Quantifying Growth Control of Lantana Cultivars Varying in Vigor with Ancymidol, Flurprimidol, Paclobutrazol, and Uniconazole Substrate Drenches

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SUMMARY. Our objective was to quantify the efficacy of different plant growth regulator (PGR) substrate drenches on growth of lantana (Lantana camara) cultivars varying in growth habit. Rooted ‘Little Lucky Peach Glow’, ‘Lucky Peach’, and ‘Landmark Peach Sunrise’ lantana cuttings were individually planted into 4-inch-diameter containers filled with a commercial, soilless growing substrate. Fourteen days after planting, solutions containing 0 (control), 0.5, 1, 2, or 4 mg L⁻¹ ancymidol, flurprimidol, paclobutrazol, or uniconazole were applied to the surface of the growing substrate. Six weeks after applying PGR drenches, data were collected. The growth index (GI), an integrated measurement of plant size incorporating the height and widths of plants, was calculated. There was variation in the GI among the control plants, reflecting variation among cultivars within the species. In addition, we measured variation in activity among the different PGRs applied. Across the concentrations applied, ancymidol generally had the lowest activity across the four PGRs. For example, drenches containing 4 mg L⁻¹ ancymidol resulted in plants that were similar to plants treated with 0.5 to 1 mg L⁻¹ flurprimidol or uniconazole or 2 mg L⁻¹ paclobutrazol for ‘Lucky Peach’ lantana. Across all cultivars, flurprimidol and uniconazole had the greatest activity in suppressing plant height, width, and GI. Substrate drenches containing flurprimidol, paclobutrazol, or uniconazole are useful to control size of lantana produced in containers, though the recommended concentration depends on the active ingredient and the growth habit of cultivars being treated.

Lantana is popular for its growth and flowering throughout the heat of summer and, while it is a tender woody perennial, is most commonly used as an herbaceous annual (Armitage, 2001; Dole and Wilkins, 2005; Nau, 2011). Flower colors vary, ranging from yellow to deep red and purple, and foliage with green or variegated leaf margins. In addition, growth habits for different lantana cultivars vary from dwarf, highly compact cultivars for containers to large cultivars for use in landscapes. Container-produced lantana may require PGR applications to produce proportionately sized plants.

PGRs are useful in controlling growth of containerized ornamental crops produced in greenhouses (Dole and Wilkins, 2005; Gaston et al., 2001; Whipker et al., 2011). Commercial recommendations for controlling lantana are to apply foliar sprays containing chlormequat chloride every 2 weeks starting ≈1 week after pinching (Nau, 2011). Numerous studies report the effect of foliar sprays containing chlormequat chloride, chlormequat chloride and dimazoxide, ethephon, paclobutrazol, and uniconazole (Barrett and Schoellhorn, 2001; Kamoutsis and Matsoukis, 2003; Matsoukis et al., 2004; Matsoukis and Chronopoulos-Sereli, 2005; Ruter, 1996).

Applying PGRs with substrate drenches can provide longer growth control when compared with foliar sprays (Gent and McAvoy, 2000; Whipker et al., 2011). We have found few reports of using substrate drenches for controlling excessive growth of lantana in containers (Barrett and Schoellhorn, 2001; Ruter, 1996). Barrett and Schoellhorn (2001) reported that paclobutrazol and uniconazole effectively suppressed ‘Trailing Lavender’ lantana width. Similarly, Ruter (1996) reported that paclobutrazol drenches inhibited growth of ‘New Gold’ lantana. Although informative, these studies on two cultivars and a narrow range of concentrations of two active ingredients are the only reports on using PGR drenches for controlling lantana growth.

The limited information on using PGR drenches to control growth of lantana is promising. Therefore, a broader understanding of the interaction between cultivar, active ingredient, and concentration would improve the use of substrate drenches for growth control. Our objective was to quantify the efficacy of different PGR substrate drenches on growth of lantana cultivars varying in growth habit.

Materials and methods

PLANT MATERIAL. Unrooted cuttings of ‘Landmark Peach Sunrise’, ‘Lucky Peach’, and ‘Little Lucky Peach Glow’ lantana (vigorous-, moderate-, and compact-growing cultivars, respectively) were received at Iowa State University, Ames (la. 42°N). Cuttings were individually placed in 105-cell propagation trays (28-mL individual cell volume; T.O. Plastics, Clearwater, MN) filled with a propagation substrate composed of (v/v) two parts soilless substrate composed of canadian sphagnum peatmoss, perlite and amended with dolomitic limestone, starter charge, and wetting agent (Sunshine Mix #1; Sun Gro Horticulture, Agawam, MA) and one part coarse perlite (Therm-O-Rock East, New Eagle, PA).

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  |
| 28.3495                | oz          | g         | 0.0353  |
| 28,350                 | oz          | mg        | 3.5274 × 10⁻³ |
| 1                      | ppm         | mg L⁻¹    | 1       |
| 0.1019                 | qt./100 ft² | L·m⁻²     | 9.8170  |
| (°F – 32) / 1.8        | °F          | °C        | (°C × 1.8) + 32 |
GREENHOUSE CULTURE. Four weeks after placing lantana cuttings into propagation, rooted cuttings were individually planted in 4-inch-diameter containers (480 mL volume; HC Companies, Middlefield, OH) filled with a commercial soilless substrate (Sunshine Mix #1). Plants were grown in a glass-glazed greenhouse with pad-and-fan cooling, radiant hot-water floor and perimeter heating, and retractable shade curtains controlled by...
an environmental computer (Titan; ARGUS Control Systems, Surrey, BC, Canada). The day and night greenhouse air temperature set points were 22.0 ± 1.0 °C and 20.0 ± 1.0 °C, respectively. High-pressure sodium lamps delivered a supplemental photosynthetic photon flux of 103 ± 43 μmol·m⁻²·s⁻¹ at plant height [as measured with a quantum sensor (Field Scout Quantum Light Meter; Spectrum Technologies, Aurora, IL)] to create a 16-h photoperiod (0600 to 2200 HR). Plants were irrigated as necessary, alternating between clear tap water and water supplemented with a blend of water-soluble fertilizers (100 and 200 mg·L⁻¹ N provided from 21N–2.2P–16.6K and 15N–2.2P–12.5K, respectively; Everris NA, Marysville, OH) to provide the following (in mg·L⁻¹): 300.0 nitrogen, 38.9 phosphorous, 322

Fig. 2. Shoot dry weight of lantana cultivars Landmark Peach Sunrise (vigorous), Lucky Peach (moderate-growing), and Little Lucky Peach Glow (compact) grown in 4-inch-diameter (10.2 cm) containers filled with commercial soilless substrate composed of peat and perlite treated with substrate drenches containing 0, 0.5, 1, 2, or 4 mg·L⁻¹ (A–C) ancymidol, (D–F) flurprimidol, (G–I) paclobutrazol, or (J–L) uniconazole 2 weeks after planting. Data were collected 8 weeks after planting. Each symbol represents the mean of eight plants, and error bars represent the se; ***significant at P ≤ 0.001; 1 mg·L⁻¹ = 1 ppm, 1 g = 0.0353 oz.
245.1 potassium, 66.7 calcium, 26.7 magnesium, 1.1 iron, 0.75 manganese, 0.75 zinc, 0.37 copper, 0.37 boron, and 0.15 molybdenum.

**PGR treatments.** Fourteen days after planting, PGR drench treatments were applied. Eight individual plants of each cultivar were provided with 2-fl oz aliquots of solutions containing deionized water or 0.5, 1, 2, or 4 mg L$^{-1}$ ancymidol (Abide; Fine Americas, Walnut Creek, CA), flurprimidol (Topflor; ScPRO, Carmel, IN), paclobutrazol (Piccolo; Fine Americas), or uniconazole (Concise; Fine Americas).

**Data collection and calculation.** Eight weeks after planting rooted cuttings, data were collected. Plant height from the surface of the substrate to the tallest growing point and the widths at the widest point and 90° from the widest point were recorded. These measurements were used to calculate the GI (GI = (plant height + [(diameter 1 + diameter 2)/2])/2), an integrated measurement of plant size (Jeong et al., 2009; Krug et al., 2010). Shoots were severed at the surface of the substrate and placed in a forced-air oven maintained at 67 °C, after which shoots were weighed and dry weight was recorded. Time to flower was not quantified because the cuttings were forming flower buds from the beginning of the experiment.

**Experimental design and statistical analyses.** For each cultivar and chemical, data were modeled with an exponential decay model ($y = y_0 + ae^{-bx}$) and regression analyses were performed using Sigma Plot 12.5 (Systat Software, San Jose, CA). In addition, the above equation was solved for the concentration of active ingredient where suppression of plant height was 95% of maximum suppression for each cultivar and active ingredient to determine the point of saturation for each chemical.

**Results and discussion**

The GI differed with cultivar, active ingredient, and concentration (Fig. 1A–L). The GI of untreated ‘Landmark Peach Sunrise’, ‘Lucky Peach’, and ‘Little Lucky Peach Glow’ was 20.6, 16.2, and 12.4, respectively. Variation was also observed in suppression of GI within and among cultivars and active ingredient (Fig. 1A–L). With the concentrations used in our study, maximum suppression of ‘Landmark Peach Sunrise’ GI occurred at 2.7 and 3.4 mg L$^{-1}$ for flurprimidol and paclobutrazol, respectively. The smallest GI for ‘Landmark Peach Sunrise’ for plants treated with 4.0 mg L$^{-1}$ ancymidol or uniconazole was 14.9 or 13.1, respectively; however, the estimated saturating concentrations for ancymidol and uniconazole were above the range employed in our research. Alternatively, the saturation of GI suppression of ‘Lucky Peach’ and ‘Little Lucky Peach Glow’ for each active ingredient was within the 0 to 4.0 mg L$^{-1}$ range of concentrations. Using our models, maximal ‘Lucky Peach’ GI suppression occurs at 0.8, 1.3, 2.5, or 4.0 mg L$^{-1}$ for flurprimidol, uniconazole, paclobutrazol,

![Plant growth regulator (mg L$^{-1}$)](image-url)

Fig. 3. ‘Landmark Peach Sunrise’ lantana, a vigorous cultivar, grown in 4-inch-diameter (10.2 cm) containers filled with commercial soilless substrate composed of peat and perlite treated with substrate drenches containing 0, 0.5, 1, 2, or 4 mg L$^{-1}$ ancymidol, flurprimidol, paclobutrazol, or uniconazole 2 weeks after planting. Photos were taken 8 weeks after planting; 1 mg L$^{-1}$ = 1 ppm.
and ancymidol, respectively. Alternatively, maximal GI suppression for ‘Little Lucky Peach Glow’ ranged from 14% or 17% (paclobutrazol or ancymidol, respectively) to 23% or 25% (uniconazole or flurprimidol, respectively) and saturation was observed at 0.6, 0.8, 1.7, or 4.0 mg.L⁻¹ for paclobutrazol, ancymidol, flurprimidol, or uniconazole, respectively.

The trends observed in shoot dry weight in response to active ingredient and concentration were similar to those observed for GI. For example, shoot dry weights of untreated ‘Landmark Peach Sunrise’, ‘Lucky Peach’, and ‘Little Lucky Peach Glow’ were 4.3, 4.0, and 2.8 g, respectively (Fig. 2A–L). Though the general trends of diminished shoot dry weight of all three cultivars in response to increasing concentrations of ancymidol, paclobutrazol, and uniconazole were similar to the response of GI, shoot dry weight appeared to be more sensitive to increasing concentrations. For example, though saturation of ‘Landmark Peach Sunrise’ GI suppression in response to ancymidol and uniconazole drenches was not within the range of concentrations employed in this study, reduction in shoot dry weight gain was saturated at 2.3 and 1.5 mg.L⁻¹ for ancymidol and uniconazole, respectively (Fig. 2A and J).

We observed clear differences in growth of lantana cultivars across active ingredient and concentrations. Landmark Peach Sunrise, a vigorous-growing cultivar, clearly requires more PGR for appropriate control, whereas the compact-growing cultivar Little Lucky Peach Glow does not require chemical growth regulation to produce marketable plants. Although we have found no other reports of variation in response to PGRs among cultivars of lantana, we found similar studies evaluating PGR efficacy among cultivars of angelonia [Angelonia angustifolia (Boldt, 2008)], potted sunflower [Helianthus annuus (Whipker and McCall, 2000)], and poinsettia [Euphorbia pulcherrima (Currey and Lopez, 2011)]. Boldt (2008) treated seven different angelonia cultivars with paclobutrazol drenches (5, 10, or 20 mg.L⁻¹) or ethephon (250, 500, or 1000 mg L⁻¹) or daminozide (1250, 2500, or 5000 mg.L⁻¹) foliar sprays 2 weeks after pinching. Across all the treatments, ‘Angelina Violet and White’ and ‘AngelMist Purple Stripe’ were the most sensitive to paclobutrazol drenches and daminozide or ethephon treatments, respectively, whereas ‘AngelMist Dark Lavender’ was the least responsive for all treatments. Whipker and McCall (2000) grew ‘Big Smile’, ‘Pacino’, ‘Sundance Kid’, ‘Sunspot’, and ‘Teddy Bear’ sunflowers in 6-inch-diameter containers and treated with daminozide foliar sprays (4000 or 8000 mg/L⁻¹), paclobutrazol drenches (2 or 4 mg/container), or left untreated. Although 8000 mg/L⁻¹ daminozide or 5 mg/container paclobutrazol drenches resulted in plants that were 24% (4.8 cm) or 36% (7.1 cm) shorter, respectively, than untreated ‘Big Smiles’, or 9% (5.4 cm) or 26% (15.3 cm) shorter, respectively, than untreated ‘Pacino’, untreated ‘Pacino’ were nearly three times the height of untreated ‘Big Smiles’. Similar variation was reported among poinsettia cultivars with the application of low-dose microdrenches.
(Currey and Lopez, 2011). When four different cultivars of poinsettia were grown with target final height of 35 to 40 cm and treated with flurprimidol, Orion required a single 0.20 mg L\(^{-1}\) drench to sufficiently suppress growth, whereas one or two 0.05 mg L\(^{-1}\) drenches resulted in adequate control of Polly’s Pink or Classic Red, respectively; Freedom Salmon required no growth regulation to finish within the target height range. Our data on the varying responses of lantana cultivars to PGR drenches underscore the importance of knowing cultivar vigor and habit to make informed and accurate decisions for successful growth regulation. Though not addressed in the present study, it would be useful to characterize how lantana growth and performance in the landscape follow transplanting as affected by growth regulators applied to vigorous cultivars that, while requiring growth suppression during container production in the greenhouse, are transplanted into outdoor beds where growth suppression may be less desirable.

Ancymidol, flurprimidol, paclobutrazol, and uniconazole all effectively suppressed the growth of lantana, across cultivars; however, efficacy varied with cultivar, active ingredient, and concentration (Figs. 1–5). When both maximal growth control and concentration where suppression is saturated are taken together, ancymidol had the weakest activity for ‘Landmark Peach Sunrise’ and ‘Lucky Peach’ and second-weakest suppression for ‘Little Lucky Peach Glow’, whereas flurprimidol had the strongest growth-suppressing activity across all cultivars even though suppression-saturating concentrations were not always the lowest among the active ingredient. Although there are no reports on the effectiveness of ancymidol or flurprimidol drenches on controlling lantana growth, limited results on the effectiveness of paclobutrazol and uniconazole drenches have been published (Barrett and Schoellhorn, 2001; Rutger, 1996). Rutger (1996) treated ‘New Gold’ lantana in 2.8-L containers with 0, 0.5, 1, 2, or 4 mg L\(^{-1}\) paclobutrazol or 1, 2, or 4 mg L\(^{-1}\) uniconazole 2 weeks after planting. There were no differences between plants provided with 0.5 or 1.0 mg/container paclobutrazol; the GI and shoot dry weight of ‘New Gold’ treated with paclobutrazol was 7.1 (17%) and 5.3 g (21%) less than untreated plants, respectively. Barrett and Schoellhorn (2001) grew ‘Trailing Lavender’ lantana in 4.5-inch containers and 60-mL drenches containing 2, 4, or 8 mg L\(^{-1}\) paclobutrazol or 1, 2, or 4 mg L\(^{-1}\) uniconazole were applied 3 weeks after planting rooted cuttings. There was little difference between the active ingredient and they suppressed growth similarly at the same concentrations.

Our results on the comparative efficacy of the different active ingredients agree with previous reports (Currey and Erwin, 2012; Currey and Lopez, 2011; Currey et al., 2016). Currey and Erwin (2012) treated 11 different kalanchoe (Kalanchoe) species with a variety of PGRs, including ancymidol, paclobutrazol, and uniconazole. Although ancymidol did suppress height of four species, it had no effect on the remaining seven species. Alternatively, paclobutrazol was effective on nine kalanchoe species and uniconazole suppressed stem elongation in every species.
Similar variation in the efficacy of PGR active ingredient in controlling growth of new guinea impatients (Impatiens hawkeri) was reported by Currey et al. (2016). Three cultivars of Divine new guinea impatients were treated with seven PGRs, including ancymidol, flurprimidol, paclobutrazol, and uniconazole. In a preliminary screen of foliar sprays, flurprimidol, paclobutrazol, and uniconazole were the most efficacious active ingredients, whereas ancymidol, chlormequat chloride, daminozide, and ethephon were ineffective. In a subsequent experiment, new guinea impatients height suppression was saturated at 27–30, 20–30, and 4–5 mg L⁻¹ for flurprimidol, paclobutrazol, uniconazole, respectively, across three different cultivars.

To compare the costs of applying these different PGRs, we estimated the cost of applying flurprimidol, paclobutrazol, and uniconazole at the concentrations we identified as effective in this study using PGRcalc (Krug and Whipker, 2010). The cost of applying 2 oz/container of 0.5 to 2 mg L⁻¹ ancymidol, flurprimidol, paclobutrazol, or uniconazole is $7.63 to $30.54, $0.86 to $3.45, $0.94 to $3.77, and $5.48 to $21.93, respectively, per 1000 containers. Using an application rate of 2 qt/100 ft² and the bench area used in our study, the commercial recommendation of applying 3000 mg L⁻¹ chlormequat chloride foliar sprays for controlling lantana growth (Nau, 2011) would cost $28.65 per 1000 containers for each application; with application frequencies up to every other week recommended. Though we did not directly compare sprays and drenches in our work, we believe that drenches have a lower chemical cost based on our calculations for the costs of spray and drench applications. With respect to the cost of drenches using different active ingredients, we found flurprimidol and paclobutrazol to be the most economical active ingredients Currey et al. (2012) reported similar economics for growth control of Easter lilies (Lilium longiflorum) with substrate drenches; flurprimidol provided control comparable to uniconazole for ‘Nellie White’ Easter lilies, yet they were also more economical. Although not the sole reason for selecting PGR treatments, cost can be an important factor to consider in making production decisions.

Conclusions

Ancymidol, flurprimidol, paclobutrazol, and uniconazole are all effective in suppressing growth of different lantana cultivars. However, the degree of control varies with the combination of cultivar, active ingredient, and concentration. Based on the cost of application across the range of effective concentrations for the cultivars used in this study, flurprimidol and paclobutrazol are the most economical active ingredients and concentrations between 0.5 and 2 mg L⁻¹ are recommended for controlling growth. Producers are encouraged to conduct on-site drench trials with their cultivars, culture, and environment to develop specific concentrations for their individual operations.

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