Substrate Drench Applications of Flurprimidol and Paclobutrazol Influence Growth of Swamp Sunflower

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SUMMARY. Swamp sunflower (*Helianthus simulans*) is an underused perennial plant native to the southeastern United States that produces an abundance of golden yellow inflorescences in the fall. It is a vigorous grower and tolerates a wide variety of soil conditions, growing in wetland and nonwetland habitats. Swamp sunflower warrants wider use in perennial beds and landscapes, and research on production practices to make plants more suitable for shipping could promote its production. This study evaluated the effects of plant growth regulators (PGRs) on the growth and floral attributes of the swamp sunflower. Treatments were applied to rooted cuttings in 1-gal pots as a substrate drench of 1, 2, 4, or 6 mg/pot paclobutrazol; 0.5, 1, 2, or 4 mg/pot flurprimidol; or water (control)/pot for Expt. 1. A second experiment (Expt. 2) applied 4, 6, or 8 mg/pot paclobutrazol; 2, 4, or 6 mg/pot flurprimidol; or water (control)/pot. Six weeks after treatment (WAT) for Expt. 1, paclobutrazol applied at 4 and 6 mg/pot and flurprimidol at 2 and 4 mg/pot resulted in smaller plants (as reflected by growth index) by 29%, 34%, 22%, and 48%, respectively, compared with the control. Furthermore, at the termination (6 WAT) of Expt. 1, the highest rate of flurprimidol produced the smallest plants, with the exception of the highest rate of paclobutrazol. By 6 WAT, plants treated with the highest rate of paclobutrazol and flurprimidol had lower dry weights and higher chlorophyll measurements than control. All PGR treatments for Expt. 2 resulted in smaller plants than the control by 27% to 36% at 4 WAT and 23% to 41% at 6 WAT. Differences for internode length and flower diameter were observed for Expts. 1 and 2, respectively. Results from these experiments suggest a substrate drench application of 6 mg/pot paclobutrazol or 4 mg/pot flurprimidol can be used for producing smaller plants compared with nontreated plants for swamp sunflower under greenhouse conditions.

Swamp sunflower is an underused, fall-blooming southern United States native perennial plant producing a swath of eye-catching inflorescences. The numerous flower heads reside above the foliage in a corymbose or racemose arrangement, each with a medium-sized disk of 1.3 to 2 cm diameter. A member of the Asteraceae family, it has 12 to 23 golden-yellow ray florets surrounding the central disk florets with dark purplish-red corollas (Flora of North

America, 2006; Heiser et al., 1969; Watson, 1929). The plant typically grows ≈1.0 to 1.8 m tall but can reach 2.5 m in height. Swamp sunflower's native range is from Georgia west to Texas and Arkansas southward to the Gulf Coast into southern Florida. Other common names, such as muck sunflower, suggest it is typically found in moist or saturated soils near ponds, riparian areas, and drainage ways. As a facultative wetland

plant, this species can be found in nonwetland habitats [The Wildlife Center (TWC), 2008; Wunderlin et al., 2019]. The plant grows best in full sun to partial shade and tolerates a variety of growing conditions, reportedly staying more compact in denser, saturated soils (TWC, 2008). In addition to aesthetics, the flowers and seeds are valuable to wildlife such as native bees and birds (TWC, 2008). With the growing interest in using natives as ornamentals, swamp sunflower is a strong candidate for wider use in perennial beds and landscapes, and research on nursery and shipping protocols could result in wider production and landscape use.

To ship and sell plants feasibly and economically, their size and shape need to be kept within certain dimensions while retaining aesthetic characteristics. This can be accomplished by pruning or pinching plants, yet this is labor-intensive and costly, particularly for vigorous plants. A less labor-intensive and widely used method to control growth and branching in commercial environments is the use of plant growth regulators (Whipker, 2013). Plant growth retardants, a subgroup of PGRs, commonly inhibit biosynthesis of the plant hormone gibberellin, thereby restricting plant growth (Davis et al., 1988; Rademacher, 2000). The most widely used PGR in the United States to control excessive growth in greenhouse-grown floricultural crops is the plant growth retardant paclobutrazol (Rademacher, 2000; Whipker, 2013). Restrictions in height of annual sunflower (*Helianthus annuus*) in response to paclobutrazol and other PGRs have been demonstrated (Ahmad et al., 2015; Barbosa et al., 2008; Dasoju et al.,

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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
0.3048	ft	m	3.2808
0.0283	ft ³	m ³	35.3147
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
6.4516	inch ²	cm ²	0.1550
593.2764	lb/yd ³	g·m ⁻³	0.0017
28.3495	oz	g	0.0353
28,350	oz	mg	3.5274 × 10 ⁻⁵
0.001	ppm	g·L ⁻¹	1000
1	ppm	mg·L ⁻¹	1
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

1998; Koutroubas et al., 2014; Vernieri et al., 2003; Whipker and Latimer, 2016; Whipker and McCall, 2000). The rate of paclobutrazol has been evaluated on potted sunflower in previous studies, for example, with Dasoju et al. (1998) finding paclobutrazol at 2 mg/pot as a substrate drench on potted sunflower 'Pacino' reduced height by 17% to 25%. Similar responses from a similar application of paclobutrazol were obtained by Whipker and McCall (2000) on five cultivars of annual sunflower. Whipker and McCall (2000) and Ahmad et al. (2015) determined that 4 mg/pot effectively reduced growth of 'Pacino Gold'. Barbosa et al. (2008) observed reduced plant height with increased paclobutrazol concentration and recommended 6 mg/pot for the annual sunflower 'Golden'. Dasoju et al. (1998) tested a wide range of rates with reductions in plant height and diameter up to 16 mg/pot but observed phytotoxicity at 16 and 32 mg/pot. Insufficient height reduction by paclobutrazol on potted sunflower was reported by Whipker and Dasoju (1998) when applied as a foliar spray and suggested spraying at even higher concentrations (>80 mg/pot) or using a substrate drench application. A 2 to 3 ppm substrate drench application of paclobutrazol 1 to 2 weeks after pinching during greenhouse production is suggested for an interspecific hybrid sunflower [*Helianthus hybrida* 'Sunfinity' (Syngenta Flowers, 2017)]. The application method of paclobutrazol in precedent literature has largely been by foliar spray or substrate drench with more favorable results from the use of substrate drenches (Hawkins et al., 2015; Keever et al., 1990; Whipker and Dasoju, 1998). Recommendations for greenhouse floriculture growers advise the application of paclobutrazol as a high-rate substrate drench for enduring effects throughout the growing season. For sunflower, the recommended application is a 2- to 4-mg substrate drench of 4 fl oz per 6-inch pot (Whipker, 2013).

Flurprimidol is another popular plant growth retardant for ornamentals that inhibits the biosynthesis of gibberellin and has restricted plant height and diameter of potted 'Pacino' annual sunflower when applied as a substrate drench or foliar spray (Whipker, 2013; Whipker et al.,

2004). Whipker et al. (2004) compared two PGRs to flurprimidol and found results from a 2 mg/pot substrate drench application of flurprimidol to be similar to those of paclobutrazol. Another comparison by Vernieri et al. (2003) found flurprimidol at 60 mg·L⁻¹ applied as a foliar spray on sunflower was less effective on height reduction than a low dose of paclobutrazol (2 mg/pot) applied as a substrate drench. Application of flurprimidol in other species as a drench rather than spray has been shown to produce more ideal plant effects, including reduction in plant size, while not affecting flowering time or flower size (Krug et al., 2005a, 2005b; Rezazadeh and Harkess, 2015; Whipker et al., 2006).

The objective of this study was to evaluate the effects of two common plant growth retardants, paclobutrazol and flurprimidol, applied as substrate drenches on the growth and flowering of swamp sunflower.

Materials and methods

EXPT. 1. Subterminal cuttings of three to four nodes were taken 10 Apr. 2018 from clonal material of swamp sunflower from a stock plant at the University of Georgia's (UGA) Durham Horticulture Farm in Watkinsville. Cuttings were dipped in a fungicide solution of 15.58 g·L⁻¹ azoxystrobin (Abound; Syngenta Crop Protection, Greensboro, NC) for 10 to 15 s before sticking in propagation substrate in 1020 trays (21.2 × 10.8 × 2.3 inches; Landmark Plastic, Akron, OH). Propagation substrate was wet 1 to 2 d before sticking cuttings and consisted of 2 potting mix: 1 perlite (by volume). Potting mix used was Jolly Gardener Proline C/L Growing Mix (Oldcastle, Shady Dale, GA) and was amended with micronutrients (Micromax; Everris NA, Dublin, OH) at 1.00 lb/yards³. After cuttings were stuck, a humidity dome was placed over the tray, placed under mist (8 s every 5 min from 7:00 AM to 7:00 PM), and covered by shade cloth (50% exclusion) under greenhouse conditions. After 30 d, rooted cuttings were removed from trays and placed in 4-inch (height) square pots (Kord; The HC Companies, Twinsburg, OH) filled with potting substrate (Promix BX Mycorrhizea; Premier Tech Horticulture, Rivière-du-Loup, QC, Canada) amended with same micronutrients as above. Rooted

cuttings were placed in a shaded area in greenhouse, watered as needed, and fertilized weekly with a 20N-4.4P-16.6K water-soluble liquid fertilizer at 200 mg·L⁻¹ nitrogen (Jack's Professional; J.R. Peters, Allentown, PA). After ≈16 d, rooted cuttings were moved to an unshaded area of polyethylene greenhouse and continued to grow for ≈1 week. Rooted cuttings were then transplanted to 1-gal pots filled with potting substrate (pine bark, peat, and sand mix; Oldcastle) and top-dressed with a 16N-2.6P-10.0K controlled-release fertilizer at 10 g/pot (Harrell's Polyon, Lakeland, FL). Plants were transferred on the same day to a polycarbonate greenhouse at the UGA Trial Gardens in Athens, GA, and allowed to grow before initiating the experiment. Plants were cut back for uniformity (≈15 to 20 cm from the substrate) on 21 May 2018. Fans in the greenhouse were programmed to vent when internal temperature ≥27 °C day and night; however, daytime temperatures in the summer often exceeded 32 °C within the greenhouse. The experiment was a completely randomized design with 12 replicates per treatment level in which a replicate was a single plant in a 1-gal pot and pots were spaced ≈18 inches apart.

Four days before application, plants were cut back to two nodes/stem. The evening (6:00 PM) before treatment application, plants were watered to container capacity. Treatments were applied 25 June 2018 beginning at 8:15 AM as a 120-mL substrate drench of paclobutrazol (Piccolo 10 XC; Fine Americas, Walnut Creek, CA), flurprimidol (Topflor; SePRO, Carmel, IN), or municipal water (control). PGR treatment was delivered as 1.0, 2.0, 4.0, or 6.0 mg/pot paclobutrazol or 0.5, 1.0, 2.0, or 4.0 mg/pot flurprimidol. Plants were hand watered as needed and fertigated once weekly with liquid fertilizer at 200 mg·L⁻¹ nitrogen (20N-4.4P-16.6K, Jack's Professional). The experiment ended at 6 WAT (6 Aug. 2018).

Plant height and width measurements were taken the day following treatment application (Day 1) and 2, 4, and 6 WAT. Plant height was measured from the surface of the substrate to the highest point of the plant. Width was the average of the two widest perpendicular dimensions. Height and width increases

Table 1. Expt. 1 data of final height decrease as percent of the control, dry weight, and chlorophyll meter measurements of swamp sunflower plants 6 weeks after treated with a plant growth regulator or control on 25 June 2018.

Treatment (mg/pot) ^z		Final ht decrease (% control) ^y	Dry wt (g) ^z	Chlorophyll meter measurements
Control			66.3 a	32.6 c
Paclobutrazol	1	2.8 c ^x	65.4 ab	32.8 c
	2	3.8 c	61.1 abc	34.0 c
	4	27.0 b	54.7 cd	35.6 bc
	6	35.6 ab	49.4 de	39.4 a
Flurprimidol	0.5	6.1 c	61.2 abc	32.5 c
	1	9.1 c	58.5 bc	33.9 c
	2	19.5 bc	55.7 c	34.5 c
	4	46.5 a	46.1 e	38.2 ab
Significance		***	***	***

^z1 mg = 3.5274×10^{-5} oz, 1 g = 0.0353 oz.

^yFinal height decrease as percent of control = $\{1 - [(height\ 6\ weeks\ after\ treatment - height\ on\ day\ immediately\ after\ treatment\ application) \div average\ height\ increase\ of\ control]\} \times 100$.

^xMeans separations (in columns) by all pairwise comparison tests with Bonferroni adjustment $P \leq 0.05$ (lowercase letters). Treatment levels within columns having the same letter are not significantly different.

***indicates significance at $P \leq 0.001$ ($n = 12$).

Fig. 1. Effects of the plant growth regulators (PGRs) flurprimidol (Flur) and paclobutrazol (Pac) substrate drenches (milligrams/pot) on the height increases of container-grown swamp sunflower at 2, 4, and 6 weeks after treatment (WAT) for Expt. 1 (initiated 25 June 2018). Control had no PGR applied. Height increase = (height at week 2, 4, or 6 – height on day after treatment application). Analysis of variance was conducted for each week of data collection [$P \leq 0.05$ ($n = 12$)]. Means separation by pairwise comparison tests with Bonferroni adjustment $P \leq 0.05$ (lowercase letters) at each week of data collection. Treatment levels within week having the same letter are not significantly different; 1 mg = 3.5274×10^{-5} oz, 1 cm = 0.3937 inch.

were calculated by subtracting the initial plant height or width measured on Day 1 from the height or width at the week of data collection. Growth index (GI) was calculated as height $\times$ width1 $\times$ width2 to reflect overall plant volume in cubic centimeters and increases were calculated as differences from Day 1 to a specific week of data collection. Chlorophyll meter (SPAD-502; Minolta Camera Corp.,

Osaka, Japan) measurements were taken between the midvein and margin of three random leaves and were averaged per plant to evaluate leaf greenness with a chlorophyll meter measurement. Dry weight was obtained by cutting stems at the top of the substrate and oven-drying for ≈ 3 d at 60 °C. Dry weight, chlorophyll meter, and internode length measurements were collected just

before the termination of the experiment. Internode length was taken by averaging the lengths between the second and third node from the apex of three random stems per plant.

Expt. 2. Plants were obtained using the method outlined earlier and the experiment was conducted in the same location as described in Expt. 1. Cuttings were taken 3 June 2018, allowed to root in 1020 trays (21.2 $\times$ 10.8 $\times$ 2.3 inches, Landmark Plastic), and transplanted to 4 inch square pots (Kord, The HC Companies) 28 d after sticking. Rooted cuttings were then transplanted to 1-gal pots after 24 d and brought to the UGA Trial Gardens in Athens, GA. Plants were cut back for uniformity 26 d before treatment (12 Aug. 2018). Greenhouse temperatures were maintained similar to Expt. 1, and beginning 22 Oct., heat was provided to maintain internal greenhouse temperatures at ≥ 24 °C day/ ≈ 18 °C night. Experimental design and setup were the same as Expt. 1 with one less treatment level for each PGR. Rates of PGRs for Expt. 2 were adjusted based on results from Expt. 1 and treatments were applied 7 Sept. 2018 using the same method as Expt. 1. Treatment was 4.0, 6.0, or 8.0 mg/pot paclobutrazol or 2.0, 4.0, or 6.0 mg/pot flurprimidol. The experiment was ended at 8 WAT (2 Nov. 2018), 2 weeks longer than Expt. 1 to allow for flowering observations.

Height and width measurements were taken identical to Expt. 1 with an additional measurement of height at 8 WAT. Chlorophyll meter readings and dry weight were also measured identically to Expt. 1. Internode length for Expt. 2 was not measured due to the development of inflorescences.

Floral data were collected for Expt. 2 (but not Expt. 1), since it blooms in the fall (August to November) (Flora of North America, 2006; TWC, 2008). At termination (8 WAT), the number of flowers and buds was counted to obtain the total flower count. Flower diameter (to nearest 0.25 cm) was measured, and the number of ray florets was counted on three random mature flowers for each plant; a mature flower was one with disc florets at anthesis. Eleven plants were used per treatment for flower diameter and ray floret number

Fig. 2. Effect of the plant growth regulators (PGRs) paclobutrazol and flurprimidol substrate drenches on the growth of container-grown swamp sunflower at 6 weeks after PGR application for Expt. 1 (initiated 25 June 2018). Control had no PGR applied. Paclobutrazol rates were 1, 2, 4, and 6 mg/pot (left-right) and flurprimidol rates applied were 0.5, 1, 2, and 4 mg/pot (left-right); $1 \text{ mg} = 3.5274 \times 10^{-5}$.

Fig. 3. Effects of the plant growth regulators (PGRs) flurprimidol (Flur) and paclobutrazol (Pac) substrate drenches (milligrams/pot) on the height increases of container-grown swamp sunflower at 2, 4, 6, and 8 weeks after treatment (WAT) for Expt. 2 (initiated 7 Sept. 2018). Control had no PGR applied. Height increase = (height at week 2, 4, 6, or 8 – height on day after treatment application). Analysis of variance was conducted for each week of data collection ($P \leq 0.05$, $n = 12$). Means separation by pairwise comparison tests with Bonferroni adjustment $P \leq 0.05$ (lowercase letters) at each week of data collection. Treatment levels within week having the same letter are not significantly different; $1 \text{ mg} = 3.5274 \times 10^{-5}$, $1 \text{ cm} = 0.3937 \text{ inch}$.

per flower because not all plants had three mature flowers. Flower timing data were taken for the date of first visible yellow ray floret, date of the first opened flower and the date of full flower. An opened flower had ray florets at $\approx 60^\circ$ from the center of the head, and a plant was in full flower when at least 80% of flowers were opened.

DATA ANALYSIS. Data for both experiments were analyzed by a one-way analysis of variance for each week of collection to obtain significance, and means comparisons of treatment levels were analyzed with the Bonferroni adjustment ($P \leq 0.05$) in the R program (R Core Team, 2016).

Results

EXPT. 1. Application of paclobutrazol and flurprimidol as substrate drenches at the specified rates affected plant height and width, dry weight, and chlorophyll meter measurements of swamp sunflower (Table 1; Figs. 1–3). Height increase was less than the control for plants treated with the two highest rates of paclobutrazol and flurprimidol at 2, 4, and 6 WAT (Table 1; Fig. 1). Reductions in height increase of plants treated with the aforementioned PGR rates compared with the control were 21% to 45% at 4 WAT and 19% to 46% at 6 WAT. For flurprimidol, plants receiving 1.0 mg/pot were shorter than the control at 2 WAT (Fig. 1). Among PGR rates, the two highest rates of paclobutrazol and the highest rate of flurprimidol restricted plant height at 6 WAT compared with other PGR rates by at least 20%, with the exception of flurprimidol at 2.0 mg/pot. Similar differences in height increase among PGR applications at 6 WAT were observed at 4 WAT with the highest rate of flurprimidol having a minimum of 22% height restriction.

Increase in plant width was reduced from the control by application of the highest rate of paclobutrazol and the two highest rates of flurprimidol at 2, 4, and 6 WAT (Fig. 4). At the termination of the study (6 WAT), the two highest PGR rates, paclobutrazol at 6.0 mg/pot and flurprimidol at 4.0 mg/pot, restricted plant width compared with flurprimidol at 1.0 mg/pot by 10% and 18%, respectively. Similar differences were observed between the lowest and highest rates of PGRs at 2 and 4

Fig. 4. Effects of the plant growth regulators (PGRs) flurprimidol (Flur) and paclobutrazol (Pac) substrate drenches (milligrams/pot) on the width (width1 $\times$ width2) increases of container-grown swamp sunflower at 2, 4, and 6 weeks after treatment (WAT) for Expt. 1 (initiated 25 June 2018). Control had no PGR applied. Width increase = (width at week 2, 4, or 6 – width on day after treatment application). Analysis of variance was conducted for each week of data collection ($P \leq 0.05$, $n = 12$). Means separation by pairwise comparison tests with Bonferroni adjustment $P \leq 0.05$ (lowercase letters) at each week of data collection. Treatment levels within week having the same letter are not significantly different; 1 mg = 3.5274×10^{-5} , 1 cm² = 0.1550 inch².

WAT (Fig. 4). At 4 WAT, application of the highest rate of flurprimidol restricted width growth by 18% to 23% from the two lowest rates of both PGRs. Among paclobutrazol rates at 4 WAT, plants treated with the highest paclobutrazol rate were 13% narrower than the lowest paclobutrazol rate.

Growth index was affected by PGR application at 2 and 4 WAT. Plants treated with the two highest rates of paclobutrazol and all but the lowest rate of flurprimidol were smaller than the control by 18% to 50% at 2 and 4 WAT (data not shown). After 2 weeks of growth, application of paclobutrazol at the two highest rates restricted growth compared with the lowest paclobutrazol rate, and the application of the highest rate of flurprimidol restricted growth compared with the two lowest flurprimidol rates. After 4 weeks, the highest rate of flurprimidol produced smaller plants than other PGR treatments, with the exception of the highest rate of paclobutrazol. At termination (6 WAT), the two highest rates of each PGR yielded smaller plants than the control by 22% to 48% (Table 2). Furthermore, plants treated with the two highest rates of paclobutrazol were smaller than those

treated with the lowest rate of paclobutrazol by 28% and 33%, and the highest rate of flurprimidol resulted in smaller plants than all PGR treatments by at least 27%, with the exception of the highest rate of paclobutrazol.

Dry weight of plants treated with the two highest rates of paclobutrazol and all but the lowest rate of flurprimidol was restricted by 12% to 30% compared with the control (Table 1). The highest rate of flurprimidol resulted in plants with the lowest dry weight of all treatments, apart from the highest paclobutrazol rate. The two highest concentrations of paclobutrazol resulted in plants with 16% and 24% lower dry weights than the lowest concentration of paclobutrazol. Similarly, the highest concentration of flurprimidol resulted in plants with 17% to 25% lower dry weights than other rates of flurprimidol.

The highest rate of paclobutrazol had the highest chlorophyll meter measurement of all treatments (with a 17% increase from the control), apart from the highest rate of flurprimidol that had a 15% increase from the control (Table 1).

The highest rate of paclobutrazol and flurprimidol had shorter internode lengths by 1.2 and 1.4 cm,

respectively, at 6 WAT ($P \leq 0.01$) compared with the lowest rate of flurprimidol (data not shown).

Expt. 2. Application of paclobutrazol and flurprimidol as substrate drenches at the specified rates affected increase in plant height and width and flower diameter of swamp sunflower (Table 3; Figs. 3 and 5). All PGR application rates resulted in shorter plants than the control at each week of data collection, with the greatest reductions occurring 4 WAT [34% to 40% (Fig. 3)]. After 8 weeks of growth, plants treated with the highest concentration of paclobutrazol (8.0 mg/pot) were shorter than plants treated with half that concentration (4.0 mg/pot), but no other differences of height increase among PGR treatments were observed (Table 3; Fig. 3).

The application of paclobutrazol at 6.0 and 8.0 mg/pot restricted the increase in plant width at 6 WAT compared with the control by 29% and 26%, respectively (Table 3). Increase in plant width at 2 and 4 WAT was not influenced by PGR treatment (data not shown).

Growth index was affected by PGR treatment at each week of data collection (6 WAT growth index shown in Table 2). The highest rate of flurprimidol and the two highest rates of paclobutrazol yielded smaller plants than the control by 35% to 40% at 2 WAT (data not shown). All PGR treatments yielded smaller plants than the control by 27% to 36% at 4 WAT and 23% to 41% at 6 WAT [Table 2 (data not shown for 4 WAT)].

Treatment effect on dry weight was not found to be significant (data not shown). Chlorophyll meter measurements were not different among treatments when measured at 8 WAT (data not shown).

The diameter of mature flowers (Table 3) and the number of flowers and flower buds per plant ($P = 0.041$), when measured or counted 8 WAT, were affected by PGR treatments. The diameter of flowers on plants treated with flurprimidol at 6.0 mg/pot was 7% wider than plants treated with paclobutrazol at the same rate (Table 3). The number of flowers and flower buds per plant ranged from 95 to 115, and although treatment was found to have an effect on this parameter, no differences between treatment levels were found using

Table 2. Volumetric growth increases for plants of swamp sunflower treated with plant growth regulator (PGR) or control on 25 June 2018 (Expt. 1) or 7 Sept. 2018 (Expt. 2).

Treatment (mg/pot) ^z		Final volumetric growth decrease (% control) ^y		Final volumetric growth (m ³) ^x	
		Expt. 1	Expt. 2	Expt. 1	Expt. 2
Control				0.22 a	0.38 a
Paclobutrazol	1	2.7 d ^w	n/a ^v	0.21 a	n/a
	2	12.1 cd	n/a	0.19 abc	n/a
	4	28.6 bc	22.9 a	0.15 cd	0.29 b
	6	34.5 ab	38.5 a	0.14 de	0.23 b
	8	n/a	41.2 a	n/a	0.22 b
Flurprimidol	0.5	8.5 d	n/a	0.20 ab	n/a
	1	8.1 d	n/a	0.20 ab	n/a
	2	22.0 bc	23.9 a	0.17 bcd	0.29 b
	4	48.1 a	27.2 a	0.11 c	0.28 b
	6	n/a	30.1 a	n/a	0.26 b
Significance		***	*	***	***

^z1 mg = 3.5274 × 10⁻⁵ oz.^yFinal volumetric growth decrease as percent of control = {1 - [(volume 6 weeks after treatment - volume on day immediately after treatment application) ÷ average volume increase of control]} × 100, where volume = (height × width × width).^xFinal volumetric growth = (volume 6 weeks after treatment - volume on day immediately after treatment application); 1 m³ = 35.3147 ft³.^wMeans separations (in columns) by all pairwise comparison tests with Bonferroni adjustment $P \leq 0.05$ (lowercase letters). Treatment levels within column having the same letter are not significantly different.^vIndicates no PGR was applied at a specific rate for a particular experiment.***, * indicate significance at $P \leq 0.001$ or 0.05, respectively (n = 12).**Table 3. Expt. 2 data of final height increase as percent of control, width, and flower diameter of swamp sunflower plants treated with plant growth regulator or control on 7 Sept. 2018.**

Treatment (mg/pot) ^z		Final ht decrease (% control) ^y	Final width increase (cm ²) ^x	Flower diam (cm) ^w
Control			29.8 a	9.8 ab
Paclobutrazol	4	15.7 ^v	27.5 ab	10.3 ab
	6	22.6	21.0 b	9.7 b
	8	26.5	21.9 b	9.9 ab
Flurprimidol	2	20.2	26.7 ab	10.1 ab
	4	22.5	27.4 ab	10.2 ab
	6	21.0	25.1 ab	10.4 a
Significance		NS	**	*

^z1 mg = 3.5274 × 10⁻⁵ oz.^yFinal height decrease as percent of control = {1 - [(height 8 weeks after treatment - height on day immediately after treatment application) ÷ average height increase of control]} × 100.^xMeans separations (in columns) by pairwise comparison tests with Bonferroni adjustment $P \leq 0.05$ (lowercase letters). Treatment levels within columns having the same letter are not significantly different.^wFinal width increase = (width 6 weeks after treatment - width on day immediately after treatment application), where width = [(width1 × width2) ÷ 2]; 1 cm² = 0.1550 cm².^vFlower diameter measured 8 weeks after treatment application and is the average of three mature flowers per plant, where a mature flower had disc florets that had reached anthesis; 1 cm = 0.3937 inch.NS, ***, **, * indicate nonsignificance or significance at $P \leq 0.001$, 0.01, or 0.05, respectively (n = 12).

pairwise comparison tests (data not shown). The number of ray florets per mature flower, which ranged from 13 to 15, was unaffected by treatment (data not shown). The number of days to first visible yellow of ray florets, first fully open flower, and full flower from the day of treatment application were unaffected by treatment (data not shown). The means of the number of days to first visible

yellow florets ($\pm$ SE) were 33.9 $\pm$ 1.1 for the control; 36.6, 36.4, and 35.9 $\pm$ 1.1 in ascending order by the rate for paclobutrazol; and 35.8, 36.7, and 37.2 $\pm$ 1.1 in ascending order by rate for flurprimidol. The means of the number of days to first full flower ($\pm$ SE) were: 37.8 $\pm$ 1.3 for the control; 40.6, 40.0, and 39.7 $\pm$ 1.3 in ascending order by rate for paclobutrazol; and 39.4, 40.4, and 40.9 $\pm$ 1.3 in

ascending order by rate for flurprimidol. The means of the number of days to full flower ($\pm$ SE) were 50.8 $\pm$ 2.2 for the control; 57.2, 55.3, and 53.7 $\pm$ 2.2 in ascending order by rate for paclobutrazol; and 54.8, 55.0, and 55.8 $\pm$ 2.2 in ascending order by rate for flurprimidol.

Discussion

Restrictions of plant height from the control that were observed in Expts. 1 and 2 for paclobutrazol and flurprimidol are similar to previous studies. After 6 weeks for Expt. 1 and 4 WAT for Expt. 2, plants treated with paclobutrazol at 4.0 mg/pot had 27% and 36% reductions in height growth, respectively, compared with the control. Similar results with a substrate drench application of 4 mg/pot paclobutrazol were observed as 26% to 36% shorter plants than the control by Dasoju et al. (1998), Whipker and McCall (2000), and Ahmad et al. (2015) for potted annual sunflower. Although previous studies observed 20% to 27% shorter plants with a 2 mg/pot drench of paclobutrazol on potted sunflower (Ahmad et al., 2015; Dasoju et al., 1998; Whipker and McCall, 2000; Whipker et al., 2004), the same application method and concentration in this study on swamp sunflower was not different from the control. Expts. 1 and 2 had further height restrictions with plants treated at paclobutrazol rates higher than 4.0 mg/pot (Figs. 1 and 4) which was similarly observed in potted sunflower by Barbosa et al. (2008), who recommended 6 mg/pot for 'Golden', and Vernieri et al. (2003) with a reported 50% reduction in height at 16 mg/pot (but with variation among cultivars). Dasoju et al. (1998) reported severe retardation in the growth of potted sunflower at 16 and 32 mg/pot. Substrate drench application of flurprimidol at 2 mg/pot by Whipker et al. (2004) restricted the height of potted sunflower by 22%. Similar results were observed in this study at the same PGR rate with a 21% and 34% height growth restriction of plants from the control for Expts. 1 and 2, respectively, 4 WAT. In contrast to Whipker et al. (2004), this study found further height restrictions from the control with an increasing rate of flurprimidol (Figs. 1 and 3).

Fig. 5. Effect of the plant growth regulators (PGRs) paclobutrazol and flurprimidol substrate drenches on the growth of container-grown swamp sunflower at 8 weeks after PGR application for Expt. 2 (initiated 7 Sept. 2018). Control had no PGR applied. Paclobutrazol rates were 4, 6, and 8 mg/pot (left-right) and flurprimidol rates applied were 2, 4, and 6 mg/pot (left-right); 1 mg = 3.5274×10^{-5} oz.

Chlorophyll meter measurements for paclobutrazol 6.0 and flurprimidol 4.0 mg/pot during Expt. 1 were higher than the control. These results are consistent with those of Ahmad et al. (2015) who observed darker green foliage for ‘Pacino Gold’ potted sunflower treated with 2 to 4 mg/pot paclobutrazol substrate drenches and for Barbosa et al. (2008) who reported increased chlorophyll meter measurements with increased paclobutrazol substrate drench rates, peaking between 4 to 6 mg/pot for ‘Golden’ potted sunflower. Increased foliar chlorophyll content with increasing paclobutrazol rate has been reported in additional plant genera to sunflowers [*Helianthus* sp. (Bañón et al., 2001; Dahab et al., 2015; França et al., 2017)]. Increase in relative chlorophyll with the application of antigibberellin

compounds in Expt. 2 is likely explained by secondary effects of reduced leaf expansion leading to an increased density of chloroplasts, as well as an increase of chlorophyll biosynthesis (Davis et al., 1988). The lack of increased chlorophyll meter measurements with an increase of PGR rate for Expt. 2 could have been due to the use of foliar resources for inflorescence development (Kitonyo et al., 2018; Leopold, 1961). Interestingly, chlorophyll meter measurements for Expt. 1 were lower (range: 32.5 to 39.4) than for Expt. 2 (range: 40.6 to 43.9) for all treatment levels.

Flowering dates for the control and PGR-treated plants occurred between 4 and 8 WAT when treatment was applied 7 Sept. 2018, and no effect on flowering date was observed due to PGR application. There was no

delay to anthesis for potted sunflower which was similarly observed by Whipker et al. (2004) with the application of paclobutrazol (2 mg/pot drench) or flurprimidol (10–50 mg·L⁻¹ spray or 0.5–4 mg/pot drench) and by Whipker and Dasoju (1998) with paclobutrazol application of 5 to 40 mg·L⁻¹ as foliar spray. However, delays in flowering of 4 to 6 d for potted sunflower by PGRs have been reported by Dasoju et al. (1998) with paclobutrazol substrate drench at 2 to 32 mg/pot during winter production and by Whipker and Dasoju (1998) with a foliar spray of paclobutrazol 80 mg·L⁻¹. Flowering delays resulting in less impact to the plants’ marketability have been reported for paclobutrazol substrate drenches by Whipker and McCall [2000 (2 and 4 mg/pot)] and by Vernieri et al. [2003 (2–16 mg/pot)], and for flurprimidol (7.5–60 mg·L⁻¹ foliar spray; Vernieri et al., 2003) on potted sunflower. Plant growth regulator effect on flowering can vary among species with no effect observed by paclobutrazol treatment on pinklady [*Dissotis rotundifolia* (Hawkins et al., 2015)] or on bulbs of ‘Anna Marie’ hyacinth [*Hyacinthus orientalis* (Krug et al., 2005b)], but delays observed from paclobutrazol on african daisy [*Osteospermum ecklonis* (Barnes et al., 2009)] and by flurprimidol on ‘Star Gazer’ oriental lily [*Lilium* hybrids (Krug et al., 2005a)] and ‘Anna Marie’ hyacinth bulbs (Krug et al., 2005b).

Flower diameter results from Expt. 2 were interesting in that no differences from the control were observed for different PGR rates, but flurprimidol 6.0 mg/pot had a 7% wider flower than paclobutrazol 6.0 mg/pot. Precedent studies with potted annual sunflower found no differences of flower diameter from control when treated with paclobutrazol substrate drench at 2 or 4 mg/pot (Whipker and McCall, 2000) or as a foliar spray at 5 to 80 mg·L⁻¹ (Whipker and Dasoju, 1998). On the other hand, reductions of flower diameter by application of higher paclobutrazol substrate drench rates (4–32 mg/pot) and flurprimidol spray (60 mg·L⁻¹) have been observed (Dasoju et al., 1998; Vernieri et al., 2003). The number of flowers and flower buds was totaled for each plant to evaluate PGR treatment

effect on floriferousness; however, no significant pairwise comparisons were found. This parameter was evaluated because an increased number of flowers could increase the marketability of a plant.

In summary, paclobutrazol 4.0 and 6.0 mg/pot and flurprimidol 1.0, 2.0, and 4.0 mg/pot applied 25 June 2018 resulted in smaller plants (by GI) at 2 and 4 WAT and less biomass at 6 WAT than the control. After 6 weeks, paclobutrazol 4.0 and 6.0 and flurprimidol 2.0 and 4.0 mg/pot yielded smaller plants than the control. Furthermore, plants treated with paclobutrazol at 4.0 and 6.0 mg/pot were smaller and had less dry weight than 1.0 mg/pot of the same PGR at 6 WAT. Plants treated with paclobutrazol 6.0 mg/pot and flurprimidol 4.0 mg/pot had higher chlorophyll meter measurements than the control and shorter internodes than the lowest rate of flurprimidol at 6 WAT.

For Expt. 2, initiated 7 Sept. 2018, all PGR treatments were smaller (by GI) than the control by 4 and 6 WAT. At termination (8 WAT), plants treated with paclobutrazol 8.0 mg/pot were had less growth in height than plants receiving half that rate. Because the statistical analyses showed no difference in restrictions of plant GI among PGR rates at 4 and 6 WAT in Expt. 2 (Fall 2018), applying the lowest rate of PGR (i.e., flurprimidol at 0.5 mg/pot) would result in a similar smaller size (compared with no PGR) of plants as applying the highest PGR rate (i.e., paclobutrazol at 8 mg/pot). Expt. 2 results also suggest an application of flurprimidol 6.0 mg/pot over paclobutrazol at the same rate would result in plants with a 7% wider flower.

In conclusion, optimal PGR substrate drench application rates for reducing overall plant growth of swamp sunflower are paclobutrazol at 4.0 or 6.0 mg/pot or flurprimidol at 2.0 or 4.0 mg/pot. Plants treated with these PGR and rate combinations appeared upright and compact (Figs. 2 and 5), particularly compared with no PGR application. Application of paclobutrazol at 4.0 or 6.0 mg/pot would result in plant sizes 27% to 29% or 34% to 35% less, respectively, compared with no PGR application for about 2 to 6 weeks. For flurprimidol, application of 2.0 or 4.0 mg/pot

would result in plant sizes 30% or 50% less, respectively, compared with no PGR application after 4 weeks.

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