Concentration and Timing of Ethephon Drench Applications Interact to Affect Growth and Flowering of Containerized Angelonia and Geranium

Christopher J. Currey^{1,4}, Kenneth G. McCabe², and Kellie J. Walters³

Department of Horticulture, Iowa State University, 127 Horticulture Hall, Ames, IA 50011

Additional index words. floriculture, greenhouse production, *Pelargonium*, plant growth retardant, summer snapdragon

Abstract. Etephon drenches have been reported to effectively control growth of containerized bedding plants. However, previous researchers have indicated that the effects of ethephon drenches on growth and flowering may differ depending on the timing of applications. Our objectives were to quantify the effects of ethephon concentration, timing of substrate drench application, and their interaction on the growth, size, and flowering of two annual bedding plants. *Angelonia* (*Angelonia angustifolia*) and geranium (*Pelargonium × hortorum*), seedlings were planted in 10.2-cm-diameter containers filled with a commercial, soilless growing substrate composed of (by vol.) 75% sphagnum peatmoss, and 25% perlite. Five, 10, 15, or 20 days after transplanting seedlings, 70-mL aliquots containing 0, 50, 100, or 200 mg·L⁻¹ ethephon were applied as substrate drenches. Species varied in their growth and flowering responses to ethephon concentration, drench application timing, and their interaction. For angelonia, flowering was delayed most with early applications and high concentrations, and delay was diminished with later applications. Angelonia height was unaffected by late applications, though lateral growth was suppressed 20 days after transplant with 200 mg·L⁻¹ ethephon. Flowering of geranium was only delayed when ethephon was applied 5 days after transplanting, whereas flowering, vegetative height, and shoot dry weight were affected more by earlier applications and higher concentrations. Width and root weight were only affected by ethephon concentration, with growth suppression increasing as concentrations increased. Etephon is an effective growth regulator when applied as a substrate drench. However, the degree of activity and resulting impact on flowering, size, and growth is influenced by the interaction between ethephon concentrations and the timing of drench applications after transplanting.

In 2015, the wholesale value of floriculture crops for the top 15 producing states was \$4.37 billion USD (U.S. Department of Agriculture, 2016). Of that total value, annual bedding and garden plants were the most valuable sector, valued at \$1.29 billion USD. Controlling growth of containerized annuals is desirable for several reasons, including producing a plant that is proportionately sized for containers (Vernieri et al., 2003), as well as increasing planting densities during greenhouse production (Carey et al., 2007) and

on shipping carts for transportation (Fair et al., 2012). Although plant growth and final size are affected by genetics (Currey et al., 2016), environmental conditions and cultural practices including temperature (Erwin and Heins, 1995), irrigation (Alem et al., 2015), and mineral nutrition (Haver and Schuch, 1996) can be manipulated to control growth. However, it can be difficult to employ these techniques when a wide range of species are produced in a single greenhouse, as is commonly the case during spring annual production. Chemical plant growth retardants (PGRs) are frequently used to suppress stem elongation and targeted, species-specific applications can be made and are useful in controlling annual bedding plant growth (Dole and Wilkins, 2005; Whipker et al., 2011).

The mode of action for the majority of PGRs is inhibiting specific steps of the gibberellic acid biosynthesis pathway (Rademacher, 2000). Chlormequat chloride inhibits the conversion of geranylgeranyl pyrophosphate to copalyl diphosphate and, to a lesser extent, *ent*-kaurene synthesis. Ancymidol, flurprimidol, paclobutrazol, and uniconazole are all closely related compounds which inhibit synthesis of *ent*-kaurenoic acid, whereas daminozide

inhibits conversion of biologically inactive forms of gibberellic acid into active forms. Cell elongation is suppressed as a result of gibberellic acid biosynthesis inhibition and, therefore, stem elongation and plant size can be controlled. Although ethephon is a commonly used PGR, its mode of action differs compared with other PGR active ingredients. Instead of affecting gibberellic acid synthesis, ethephon breaks down inside plant cells and generates ethylene (Barrett, 2001). In addition to diminishing apical dominance, suppressing flower development and inducing flower abortion, and promoting fruit ripening, increased ethylene concentrations causes microfibril orientation in cell walls to change and inhibits latitudinal cell elongation, which diminishes stem elongation and, therefore, plant size (Burg, 1973).

The majority of PGR applications are administered using either foliar sprays or substrate drenches (Gent and McAvoy, 2000). Spray applications are easy to apply and can provide adequate growth control, though substrate drenches can increase growth control uniformity and duration (Currey et al., 2010; Currey and Lopez, 2011; Currey et al., 2012). Etephon is not currently labeled for application via substrate drenches, though recent research reports the promise of using drenches for growth control (Aiken et al., 2015; Miller et al., 2012). Miller et al. (2012) noted that ethephon drench activity appeared to vary when plants were treated early (2 d after transplanting) as opposed to later (10 d after transplanting); however, application times were not a controlled factor and varied across locations. Since PGR application timing is important to elicit desirable and appropriate plant responses, it is important to quantify the effect of application timing to determine best management practices for using ethephon drenches (Bailey and Whipker, 1998). The objectives of our study were to quantify the effect of ethephon drench concentration and application time after transplanting on growth and development of containerized flowering annuals.

Materials and Methods

‘Serena White’ angelonia and ‘Pinto Premium Deep Red’ geranium grown in 288-cell trays were received from a commercial plug producer (Wagner Greenhouses, Minneapolis, MN). Seedlings were individually planted in 10.2-cm-diameter containers (490 mL vol.; HC Companies, Middlefield, OH) filled with a commercial soilless substrate composed of (by vol.) 75% canadian sphagnum peatmoss and 25% perlite and amended with dolomitic limestone, starter nutrient charge, and a surfactant (Sunshine Mix No. 1; Sun Gro Horticulture, Agawam, MA).

Plants were grown on expanded metal benches in a glass-glazed greenhouse at Iowa State University, Ames, IA (lat. 42°N) with fog cooling, radiant hot-water floor and perimeter heating, and retractable shade curtains controlled by an environmental computer (ARGUS Titan, ARGUS Control Systems, Surrey, British Columbia, Canada). The day

Received for publication 2 Aug. 2016. Accepted for publication 3 Oct. 2016.

We gratefully acknowledge Peter Lawlor for greenhouse assistance, Nicholas Flax and Alexander Litvin for thoughtful critique of the manuscript, Wagner Greenhouses for plant material, and Fine Americas for the plant growth regulator.

The use of trade names in this publication does not imply endorsement by Iowa State University of products named nor criticism of similar ones not mentioned.

¹Assistant professor.

²Research associate and former graduate student.

³Former graduate student.

⁴Corresponding author. E-mail: ccurrey@iastate.edu.

and night greenhouse air temperature set points were 22.5 ± 1 and 18.0 ± 1 °C, respectively. High-pressure sodium lamps delivered a supplemental photosynthetic photon flux of $\approx 190 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at plant height [as measured with a quantum sensor (LI-190 SB; LI-COR Biosciences, Lincoln, NE)] when ambient light intensity was below $100 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ between 0600 and 2200. Plants were irrigated with tap water supplemented with a blend of water-soluble fertilizers (50 and 100 mg·L⁻¹ N provided from 21N–2.2P–16.6K and 15N–2.2P–12.5K, respectively; Everris NA, Inc., Marysville, OH) to provide the following (in mg·L⁻¹): 150 nitrogen, 20 phosphorous, 123 potassium, 33 calcium, 13 magnesium, 0.5 iron, 0.4 manganese and zinc, 0.2 copper and boron, and 0.08 molybdenum.

Five days after transplanting seedlings, PGR drench treatments were initiated. Each plant was provided with a 70-mL aliquot of solution containing deionized water and 0, 50, 100, or 200 mg·L⁻¹ ethephon (Collate; Fine Americas, Inc., Walnut Creek, CA) 5, 10, 15, or 20 d after transplanting.

The date the first flower opened was recorded for each plant during the experiment. Angelonia and geranium growth data were collected 7 and 8 weeks after planting, respectively. Plant height from the surface of the substrate to the tallest growing point (angelonia and geranium) and top of the leaf canopy (geranium only) and the widths at the widest point and 90° from the widest point were recorded. Shoots, severed at the surface of the substrate, and roots, with the substrate gently washed from roots, were placed in separate paper bags and placed in a forced-air oven maintained at 67 °C for 3 d, after which they were weighed and dry weight was recorded.

The experimental design was a completely randomized design in factorial arrangement for each species, with ethephon concentration (four levels) and application time (four levels) as factors. There were 10 replicates (individual plants) for each ethephon concentration and application time combination. Analyses of variance and mean separation using Tukey's honestly significant difference test at $P \leq 0.05$ were performed using SPSS 21.0 (IBM Corporation, Armonk, NY).

Results

Angelonia. Flowering of angelonia was affected by the interactions of ethephon drench concentration and application time (Table 1). Plants treated with 0 mg·L⁻¹ ethephon flowered in 34.9–35.7 d across application times. Alternatively, for plants treated with 50–200 mg·L⁻¹ ethephon, flowering delay decreased with later application times, but increased with concentration. When 50 or 200 mg·L⁻¹ was applied 5 d after transplanting, flowering was delayed by 4.2 or 7.7 d, respectively, compared with control plants. For plants treated 20 d after transplanting flowering was only delayed by 2.0 or 2.2 d compared with control plants when treated with 100 or 200 mg·L⁻¹ ethephon.

Concentration and application also interacted to affect the height and width of angelonia

Table 1. Time to flower, flowering height, canopy height, and shoot dry weight of angelonia (*Angelonia angustifolia* 'Serena White') treated with ethephon drenches. Seedlings were planted into 10.2-cm-diameter round containers filled with a commercial soilless substrate composed of (by vol.) 75% canadian sphagnum and 25% peatmoss and perlite and provided with 70-mL aliquots containing 0, 50, 100, or 200 mg·L⁻¹ ethephon applied 5, 10, 15, or 20 d after transplanting seedlings.

Ethephon concn (mg·L ⁻¹)	Application time (d after transplanting)			
	5	10	15	20
Time to flower (d)				
0	35.3 c ^z A ^y	35.6 bA	35.7 cA	34.9 bA
50	39.5 bA	38.4 aAB	36.4 bcBC	35.4 abC
100	40.7 abA	38.5 aAB	38.1 abB	36.9 aB
200	43.0 aA	40.3 aAB	39.2 aBC	37.1 aC
Concn (C)	***			
Time (T)	***			
C × T	***			
Height (cm)				
0	31.4 aA	30.2 aA	30.5 aA	30.5 aA
50	22.0 bB	28.0 abA	30.3 aA	30.3 aA
100	21.2 bcB	26.0 bcA	27.9 aA	28.5 aA
200	19.2 cC	24.8 cB	27.7 aA	28.4 aA
C	***			
T	***			
C × T	***			
Width (cm)				
0	27.2 aA	27.2 aA	28.1 aA	27.0 aA
50	14.4 bC	21.3 bB	24.3 bAB	25.4 abA
100	12.3 bcC	17.0 cB	21.0 bcA	23.3 abA
200	11.3 cC	16.1 cB	18.3 cB	21.9 bA
C	***			
T	***			
C × T	***			
Shoot dry weight (g)				
0	5.2 aA	5.0 aA	5.6 aA	5.3 aA
50	2.1 bC	4.1 bB	5.1 abA	5.2 aA
100	1.8 bC	3.3 cB	4.5 bcA	4.6 bA
200	1.7 bD	3.0 cC	3.9 cB	4.6 bA
C	***			
T	***			
C × T	***			
Root dry weight (g)				
0	1.06 aA	0.94 aA	1.04 aA	0.96 aA
50	0.33 bC	0.69 bB	0.76 bAB	0.88 abA
100	0.29 bcC	0.57 bB	0.66 bcB	0.79 bcA
200	0.23 cD	0.43 cC	0.57 cB	0.73 cA
C	***			
T	***			
C × T	***			

^zWithin-column means followed by different lower case letters are significantly different by Tukey's honestly significant difference () test at $P \leq 0.05$.

^yWithin-row means followed by different upper case letters are significantly different by Tukey's test at $P \leq 0.05$.

***Indicates significant at $P \leq 0.001$.

(Table 1). Plants were 30.2–31.4 cm tall across application times when no ethephon was applied. When angelonia were treated 5 d after transplanting, plant height was 9.4 to 12.2 cm shorter than untreated plants as ethephon concentration increased from 50 to 200 mg·L⁻¹. There were no differences in height for plants untreated or treated with ethephon 10 or 20 d after transplanting.

Angelonia width was 27.0–28.1 cm for untreated plants across application times. For early applications (5 d after transplanting) widths were less with increasing ethephon concentrations, from 14.4 cm (50 mg·L⁻¹) to 11.3 cm (200 mg·L⁻¹). For the latest application (20 d after transplanting), width of plants treated with 200 mg·L⁻¹ was 5.1 cm less than untreated plants.

Concentration, application time, and their interaction affected shoot and root dry weight of angelonia (Table 1). The shoot weight of

the untreated controls ranged from 5.0 to 5.6 g. Shoot dry weight was lower than untreated plants with increasing ethephon concentrations, but the effect diminished with later applications. For example, shoot weight was 3.1–3.5 g less than untreated plants treated when treated 5 d after transplanting. Alternatively, when 100 or 200 mg·L⁻¹ ethephon was applied 20 d after transplanting, shoot dry weight was 0.7 g less than untreated plants.

Root dry weight was 0.94–1.06 g across application times for plants treated with 0 mg·L⁻¹ ethephon. When ethephon was applied 5 d after transplanting, root weight was 0.73–0.83 g less for plants treated with 50–200 mg·L⁻¹ ethephon compared with control plants; alternatively, root weight was 0.17 or 0.23 g less than untreated plants when applications were made 20 d after transplanting.

Geranium. Ethephon drench concentration and application time interacted to affect

geranium flowering (Table 2). Plants treated with 0 mg·L⁻¹ ethephon flowered 46.7–48.7 d after transplanting, across application time. When 50–200 mg·L⁻¹ ethephon was applied 5 d after transplanting, flowering was delayed by 17.0–19.3 d compared with untreated plants. Alternatively, there were no differences in time to flower across ethephon concentrations when drenches were applied 10 d or more after transplanting.

Flowering heights of untreated geranium plants were 29.0–29.6 cm (Table 2). Although all ethephon drenches suppressed pedicle elongation regardless of application time, the magnitude of effect was greater for earlier applications. For example, flowering height was 6.8 to 8.9 cm shorter than untreated plants, respectively, as concentration increased from 50 to 200 mg·L⁻¹ when applied 5 d after transplanting, or 3.3 to 5.6 cm shorter, respectively, when treated 20 d after transplanting.

For applications made between 5 and 15 d after transplanting, only plants treated with 100 or 200 mg·L⁻¹ had shorter canopy heights, whereas plants treated 20 d after transplanting were 3.1–3.2 cm shorter than untreated plants (Table 2).

Width was affected by ethephon concentration and not application time nor their

interaction (Table 3). As ethephon concentrations increased from 50 to 200 mg·L⁻¹, suppression of plant width increased from 1.0 to 1.5 cm.

Ethephon concentration and application time interacted to affect shoot dry weight (Table 2). For plants treated with 0 mg·L⁻¹ ethephon drenches, shoot dry weight was 7.4–8.0 g. When drenches were applied 5 d after transplanting, shoot dry weight was 1.0 to 1.9 g less than untreated plants as ethephon concentration increased from 50 to 200 mg·L⁻¹. Alternatively, when drenches were applied 20 d after transplanting, shoot dry weight was only impacted by plants treated with 200 mg·L⁻¹ and was 0.9 g less than untreated plants.

Root dry weight was unaffected by ethephon concentration, but not application time or the interaction of ethephon concentration and application time (Table 3). Root weight for plants treated with 0 mg·L⁻¹ was 0.85 g, but was 0.76 g as ethephon concentration increased to 200 mg·L⁻¹.

Discussion

We found that ethephon substrate drenches delayed flowering of angelonia and geranium.

Our results agree with previous reports on the effects of ethephon drenches on annuals (Aiken et al., 2015; Miller et al., 2012). Miller et al. (2012) reported time to flower for numerous annuals treated with ethephon at different institutions. Plants were treated 2 d after transplanting at Cornell University and, while flowering for snapdragon (*Antirrhinum majus*) and dianthus (*Dianthus chinensis*) were unaffected by ethephon, flowering of eight other species was delayed by 1.8–30.7 d. When plants at Michigan State University were treated 10 d after transplanting, tomato (*Lycopersicon esculentum*) and petunia flowering was delayed, whereas snapdragon, bedding impatiens (*Impatiens walleriana*), and osteospermum (*Osteospermum fruticosum*) flowering was not. Interestingly, the same osteospermum cultivar (Zion Copper Amethyst) and cell size was used at both Cornell and Michigan State and, whereas flowering was delayed for plants treated 2 d after transplanting at Cornell, time to flower was unaffected by ethephon applied 10 d after transplanting at Michigan State. Aiken et al. (2015) reported that while veronica (*Veronica spicata*) flowering was unaffected by ethephon drenches, verbena (*Verbena bonariensis*) flowered up to ≈2 weeks later than untreated plants; though flowering delays were greater when substrate pH was more acidic.

Ethephon is used to purposefully delay flowering for different types of crops. For example, stock plant producers may use ethephon to maintain stock plants and keep cuttings in a vegetative state (Glady et al., 2007; Hayashi et al., 2001). Similarly, cuttings can be treated with ethephon during propagation to further inhibit premature flowering (Runkle, 2013). After transplanting, plants may be treated with ethephon to prevent premature flowering during vegetative growth or the “bulking up” phase, or when production times are long (Currey and Flax, 2015). Using ethephon to control flowering is primarily for crops that are already mature and flower readily, such as

Table 2. Time to flower, flowering height, canopy height, and shoot dry weight of geranium (*Pelargonium ×hortorum* ‘Pinto Premium Deep Red’) treated with ethephon drenches. Seedlings were planted into 10.2-cm-diameter round containers filled with a commercial soilless substrate composed of (by vol.) 75% canadian sphagnum peatmoss and 25% perlite and provided with 70-mL aliquots containing 0, 50, 100, or 200 mg·L⁻¹ ethephon applied 5, 10, 15, or 20 d after transplanting seedlings.

Ethephon concn (mg·L ⁻¹)	Application time (d after transplanting)			
	5	10	15	20
Time to flower (d)				
0	48.7 b ² A ^y	47.6 aA	46.7 aA	47.7 aA
50	65.7 aA	51.1 aB	47.6 aB	48.0 aB
100	68.0 aA	52.4 aB	48.0 aB	48.3 aB
200	68.0 aA	52.6 aB	48.2 aB	48.5 aB
Concn (C)	***			
Time (T)	***			
C × T	***			
Flowering height (cm)				
0	29.2 aA	29.6 aA	29.3 aA	29.0 aA
50	22.4 bB	25.9 bA	26.2 bA	25.7 bA
100	23.1 bA	23.6 bA	24.5 bA	24.5 bA
200	20.3 cB	20.1 dB	22.1 cA	23.4 cA
C	***			
T	***			
C × T	***			
Canopy height (cm)				
0	19.5 aA	19.2 aA	18.8 aA	19.8 aA
50	17.1 abAB	18.0 abA	18.0 aA	16.7 bB
100	18.0 bA	16.5 bB	16.1 bB	16.8 bB
200	16.6 cA	16.5 bA	16.1 bA	16.6 bA
C	***			
T	NS			
C × T	***			
Shoot dry weight (g)				
0	7.5 aA	7.5 aA	7.4 aA	8.0 aA
50	6.5 bB	7.4 bA	7.6 aA	7.6 abA
100	6.8 bC	6.9 abBC	7.5 aAB	7.9 aA
200	5.7 cC	6.5 bB	6.7 bAB	7.1 bA
C	***			
T	***			
C × T	*			

²Within-column means followed by different lower case letters are significantly different by Tukey’s honestly significant difference (HSD) test at $P \leq 0.05$.

^yWithin-row means followed by different upper case letters are significantly different by Tukey’s HSD test at $P \leq 0.05$.

NS, *, ***Nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively.

Table 3. Width and root dry weight of geranium (*Pelargonium ×hortorum* ‘Pinto Premium Deep Red’) treated with ethephon drenches. Seedlings were planted into 10.2-cm-diameter round containers filled with a commercial soilless substrate composed of (by vol.) 75% canadian sphagnum peatmoss and 25% perlite and provided with 70-mL aliquots containing 0, 50, 100, or 200 mg·L⁻¹ ethephon. Since neither application time nor the interaction of concentration with application time were significant, data across application time were pooled.

Ethephon concn (mg·L ⁻¹)	Width (cm)	Root weight (g)
0	22.8 a ²	0.85 a
50	21.8 bc	0.85 a
100	22.1 b	0.83 ab
200	21.3 c	0.76 b
Concn (C)	***	***
Time (T)	NS	NS
C × T	NS	NS

²Within-column means followed by different lower case letters are significantly different by Tukey’s honestly significant difference test at $P \leq 0.05$.

NS, ***Nonsignificant or significant at $P \leq 0.05$.

vegetatively propagated crops, or for production in larger containers where plants begin to flower before they are proportionally sized. Production cycles are relatively short and flowering delays increase crop time for seed-propagated annual bedding plants grown in containers. Although recommendations for foliar ethephon spray applications are to cease 6 weeks before marketing to allow flowers to develop for sales and marketing, we observed an opposite trend in our research with the earliest drenches impacting flowering the most and later applications having minimal (angelonia) or no effect (geranium) on time to flower (Tables 1 and 2). The effect of ethephon drenches and sprays on flowering warrants further study to elucidate and better understand how these application methods impact flowering differently. Substrate drenches may serve as a preferred ethephon application method for short-term crops when controlling size, but not flowering, is desired.

In addition to flowering, ethephon drenches controlled size (heights and widths) and growth (dry weight) of angelonia and geranium. This work agrees with previous research on ethephon drenches which reported successful growth control of containerized annuals and perennials (Aiken et al., 2015; Miller et al., 2012). Aiken et al. (2015) reported that veronica treated with ethephon drenches were narrower than untreated plants with no differences in plant height, whereas height and width of treated verbena were consistently smaller than untreated plants. Variation in plant responses to ethephon across study locations was reported by Miller et al. (2012). Although height at flowering for snapdragon or bedding impatiens was suppressed compared with untreated plants, ethephon had no effect on osteospermum or petunia height at Michigan State University. At Cornell University, although ethephon drenches did not affect lobelia (*Lobelia erinus*), 10 other bedding plants were 18% to 70% shorter than untreated plants when treated with ethephon. It is clear that bedding plant growth can be controlled when our results on ethephon drenches are taken together with previous studies. However, there are species-specific responses to ethephon drenches that warrant broad studies screening various containerized bedding plants for responses to ethephon drenches.

In addition to size, ethephon drenches also diminished angelonia and geranium shoot and root dry weight. Shoot dry weight of verbena and veronica treated with ethephon drenches was less compared with treated plants across a range of substrate pH (Aiken et al., 2015). Miller et al. (2012) reported shoot and root weights were affected by ethephon drenches differently across locations. Shoot and root dry weight of annuals treated at Cornell University were 12% to 81% and 2% to 85% less, respectively, than untreated plants. Alternatively, when ethephon was applied 10 d after transplanting to bedding plants at Purdue University, shoot and root weight were 5% to 61% and 4% to 73% smaller, respectively, compared with untreated plants. Though shoot and root weight were affected by ethephon drenches at both locations, growth suppression

was greater for plants treated earlier (Cornell University) as opposed to those treated later (Purdue University). Less shoot weight can be acceptable as long as plants are still considered marketable with respect to size and quality. Since containerized bedding plants are transplanted to large containers such as hanging baskets or patio containers or into beds, care should be taken to minimize excessive suppression of root growth which may negatively impact transplant establishment and subsequent performance. Extremely, early application (i.e., 5 d after transplanting) of ethephon drenches should be avoided for this reason.

Although we have found no research systematically evaluating the effect of ethephon drench application time after transplanting, we have found previous reports of ethephon drench applications to bulb crops at different physiological stages (Moe, 1980; Wees, 1993). Moe (1980) reported suppression of daffodil (*Narcissus pseudonarcissus*) peduncle and leaf elongation increased with ethephon concentration, but decreased with later applications. For example, when daffodil were treated with ethephon when leaves were 6 cm long, flowers and leaves were 12% to 29% and 11% to 18% shorter, respectively, compared with untreated plants. However, when ethephon was applied when leaves were 18 cm long, daffodil flowers and leaves were 9% to 24% and 9% to 17% shorter, respectively, than untreated plants. Similarly, Wees (1993) treated 'Nellie White' easter lilies (*Lilium longiflorum*) when shoots were 10–16 cm tall (1989 or 1990 season) or 7–9 cm tall (1990 or 1991 season). Easter lilies were 17% to 53% shorter than untreated plants when taller shoots were treated, whereas lilies were 36% to 67% shorter than untreated plants when shorter shoots were treated. The results from these studies and our research support the hypothesis that ethephon drench application timing affects the magnitude of growth inhibition, whereby early applications have a greater growth-suppressing effect compared with later applications. However, the stronger activity associated with earlier application times can be excessive, with respect to the degree of growth control.

Conclusions

When the effects of ethephon concentration, application timing, and their interaction on flowering, size, and growth are taken together for both angelonia and geranium and from previous research, we may draw some conclusions for drench applications to herbaceous annuals. We believe that applying ethephon drenches ≤ 5 d after transplanting should not be used for growth control in commercial production. For angelonia, flowering delays were greatest and commercially significant (i.e., >7 d) with early applications, whereas control of size and growth was excessive and resulted in unmarketable plants (Fig. 1). Though the size and growth of geraniums treated 5 d after transplanting resulted in appropriately sized plants for marketing, the flowering delay of >2 weeks is unacceptable

for commercial production (Fig. 2). For applications made between 10 and 20 d after transplanting, concentration selection should depend on the degree of activity desired. Within a given application time, increasing the concentration will increase the magnitude of effect, so greater growth control may be achieved by simply increasing concentrations. We believe that when trying to achieve a similar degree of growth control across application times, ethephon concentration should increase with application time. For example, a lower concentration of 50 mg·L⁻¹ may produce appropriate control for earlier applications (10 d after transplanting), whereas a higher concentration of 200 mg·L⁻¹ may produce acceptable control for later applications (20 d after transplanting).

Fig. 1. Angelonia (*Angelonia angustifolia* 'Serena White') grown in 10.2-cm-diameter containers filled with a commercial soilless substrate composed of (by vol.) 75% canadian sphagnum peatmoss and 25% perlite and provided with 70-mL aliquots containing 0, 50, 100, or 200 mg·L⁻¹ ethephon. Photos taken 6 weeks after transplanting.

Fig. 2. Geraniums (*Pelargonium xhortorum* 'Pinto Premium Deep Red') grown in 10.2-cm-diameter containers filled with a commercial soilless substrate composed of (by vol.) 75% canadian sphagnum peatmoss and 25% perlite and provided with 70-mL aliquots containing 0, 50, 100, or 200 mg·L⁻¹ ethephon. Photos taken 7 weeks after transplanting.

Literature Cited

- Aiken, M.G., H.L. Scoggins, and J.G. Latimer. 2015. Substrate pH impacts efficacy of ethephon drenches on growth of herbaceous perennials. *HortScience* 50:1187–1191.
- Alem, P., P.A. Thomas, and M.W. van Iersel. 2015. Controlled water deficit as an alternative to plant growth regulation of poinsettia stem elongation. *HortScience* 50:565–569.
- Bailey, D. and B. Whipker. 1998. Best management practices for plant growth regulators used in floriculture. North Carolina State Univ. Hort. Info. Lfl. 529.
- Barrett, J. 2001. Mechanisms of action, p. 32–41. In: M.L. Gaston, P.S. Konjoian, L.A. Kunkle, and M.F. Wilt (eds.). *Tips on regulating growth of floriculture crops*. OFA Services, Columbus, OH.
- Burg, S.P. 1973. Ethylene in plant growth. *Proc. Natl. Acad. Sci. USA* 70:591–597.
- Carey, D., B. Whipker, I. McCall, and W. Buhler. 2007. Cytokinin based PGR affects growth of vegetative petunia. *Southern Nursery Assn. Res. Conf.* 52:102–108.
- Currey, C.J., D.M. Camberato, A.P. Torres, and R.G. Lopez. 2010. Plant growth retardant drench efficacy is not affected by substrate containing parboiled rice hulls. *HortTechnology* 20:863–866.
- Currey, C.J., K.J. Walters, and K.G. McCabe. 2016. Plant growth regulator drenches affect lantana cultivars differently. *HortTechnology* 26:20–25.
- Currey, C.J. and N.J. Flax. 2015. Ethephon foliar sprays prevent premature flowering of tissue culture-propagated streptocarpus hybrids. *HortTechnology* 25:635–638.
- Currey, C.J. and R.G. Lopez. 2011. Early flurprimidol drench applications suppress final height of four poinsettia cultivars. *HortTechnology* 21: 35–40.
- Currey, C.J., R.G. Lopez, B.A. Krug, I. McCall, and B.E. Whipker. 2012. Substrate drenches containing flurprimidol suppress height of 'Nellie White' easter lilies. *HortTechnology* 22:164–168.
- Dole, J.M. and H.F. Wilkins. 2005. *Floriculture: Principles and species*. 2nd ed. Pearson Prentice Hall, Upper Saddle River, NJ.
- Erwin, J.E. and R.D. Heins. 1995. Thermomorphogenic responses in stem and leaf development. *HortScience* 30:940–949.
- Fair, B.A., B. Whipker, I. McCall, and W. Buhler. 2012. Height control of 'Hot Lips' hybrid sage to flurprimidol substrate drench. *HortTechnology* 22:539–541.
- Gent, M.P.N. and R.J. McAvoy. 2000. Plant growth retardants in ornamental horticulture, p. 89–146. In: A.S. Basara (ed.). *Plant growth regulators in agriculture and horticulture: Their role and commercial uses*. Food Products Press, Binghamton, NY.
- Gladly, J.E., N.S. Lang, and E.S. Runkle. 2007. Effect of ethephon on stock plant management of *Coreopsis verticillata*, *Dianthus caryophyllus*, and *Veronica longifolia*. *HortScience* 42:1616–1621.
- Haver, D.L. and U.K. Schuch. 1996. Production and postproduction performance of new guinea *Impatiens* cultivars grown with controlled-release fertilizer and no leaching. *J. Amer. Soc. Hort. Sci.* 121:820–825.
- Hayashi, T., R.D. Heins, A.C. Cameron, and W.H. Carlson. 2001. Ethephon influences flowering, height, and branching of several herbaceous perennials. *Sci. Hort.* 91:305–323.
- Miller, W.B., N.S. Mattson, X. Xie, D. Xiu, C.J. Currey, K.L. Clemens, R.G. Lopez, M. Olrich, and E.S. Runkle. 2012. Ethephon substrate drenches inhibit stem extension of floriculture crops. *HortScience* 47:1312–1319.
- Moe, R. 1980. The use of ethephon for control of plant height in daffodils and tulips. *Acta Hort.* 109:197–204.
- Rademacher, W. 2000. Growth retardants: Effects on gibberellin biosynthesis and other metabolic pathways. *Annu. Rev. Plant Physiol. Plant Mol. Biol.* 51:501–531.
- Runkle, E. 2013. Using the PGRs Collate and Florel. *Greenhouse Product News* 23(6):58.
- U.S. Department of Agriculture. 2016. Floriculture crops 2015 summary. Nat. Agr. Sta. Service, Washington DC. 27 July 2016. <<http://usda.mannlib.cornell.edu/usda/current/FlorCrop/FlorCrop-04-26-2016.pdf>>.
- Vernieri, P., G. Incrocci, F. Togononi, and G. Serra. 2003. Effect of cultivar, timing, growth retardants, potting type on potted sunflowers production. *Acta Hort.* 614:313–318.
- Wees, D. 1993. Effects of ethephon and ancymidol on plant height and flower abortion of easter lily. *Can. J. Plant Sci.* 73:879–883.
- Whipker, B.E., I. McCall, and J. Latimer. 2011. Growth regulators, p. 95–105. In: J. Nau (ed.). *Ball redbook, Vol. 2. Crop production*. 18th ed. Ball Publ., West Chicago, IL.