night setpoint temperatures of 18.3/15.6 °C (65/60 °F) and then plants were pinched to six nodes. After pinching, day/night temperatures were changed to 15.6/12.8 °C (60/55 °F) for flower bud initiation. Nine PGR foliar sprays: daminozide at 2500, 5000, 5000 ap-

plied twice, 7500, or 10000 mg·L⁻¹ and a combination of daminozide at 2500 or 5000 mg·L⁻¹ + chlormequat at 1500 or 3000 mg·L⁻¹ were applied 40 d after potting at a volume of 204 mL·m⁻² (0.5 gal/100 ft²). An untreated control was included. The experimental design was a randomized complete-block with five single-plant replications for each of the 10 treatments. When plants had three flowers reaching anthesis, days to anthesis from potting, total plant height (measured from the pot rim to the highest point), canopy height (measured from the pot rim to the top of the foliage), plant diameter (measured at the widest dimension and turned 90°, and averaged), and flower and bud number were recorded. Peduncle length was calculated by subtracting canopy height from total plant height.

Data were tested by analysis of variance by general linear model (SAS Inst., Cary, N.C.). Means were separated by least significant differences (LSD) at $P \leq 0.05$.

EXPT. 2. The same procedures used in Expt. 1 were repeated in Expt. 2, except as noted. Osteospermum ‘Lusaka’ rooted cuttings were transplanted on 30 Nov. 1999. Plants were pinched at the sixth node and subjected to night temperatures of 12.8 °C commencing on 14 Dec. Eight PGR foliar sprays, which included uniconazole at 3, 6, 12, or 24 mg·L⁻¹ and paclobutrazol at 10, 20, 40, or 80 mg·L⁻¹ were applied 43 d after potting at a volume of 204 mL·m⁻². Eight

PGR drench treatments which included paclobutrazol at 2, 4, 8, or 16 mg (a.i.)/pot and uniconazole at 0.125, 0.25, 0.5, 1, or 2 mg (a.i.)/pot were applied 43 d after potting using a volume of 300 mL (10.1 fl oz) of solution per pot. An untreated control was included. The experimental design was a randomized complete-block with five single-plant replications in each of the 17 treatments. Data were recorded when flowers reached anthesis. Neither the number of flowers nor buds were recorded.

Data were tested by analysis of variance by general linear model (SAS Inst.). Means were separated by LSD at $P \leq 0.05$. Total height, canopy height, and diameter values were regressed using the PROC REG procedure (SAS Inst.) to determine the best fit linear or quadratic model for PGR (paclobutrazol or uniconazole) substrate drenches. Terms of the model were judged to be significant or nonsignificant and included in the final model based on a comparison of F values at $P \leq 0.05$.

Results and discussion

Expt. 1

PLANT GROWTH. Both ‘Congo’ and ‘Wildside’ responded similarly to the PGR treatments. Therefore, only main effects were presented (Table 1). Concentrations of daminozide of up to 10,000 mg·L⁻¹ were ineffective in controlling plant height of osteospermum. Phytotoxicity did not occur with the daminozide treatments

Table 1. Effect of daminozide and chlormequat as a foliar spray on growth of osteospermum (Expt. 1).

Treatment (mg·L ⁻¹) ^z	Plant ht (cm) ^y	Canopy ht (cm)	Plant diam (cm)	Days to anthesis ^x	Flower buds (no.)	Peduncle length (cm)
Untreated control	37.9	29.2	53.7	93	51.8	8.7
2,500 daminozide	37.6	26.6	52.5	96	46.9	11.0
5,000 daminozide	36.7	24.3	55.2	99	59.3	12.4
5,000 daminozide, applied twice ^w	38.6	26.2	53.8	100	61.8	12.4
7,500 daminozide	40.9	26.4	55.6	99	58.9	14.5
10,000 daminozide	39.2	27.0	56.6	98	59.7	12.1
2,500 daminozide + 1,500 chlormequat	36.3	24.7	50.3	98	58.9	11.6
2,500 daminozide + 3,000 chlormequat	35.6	24.0	52.2	99	58.0	11.6
5,000 daminozide + 1,500 chlormequat	35.2	24.2	51.6	99	63.3	11.0
5,000 daminozide + 3,000 chlormequat	34.8	22.7	50.4	101	64.6	12.1
Significance	***	***	**	***	*	**
LSD ($P \leq 0.05$)	2.4	1.6	3.4	1.7	10.5	2.3

^z1 mg·L⁻¹ = 1 ppm.

^y2.54 cm = 1.0 inch.

^xDays from potting to anthesis.

^wThe second daminozide foliar spray applied 14 d after the first.

***, **, *Significant at the $P \leq 0.001$, 0.01, 0.05, respectively.

Fig. 1. Paclobutrazol substrate drench effects on growth of 'Lusaka' osteospermum (Expt. 2). Regression lines were generated from the best-fit model, and points are means for each treatment ($n = 5$). ***Significant at $P \leq 0.05$ or 0.01 , respectively; L = linear, Q = quadratic. (A) Plant height, adjusted $r^2 = 0.24$. (B) Plant canopy height, adjusted $r^2 = 0.17$. (C) Plant diameter, adjusted $r^2 = 0.34$. Substrate drench concentrations are expressed as milligrams of active ingredient per pot; 28,350 mg = 1.0 oz. 2.54 cm = 1.0 inch.

Fig. 2. Uniconazole substrate drench effects on growth of 'Lusaka' osteospermum (Expt. 2). Regression lines were generated from the best-fit model, and points are means for each treatment ($n = 5$). ***Significant at $P \leq 0.001$; L = linear, Q = quadratic. (A) Plant height, adjusted $r^2 = 0.67$. (B) Plant canopy height, adjusted $r^2 = 0.83$. (C) Plant diameter, adjusted $r^2 = 0.81$. Substrate drench concentrations are expressed as milligrams of active ingredient per pot; 28,350 mg = 1.0 oz. 2.54 cm = 1.0 inch.

$\leq 10,000 \text{ mg}\cdot\text{L}^{-1}$, which is in contrast to reports by Olsen and Anderson (1995b) where $4,180 \text{ mg}\cdot\text{L}^{-1}$ was reported to cause phytotoxicity. Treatments with chlormequat at concentrations $\geq 1,500 \text{ mg}\cdot\text{L}^{-1}$ caused chlorosis on the margins of the lower leaves. Plant height was significantly shorter using $5,000 \text{ mg}\cdot\text{L}^{-1}$ daminozide + $1,500 \text{ mg}\cdot\text{L}^{-1}$ chlormequat or $5,000 \text{ mg}\cdot\text{L}^{-1}$ daminozide + $3,000 \text{ mg}\cdot\text{L}^{-1}$ chlormequat, when compared to the control (Table 1). We infer from the results that higher foliar applications of daminozide or daminozide + chlormequat may or may not give additional control and may result in increased phytotoxicity.

Canopy height was 23% shorter when osteospermum plants were sprayed with the highest concentration of daminozide + chlormequat, when compared to the untreated control. Canopy height was 15% to 18% shorter when plants were sprayed with all other daminozide + chlormequat concentrations. Similar results (17% shorter plants) occurred with the $5,000 \text{ mg}\cdot\text{L}^{-1}$ single foliar spray of daminozide, as it provided greater control than single sprays of $7,500$ or $10,000 \text{ mg}\cdot\text{L}^{-1}$, or when treated with $5,000 \text{ mg}\cdot\text{L}^{-1}$ twice. It is unclear why these results were inconsistent.

Although $2,500 \text{ mg}\cdot\text{L}^{-1}$ daminozide + $1,500 \text{ mg}\cdot\text{L}^{-1}$ chlormequat resulted in a smaller diameter plant than the control, a 6% smaller diameter would not be practically significant. Therefore, daminozide or daminozide + chlormequat did not effectively control plant diameter. Concentrations $\geq 10,000 \text{ mg}\cdot\text{L}^{-1}$ daminozide or higher concentrations of daminozide + chlormequat may or may not be effective at limiting horizontal expansion of vigorous osteospermum plants.

FLOWERING DATA. The use of daminozide or daminozide + chlormequat delayed flowering of osteospermum when compared to the control. Nontreated osteospermum plants flowered 8 d earlier than plants treated with the highest tank mix concentration (Table 1). The delay in flowering may account for lack of differences in height control among the treatments, because additional stretch of the peduncle occurred before bloom in the PGR-treated plants (Table 1).

Although more flower buds were observed on plants treated with the highest tank mix concentrations (Table

1), the additional time until anthesis would not be commercially desirable.

For wholesale growers who ship osteospermum on carts, peduncle stretch is undesirable. Growers desire flower buds close to the vegetation to avoid damage to the flower stems and flower heads during shipping. Peduncle length was longer when plants were treated with daminozide or daminozide + chlormequat, when compared to the control (Table 1). The occurrence of increased peduncle length may be attributed to the delay in flowering due to the daminozide or chlormequat or that the chemical efficacy of daminozide or chlormequat diminished late in the crop cycle, and subsequently peduncles elongated.

Expt. 2

PACLOBUTRAZOL AND UNICONAZOLE FOLIAR SPRAYS. Spray concentrations ≤ 80 mg·L⁻¹ of paclobutrazol did not control osteospermum plant height (data not shown), which is in agreement with Olsen and Anderson (1995a) who found 32 mg·L⁻¹ was not effective. Paclobutrazol sprays gave no control of plant canopy height. Greater concentrations may be required to limit internode elongation or paclobutrazol might not be effective at any concentration. Although paclobutrazol foliar sprays of 40 to 80 mg·L⁻¹ significantly limited plant diameter by 10%, when compared to the nontreated control, these concentrations do not appear to be applicable for controlling horizontal expansion in southeastern U.S. wholesale production.

Spray concentrations ≤ 24 mg·L⁻¹ uniconazole did not control osteospermum plant height, canopy height, or plant diameter (data not shown). Flowering was not delayed when plants were sprayed with either paclobutrazol or uniconazole.

PACLOBUTRAZOL SUBSTRATE DRENCHES. 'Lusaka' plant height decreased linearly with increasing paclobutrazol substrate drench concentrations (Fig. 1A). Applying paclobutrazol at 16 mg limited plant height by 21%, when compared to the untreated control. Retail growers may select paclobutrazol at concentrations of 8 to 16 mg, which had shorter canopy heights of 8% and 14%, respec-

tively, when compared to the control (Fig. 1B). Paclobutrazol substrate drenches of 8 and 16 mg also limited plant diameter by 10% and 18%, respectively, when compared to the nontreated control (Fig. 1C). Substrate drenches of paclobutrazol at 16 mg caused peduncle height to be 62% shorter than the control (data not shown). Flowering was not delayed when the substrate was drenched with paclobutrazol. Although a paclobutrazol drench at 16 mg/pot limited flower stalk elongation, the amount of growth control observed for plant canopy height and plant diameter would not be within the established wholesale production acceptable range of 20% to 35% (T. Harger, personal communication). Paclobutrazol substrate drenches of 8 mg would cost \$0.23/pot, while a 16 mg drench would cost \$0.46, based on the cost of \$116/L (\$110/qt).

UNICONAZOLE SUBSTRATE DRENCHES. Uniconazole applied as a substrate drench at 0.25 mg limited plant and canopy height. Uniconazole concentrations of 0.125 to 0.25 mg were recommended for retail growers to produce 20% shorter plants than control plants (Fig. 2A). Because wholesale growers desire 20% to 35% shorter plants when compared to untreated plants, a 0.5 mg/pot uniconazole (35%) would be an acceptable concentration. The uniconazole concentration of 1.0 mg was excessive and caused severe plant stunting.

Uniconazole drenches of 0.5 to 1.0 mg had shorter canopy heights than the control. Applying uniconazole at 0.25 mg resulted in a 14% shorter canopy height than the control (Fig. 2B), and this concentration may be more appropriate for retail growers. Wholesale growers who wish to grow smaller osteospermum for easier shipping may want to apply a 0.5 mg uniconazole substrate drench to produce a 27% shorter canopy height than the untreated plants.

Wholesale growers may want to use uniconazole drenches at doses between 0.25 to 0.5 mg for controlling horizontal expansion. Plant diameters were 18% and 32% smaller, respectively when compared to the untreated control (Fig. 2C). Uniconazole

drenches of 1.0 mg caused poor horizontal expansion of the plant causing the plant to look stunted. Uniconazole drenches of 0.125 and 0.5 mg caused flower height to be nearly 50% shorter than the control, about 1 inch (2.54 cm) above the canopy (data not shown). This trait may be desirable for wholesale growers who want to put several shelves on shipping carts and who do not want to injure the flower stems. Flowering was not delayed with an uniconazole substrate drench. A 0.25 to 0.5 mg uniconazole drench would cost \$0.06 to \$0.12, respectively, per pot, based on the cost of \$116/L.

Conclusion

The tested foliar spray concentrations of daminozide + chlormequat, paclobutrazol, or uniconazole did not limit internode elongation. Paclobutrazol, chlormequat, and uniconazole drenches were effective at controlling internode length elongation of osteospermum. Although substrate drenches of paclobutrazol of 8 to 16 mg produced compact plants, treatments may not be economical since paclobutrazol substrate drenches of 8 and 16 mg would cost \$0.23 and \$0.46/pot, respectively (assuming a volume of 300 mL/pot). The commercially recommended drench rate (D. Hartley, personal communication) of chlormequat at 1,500 mg·L⁻¹ would cost \$0.17/pot. Uniconazole at \$0.06 for a 0.25 mg drench or \$0.12 for a 0.5-mg drench could save the grower \$0.11 or \$0.05, respectively.

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