HortScience 47(9):1312–1319. 2012.

Ethephon Substrate Drenches Inhibit Stem Extension of Floriculture Crops

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Additional index words. bedding plants, Dutch bulbs, ethylene, plant growth regulators

Abstract. **Ethephon [(2-chloroethyl) phosphonic acid] is a plant growth regulator that releases ethylene on application and can abort flowers, stimulate branching, and inhibit stem elongation. Although ethephon is used as a foliar spray during the commercial production of many ornamental crops, its effectiveness as a drench has not been widely investigated. We performed experiments to quantify the effects of an ethephon drench on growth and flowering of a range of bedding plant and *Narcissus* cultivars and to assess the effect of lime on ethylene release from a peat substrate. A substrate drench of 0, 100, 250, or 500 mg·L^{-1} ethephon was applied to 12 potted *Narcissus* cultivars at one location, and up to 200 mg·L^{-1} was applied to 24 cultivars of bedding plants at three locations. Compared with untreated controls, ethephon generally reduced plant height at flowering and the effect increased with increased concentration. For example, *Narcissus* treated with a 250 mg·L^{-1} ethephon drench had stems that were 20% to 40% shorter at the end of flowering than control plants. However, ethephon drenches generally caused a 2- to 3-day flowering delay, and two cultivars had a phytotoxic response. Among the bedding plants studied, a 100-mg·L^{-1} ethephon drench suppressed plant height at flowering by greater than 30% in *Catharanthus*, *Celosia*, *Dianthus*, and *Verbena*, but by only 10% to 15% in *Lobelia*, *Lycopersicon*, and *Tagetes*. The drenches also delayed flowering in 10 of the 16 crops measured and decreased dry mass accumulation in all of the crops measured. Ethephon release from peat substrate became maximal ≈120 h after application and was dramatically increased by incorporation of dolomitic lime up to a rate of 9.5 kg lime per m^3 of peat. Collectively, these studies show that ethephon substrate drenches inhibit stem elongation in a broad range of floriculture crops, but can also delay flowering and reduce biomass accumulation.**

Potted spring-flowering bulbs and bedding and garden plants collectively account for $1.97 billion (49%) of the total U.S. wholesale value of floriculture crops for the 15 top-producing states (U.S. Department of Agriculture, 2011). These crops often have excessive stem elongation as a result of dense spacing or suboptimal environmental conditions, which results in overgrown, unattractive, and unmarketable plants (Krug et al., 2006a,b; Starman et al., 2004). For many potted flowering plants such as *Euphorbia pulcherrima* Willd. ex Klotzsch, *Lilium longiflorum* Thunb. and *Lilium* L. hybrids, and *Narcissus pseudonarcissus* L., there are industry target height recommendations for aesthetic value and ease of postharvest packing and shipping (De Hertogh, 1996; Fisher and Heins, 2002; Miller, 1992, 1993). For example, the recommended target height of spring flowering bulbs such as *Narcissus* grown in 15-cm containers is 25 to 30 cm (De Hertogh, 1996). Conversely, there are currently no target height recommendations for annuals as a result of the large number of seed- and cutting-propagated bedding plants in the market.

Plant growth regulators (PGRs) are commonly used in greenhouse production to produce uniform, compact plants that can be easily shipped and marketed to consumers (Currey et al., 2010). Foliar sprays, substrate drenches, liner dips, or bulb, tuber, and rhizome soaks or dips are common application methods for PGRs and one or more of these techniques are appropriate for nearly every active ingredient (Barrett, 2004; Blanchard and Runkle, 2007; Currey et al., 2010; Whipker and McCall, 2000). The majority of synthetic PGRs suppress stem elongation by inhibiting gibberellin biosynthesis (Davis et al., 1988; Rademacher, 2000). In contrast, ethephon [(2-chloroethyl) phosphonic acid] is a PGR that releases ethylene (C_2H_4), chlorine (Cl^-), and hydrogen phosphate ($H_2PO_4^-$) on application and is known to inhibit internode elongation, induce branching, and cause abscission of flower buds and leaves (Glady et al., 2007; Leatherwood et al., 2009; Maynard and Swan, 1963; Starman et al., 2004).

Ethephon sprays are applied to many floriculture crops 1 to 2 weeks after transplant and at 1- to 2-week intervals thereafter (Styer, 2002). Application concentrations for annual and perennials generally range from 250 to 1000 mg·L^{-1} (Glady et al., 2007; Starman et al., 2004; Styer, 2002). Currently, ethephon sprays are the main technique for height control in *Hyacinthus orientalis* L. and *Narcissus* with suggested concentrations of 500 to 2000 mg·L^{-1} depending on the cultivar, length of cooling, and forcing time (De Hertogh, 1996).

Substrate drenches of many PGRs provide more uniform results and increase the duration of effectiveness compared with foliar sprays (Boldt, 2008; Gent and McAvoy, 2000). Applying antigibberellin substrate drenches containing flurprimidol, paclobutrazol, or uniconazole early in the production of *Euphorbia*, *Lilium longiflorum*, and bedding plants is a PGR application strategy for height control (Barrett, 2004; Currey et al., 2010; Currey and Lopez, 2011; Lopez and Runkle, 2007; Runkle et al., 2006).

Although ethephon sprays are effective at inhibiting stem elongation and promoting branching, the potential of ethephon substrate drenches for bedding plant and spring bulb stem elongation control is largely unknown. Johnson et al. (1982) demonstrated growth effects from soil-applied ethephon on *Ficus benjamina* and preliminary results on *Narcissus* height control from substrate applications of ethephon have been reported (Anonymous, 1973, 1974; Briggs, 1975). However, to our knowledge, no literature on the use of ethephon as a substrate drench on bedding plants exists. Therefore, the objectives of this research were to evaluate ethephon drenches on a range of bedding plant and *Narcissus* cultivars and to assess the effect of substrate lime concentrations on ethylene release from a peat substrate.

Materials and Methods

Expt. 1: Ethephon drenches on Narcissus *at Cornell.* Bulbs of 11 *Narcissus* cultivars (Carlton, Cotinga, Exception, Geranium, Ice Follies, Ice King, Primeur, Tahiti, Tete-a-Tete, Thalia, and Westward) were planted into 15-cm round plastic containers (three bulbs per container) filled with a soilless peat-based substrate (LM-111; Lambert Peat Moss, Inc., Riviere-Ouelle, Quebec, Canada), irrigated, and placed into a 9 °C cooler for 18 weeks. Over 6 weeks, temperature was gradually reduced to 1 °C as rooting and shoot growth ensued. Containers were transferred to a glass-glazed greenhouse on 8 Feb. and 1 Mar. and grown at 17 °C constant temperature. Plants

Received for publication 12 May 2012. Accepted for publication 30 July 2012.
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Table 1. Effect of ethephon drenches on 11 *Narcissus* cultivars in 15-cm pots grown at Cornell.[z]

Ethephon concn ($mg \cdot L^{-1}$)	Time to first open flower (days)	Length at first open flower (cm)		Length at end of flowering (cm)		Growth during postharvest (cm)	
		Stem	Leaf	Stem	Leaf	Stem	Leaf
				'Carlton'			
0	15	31.1[y]	29.4[y]	52.1	43.5	21.0[x]	14.1[x]
100	17	25.2	26.9	43.7	40.3	18.6	13.4
250	19	21.7	24.0	34.4	33.8	12.7	9.9
500	18	18.9	22.8	28.3	29.9	9.4	7.1
Significance	L***Q***	L***Q***	L***Q*	L***Q***	L***Q*	L***	L***
				'Cotinga'			
0	14	26.2	28.4	40.5	35.5	14.3	7.1
100	15	23.0	26.7	31.8	31.4	8.8	4.7
250	17	17.0	23.1	24.9	28.1	8.0	5.0
500	16	15.1	21.8	22.2	26.5	7.1	4.8
Significance	L**Q*	L***Q*	L***	L***Q***	L***Q*	L***Q*	NS
				'Exception'			
0	13	36.1	32.0	51.6	47.4	15.5	15.5
100	13	30.8	31.1	45.7	45.1	14.9	14.0
250	14	26.9	26.9	37.5	37.3	10.6	10.4
500	14	24.1	24.6	31.5	31.1	7.4	6.5
Significance	L**QNS	L***Q***	L***	L***Q***	L***	L***	L***
				'Geranium'			
0	19	32.6	32.4	62.5	48.5	30.0	16.2
100	21	32.9	31.8	57.6	46.3	24.8	14.5
250	27	29.5	32.4	49.1	38.38	19.7	6.5
500	33	31.8	33.2	41.2	35.9	9.5	2.7
Significance	L***QNS	NS	NS	L***	L***	L***	L***
				'Ice Follies'			
0	11	29.4	27.0	45.8	39.9	16.5	13.0
100	12	25.7	24.4	36.9	34.9	11.2	10.6
250	12	21.5	21.6	28.3	30.6	6.8	9.0
500	13	19.9	20.3	24.5	26.9	4.6	6.6
Significance	LNSQNS	L***Q***	L***	L***Q***	L***	L***	L***
				'Ice King'			
0	12	31.9	29.2	44.6	41.9	12.7	12.7
100	12	26.6	27.0	37.2	38.5	10.6	11.5
250	14	23.9	25.2	31.9	34.6	8.1	9.4
500	13	19.1	23.1	24.9	29.4	5.9	6.4
Significance	LNSQNS	L***	L**	L***Q**	L***	L**	L**
				'Primeur'			
0	17	30.9	27.9	43.2	39.0	12.4	11.1
100	18	25.6	25.0	35.6	35.6	10.1	10.6
250	19	21.8	22.9	30.2	30.3	8.4	7.4
500	20	19.6	20.3	25.1	26.4	6.1	6.3
Significance	L*QNS	L***Q***	L***	L***Q***	L***Q*	L***	L***
				'Tahiti'			
0	18	38.8	37.4	47.9	43.6	9.1	6.2
100	19	33.3	33.9	41.2	40.5	8.0	6.6
250	19	27.4	28.1	33.6	33.5	6.3	5.4
500	21	25.2	25.5	28.6	28.2	3.4	2.8
Significance	L*QNS	L***Q***	L***Q**	L***Q***	L***	L***	NS
				'Tete-a-Tete'			
0	7	17.3	12.6	31.2	31.2	14.0	18.6
100	7	16.1	13.1	26.7	28.3	10.6	12.4
250	8	12.3	10.1	21.2	23.0	8.9	12.9
500	8	11.5	11.0	16.3	19.2	4.8	8.3
Significance	LNSQNS	L***	L**	L***Q**	L***	L***	L**
				'Thalia'			
0	25	34.4	30.0	44.7	34.4	10.4	4.4
100	28	29.3	29.1	37.7	30.6	8.4	3.5
250	—[w]	—	—	—	27.3	—	—
500	—	—	—	—	20.9	—	—
Significance	—	—	—	—	—	—	—

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Table 1. (*Continued*) Effect of ethephon drenches on 11 *Narcissus* cultivars in 15-cm pots grown at Cornell.[z]

Ethephon concn ($mg·L^{-1}$)	Time to first open flower (days)	Length at first open flower (cm)		Length at end of flowering (cm)		Growth during postharvest (cm)	
		Stem	Leaf	Stem	Leaf	Stem	Leaf
				'Westward'			
0	16	22.8	25.7	36.7	36.2	13.9	10.6
100	17	18.8	25.7	30.7	33.1	12.0	7.4
250	17	15.8	22.4	25.4	31.3	9.7	8.9
500	18	14.3	22.4	19.4	28.6	5.1	6.3
Significance	L**Q_{NS}	L***Q**		L**	L***Q**	L***	L*

[z]All plants had 18 cold weeks of cold and drenched with 120 mL of solution containing 0, 100, 250, or 500 $mg·L^{-1}$ ethephon when plants were 6 to 10 cm tall.
[y]From container rim to top of tallest bud or leaf, respectively.
[x](End of flowering) – (bud color).
[w]Many aborted flowers with these treatments.
Significance of linear (L) or quadratic (Q) regression: NS, *, **, *** denotes nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

were irrigated as needed with municipal tap water (alkalinity 112 $mg·L^{-1}$ $CaCO_3$). When shoots were 6–10 cm long, 120-mL drenches of 0, 100, 250, or 500 $mg·L^{-1}$ ethephon (Florel; Lawn and Garden Products, Inc., Fresno, CA) were applied to each container providing 0, 12, 30, and 60 mg ethephon per container.

As the first flower per container opened, data were recorded and stem and leaf length (container rim to top of each) were recorded. When the crop was showing one senesced flower per container, final data on stem and leaf length were recorded. Growth (stem or leaf elongation) during this postharvest period was calculated by difference. There were five replicates for each cultivar. Data were analyzed using regression analyses using JMP (SAS, Cary, NC).

Expt. 2: Bedding plants at Cornell. On 22 Mar., seedlings of *Catharanthus Roseus* (L.) G. Don. 'Cooler Grape', *Tagetes patula* L. 'Crested Janie Deep Orange' [in 512-cell size (3.1-mL volume) plug trays], *Celosia argentea* L. var. *plumosa* Voss. 'New Look', *Dianthus chinensis* L. 'Super Parfait Raspberry', *Petunia* × *hybrida* Vilm. 'Single Dreams Midnight', *Viola cornuta* L. 'Penny Lane Mixed' [in 288-cell size (6-mL volume) plug trays], and *Angelonia angustifolia* Benth. 'Serena Lavendar', *Pelargonium* × *hortorum* L.H. Bailey 'Pinto Red' [in 128-cell size (12-mL volume) plug trays] and rooted cuttings of *Antirrhinum majus* L. 'Dragon Buttery' and *Osteospermum fruticosium* L. 'Zion Copper Amethyst' [in 51-cell size (27.2-mL volume) strips] were obtained from a commercial greenhouse (C. Raker & Sons, Litchfield, MI). Individual plants were transplanted into 10-cm containers (495-mL volume) filled with a soilless peat-based substrate (LM-111; Lambert Peat Moss, Inc.). Plants were irrigated as needed with municipal tap water (alkalinity 112 $mg·L^{-1}$ $CaCO_3$) supplemented with water-soluble fertilizer to provide 150 $mg·L^{-1}$ nitrogen (N) (Jack's Professional LXTM Water Soluble Fertilizer All-Purpose 20N–2.2P–16.6K; J.R. Peter's Inc., Allentown, PA) with 30 $mg·L^{-1}$ magnesium added from $MgSO_4·7H_2O$. Two d after transplant, ethephon was applied as a 70-mL substrate drench at concentrations of 0, 25, 50, 100, or 200 $mg·L^{-1}$ providing 0, 1.8, 3.5, 7, or 14 mg ethephon per container. Plants were grown in

Table 2. Days to flower and plant characteristics of 11 bedding plant crops grown at Cornell treated 2 d after transplant with a 70-mL ethephon drench per container at 0, 25, 50, 100, and 200 $mg·L^{-1}$.

Ethephon concn ($mg·L^{1}$)	Days to flower	Stem length (cm)	Shoot dry mass (g)	Root dry mass (g)	R:S ratio
			Angelonia		
0	37.5	30.3	3.85	0.76	0.20
25	41.3	25.5	1.81	0.46	0.25
50	44.2	19.6	1.35	0.24	0.18
100	58.5	19.1	1.26	0.18	0.15
200	58.5	14.3	1.24	0.14	0.11
Significance	L***Q***	L***Q***	L***Q***	L***Q***	L***Q***
			Antirrhinum[z]		
0	28.3	21.7	5.92	—	—
25	24.0	19.4	3.43	—	—
50	25.0	17.3	4.31	—	—
100	25.0	17.9	2.96	—	—
200	25.0	16.0	1.95	—	—
Significance	L$_{NS}$Q$_{NS}$	L*Q*	L***Q***		
			Catharanthus		
0	62.0	12.3	3.67	0.67	0.18
25	62.0	11.9	2.28	0.42	0.19
50	66.8	10.0	1.66	0.35	0.21
100	70.0	7.8	1.02	0.21	0.21
200	70.0	5.0	0.69	0.10	0.14
Significance	L***Q***	L***Q***	L***Q***	L***Q***	L$_{NS}$Q*
			Celosia		
0	47.0	26.0	3.63	0.79	0.22
25	49.5	16.7	2.47	0.63	0.26
50	55.0	12.1	1.73	0.41	0.24
100	55.0	10.7	1.36	0.27	0.20
200	55.0	7.8	0.86	0.17	0.20
Significance	L***Q***	L***Q***	L***Q***	L***Q***	L$_{NS}$Q$_{NS}$
			Dianthus[z]		
0	55.0	15.8	3.74	—	—
25	55.0	15.3	3.21	—	—
50	53.7	12.3	2.53	—	—
100	55.0	10.3	1.73	—	—
200	55.0	10.2	1.42	—	—
Significance	L$_{NS}$Q$_{NS}$	L***Q***	L***Q***		
			Lobelia[zy]		
0	—	15.3	10.38	—	—
25	—	13.8	10.67	—	—
50	—	14.3	6.94	—	—
100	—	13.3	6.53	—	—
200	—	13.3	6.60	—	—
Significance		L$_{NS}$Q$_{NS}$	L***Q***		
			Osteospermum		
0	39.3	21.0	4.81	1.06	0.18
25	55.0	18.8	3.44	0.88	0.26
50	52.3	18.5	3.52	0.93	0.23
100	56.2	17.0	3.03	0.70	0.23
200	55.0	14.3	2.21	0.51	0.23
Significance	L*Q**	L***Q***	L***Q***	L***Q***	L$_{NS}$Q$_{NS}$

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Table 2. (*Continued*) Days to flower and plant characteristics of 11 bedding plant crops grown at Cornell treated 2 d after transplant with a 70-mL ethephon drench per container at 0, 25, 50, 100, and 200 mg·L^{-1}.

Ethephon concn (mg·L^{1})	Days to flower	Stem length (cm)	Shoot dry mass (g)	Root dry mass (g)	R:S ratio
			Pelargonium[z]		
0	64.7	28.8	12.85	—	—
25	75.0	26.7	11.34	—	—
50	75.0	24.7	10.33	—	—
100	80.3	22.8	10.92	—	—
200	83.0	19.8	8.52	—	—
Significance	L***Q***	L***Q***	L***Q***		
			Petunia[z]		
0	38.0	20.5	8.27	—	—
25	46.2	21.1	4.02	—	—
50	56.2	14.3	2.92	—	—
100	63.3	14.5	2.87	—	—
200	68.7	14.7	2.96	—	—
Significance	L***Q***	L**Q**	L**Q***		
			Tagetes		
0	27.0	10.1	3.10	0.46	0.15
25	28.8	10.0	2.47	0.45	0.18
50	27.0	9.5	2.20	0.37	0.17
100	25.8	8.9	1.84	0.32	0.18
200	39.0	8.3	1.57	0.21	0.14
Significance	L***Q***	L**Q*	L***Q***	L***Q***	LNSQ*
			Viola		
0	23.0	11.5	2.83	0.40	0.14
25	33.0	11.3	2.05	0.29	0.15
50	51.0	10.7	1.37	0.28	0.21
100	49.0	9.1	1.20	0.19	0.17
200	52.3	7.0	1.03	0.09	0.09
Significance	L***Q***	L***Q***	L***Q***	L***Q***	LNSQ*

[z]Root data were not collected for these species.
[y]Plants were already in flower at transplanting so days to flower was not applicable.
R:S ratio = root to shoot ratio; NS, *, **, *** denotes nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

a glass-glazed greenhouse at a constant air temperature set point of 18 °C and ambient light.

The date of first open flower was recorded for each plant and time from transplant to first open flower was calculated. Within a species when the last plants flowered, the following data were collected for all treatments: plant height, root (RDM) and shoot dry mass (SDM), and root to shoot ratio (R:S) was calculated. There were six replicates for each cultivar and treatment, and each treatment was randomly placed among two greenhouse benches. Data were analyzed using linear and quadratic regression in JMP (SAS).

Expt. 3: Bedding plants at Purdue. On 12 July, rooted cuttings of *Angelonia* 'Angel Mist White Cloud', *Argyranthemum frutescens* (L.) Sch. Bip. 'Madeira Cherry Red', *Calibrachoa* Cerv. hybrid 'Cabaret Pink Hot', *Diascia barberae* Hook. F. 'Wink Coral', *Nemesia fruticans* (Thunb.) Benth. 'Aromatica Royal', *Sutera cordata* Roth. 'Abunda Giant White', and *Verbena* Ruiz × *hybrida* 'Aztec Violet' were transplanted into 10-cm containers (480-mL volume) filled with a soilless peat-based substrate (Fafard Custom 1P; Conrad Fafard, Inc., Agawam, MA). Plants were irrigated as needed with acidified water supplemented with water-soluble fertilizer to provide 200 mg·L^{-1} N supplied from a combination of two fertilizers (Peters Excel© Cal-Mag 21N–2.2P–16.5K and Peters Excel© 15N–2.2P–12.5K; The Scotts Co., Marysville, OH). Irrigation water was supplemented with 93% sulfuric acid (Brenntag, Reading, PA) at 0.08 ppm to reduce alkalinity to 100 ppm and pH to a range of 5.8 to 6.2. Ten d after transplant, ethephon was applied as a 60-mL drench (0, 25, 50, 100, or 200 mg·L^{-1} ethephon) providing 1.5, 3, 6, or 12 mg ethephon per container. Plants were grown in a glass-glazed greenhouse at a constant air temperature set point of 20 °C.

On 24 Aug., stem length from the substrate to the tip of the longest shoot was recorded. Plants were then harvested and RDM and SDM were recorded for each plant and total dry mass (TDM) and R:S ratio were calculated. There were six replicates for each cultivar and treatment. Regression analyses on data were performed using SPSS (Version 18.0; SPSS, Inc., Chicago, IL).

Expt. 4: Bedding plants at Michigan State University. On 12 May, seedlings of *Lycopersicon esculentum* L. 'Beefmaster', *Petunia* × *grandiflora* 'Dreams Burgundy' [in 512-cell size (3.1-mL volume) plug trays], *Antirrhinum majus* 'Montego Purple', and *Impatiens walleriana* Hook. f. 'Super Elfin Bright Orange' [in 288-cell size (6-mL volume) plug trays] and rooted cuttings of *Osteospermum* 'Zion Orange' [in 51-cell size (27.2-mL volume) strips] were obtained from a commercial greenhouse (C. Raker & Sons, Litchfield, MI). Each was transplanted into 10-cm containers (480-mL volume) filled with a soilless peat-based substrate (Suremix; Michigan Grower Products, Inc., Galesburg, MI). Plants were irrigated as needed with reverse osmosis water supplemented with a 14N–3P–14K water-soluble fertilizer (MSU RO Water Special; GreenCare Fertilizers, Inc., Kankakee, IL) to provide 125 mg·L^{-1} N. Ten d after transplant, ethephon concentrations of 0, 50, 100, or 200 mg·L^{-1} were prepared and applied as a 60-mL drench providing 3, 6, or 12 mg per container. Plants were grown in a glass-glazed greenhouse at a constant air temperature set point of 20 °C.

The date of first open flower was recorded for each plant and time from transplant to first open flower was calculated. When each plant flowered, the following data were collected: plant height, number of visible flowers and flower buds, lateral branch number on the primary stem, and visual root rating (5 = large, well developed; 1 = small, poorly developed). Plants that did not flower within 64 d after transplant were not included in the analysis. There were 10 replicates for each species and treatment. Data were analyzed with SAS (SAS Institute, Inc., Cary, NC) linear and quadratic regression procedure (PROC REG).

Expt. 5: Ethylene release from substrates of varying pH at Cornell. Substrates of different pH were prepared by adding 0 to 11.9 kg dolomitic lime to 1 m^{-3} of Canadian sphagnum peatmoss. The mixtures were slightly moistened with water, sealed to avoid moisture loss, and held at room temperature for 3 weeks. A volume of substrate equal to a 10-cm container (≈0.5 L) was placed into 0.88-L glass jars. Ethephon (100 mg·L^{-1}, 60-mL volume) was added to the jars that were then sealed with lids fitted with rubber septa. Two controls consisting of ethephon liquid only (100 mg·L^{-1}, 60 mL) with or without 2 pellets of KOH were also used. Headspace samples of 1 mL were withdrawn at intervals and ethylene concentration determined by injection into a gas chromatograph equipped for ethylene analysis. There were five replicates per treatment.

Results

Expt. 1: Ethephon drenches on Narcissus *at Cornell.* There were few differences between the two experiments, so data were pooled for the final analysis. Ethephon drenches reduced stem and leaf growth across most *Narcissus* cultivars trialed (Table 1); this was observed at the time of first open flower and as plants began to senesce. With the ethephon concentrations used, there were significant reductions in additional stem (2- to 3-fold) and leaf (usually 2-fold) growth during the post-flowering period. Among all cultivars, ethephon drenches generally caused a 2- to 3-d flowering delay, especially at higher concentrations. There were no differences in duration of flowering or any evidence of negative effects of ethephon on flower longevity among most cultivars (data not presented). There was no visible foliar phytotoxicity at the concentrations and volume applied. However, two cultivars showed

negative effects. Flowering of 'Geranium' was severely delayed by ethephon drenches, although it eventually flowered normally. Flower stem growth was restricted and flower abortion of 'Thalia' was observed with every ethephon treatment and exacerbated at the two highest concentrations.

Expt. 2: Bedding plants at Cornell. Ethephon drenches had no effect on time to flower for *Antirrhinum*, *Dianthus*, and *Lobelia* but delayed flowering of *Angelonia*, *Catharanthus*, *Celosia*, *Osteospermum*, *Pelargonium*, *Petunia*, *Tagetes*, and *Viola* (Table 2). Most notably, flowering was delayed by 30 and 31 d for *Viola* and *Petunia*, respectively, at 200 mg·L^{-1} as compared with 0 mg·L^{-1} ethephon drenches. *Celosia*, *Osteospermum*, and *Viola* flowered later as ethephon drench concentration increased from 0 to 50 mg·L^{-1}, whereas greater concentrations did not further delay flowering. Stem length was reduced by ethephon drenches for all species except *Lobelia*. Among the species most affected were *Celosia*, *Catharanthus*, and *Angelonia* with stem length reduction of 70%, 59%, and 53%, respectively, at 200 mg·L^{-1} vs. control plants. The SDM of all 11 species was negatively affected by increasing ethephon drench concentrations. Stem length was reduced in *Catharanthus* (81%) and *Celosia* (76%) in response to 200 mg·L^{-1} ethephon, whereas the least affected species were *Pelargonium* (31%) and *Lobelia* (36%). Depending on species, reduction in RDM varied from 52% to 85% for *Osteospermum* and *Catharanthus*, respectively, for plants treated with drenches containing 200 mg·L^{-1} ethephon. The R:S ratio of *Celosia* and *Osteospermum* was unaffected by increasing ethephon concentration, whereas *Tagetes*, *Viola*, and *Catharanthus* exhibited a quadratic response.

Expt. 3: Bedding plants at Purdue. As ethephon drench concentration increased from 0 to 200 mg·L^{-1}, final stem length decreased for nearly all species (Table 3). For example, when 200 mg·L^{-1} ethephon was applied to the substrate of *Angelonia*, *Calibrachoa*, and *Nemesia*, stem length was 8.9, 8.3, and 11.6 cm shorter, respectively, compared with untreated plants. An ethephon drench had no effect on stem length of *Diascia*. Ethephon reduced TDM and SDM for all species as concentration increased and was greatest in trailing species such as *Calibrachoa*, *Nemesia*, *Sutera*, and *Verbena*. The TDM of *Calibrachoa*, *Nemesia*, *Sutera*, and *Verbena* treated with a 200 mg·L^{-1} ethephon drench was reduced by 60%, 39%, 40%, and 37%, respectively, compared with control plants. Similarly, RDM of *Calibrachoa*, *Diascia*, *Nemesia*, and *Sutera* treated with 200 mg·L^{-1} ethephon was reduced by 53%, 73%, 59%, and 43%, respectively; RDM of *Angelonia* and *Verbena* was unaffected. The R:S ratios of *Calibrachoa*, *Nemesia*, *Osteospermum*, and *Sutera* were not or marginally influenced by ethephon. In contrast, the R:S ratio increased by 44% in *Angelonia* and decreased by 60% and 15% in *Argyranthemum* and *Diascia*, respectively, as the ethephon drench concentration increased to 200 mg·L^{-1}.

Table 3. Plant characteristics of eight bedding plant crops grown at Purdue treated 10 d after transplant with a 74-mL ethephon drench per container at 25, 50, 100, and 200 mg·L^{-1}.

Ethephon concn (mg·L^{-1})	Stem length (cm)	Total dry mass (g)	Shoot dry mass (g)	Root dry mass (g)	R:S ratio
			Angelonia		
0	40.4	7.35	6.35	1.00	0.16
25	39.7	7.08	6.02	1.06	0.18
50	36.6	6.83	6.00	0.83	0.14
100	34.9	5.71	4.95	0.76	0.15
200	31.5	5.13	4.23	0.90	0.23
Significance	L***Q***	L***Q**	L***Q**	LNSQNS	L**Q**
			Argyranthemum		
0	17.1	7.53	6.31	1.22	0.19
25	16.1	6.88	5.90	0.98	0.17
50	15.3	6.93	6.02	0.91	0.15
100	14.1	5.06	4.42	0.64	0.14
200	13.9	5.39	4.66	0.73	0.16
Significance	L***Q***	L***Q***	L***Q***	L***Q***	L*Q***
			Calibrachoa		
0	25.9	5.68	5.32	0.36	0.07
25	25.0	5.09	4.81	0.28	0.06
50	23.6	3.47	3.22	0.25	0.08
100	21.1	2.98	2.75	0.23	0.08
200	17.6	2.26	2.09	0.17	0.09
Significance	L***Q***	L***Q***	L***Q***	L***Q***	L*Q*
			Diascia		
0	29.5	9.16	8.00	1.16	0.15
25	35.4	8.91	8.20	0.71	0.09
50	36.0	8.19	7.69	0.50	0.07
100	34.5	7.29	6.91	0.38	0.06
200	32.3	6.32	6.01	0.31	0.06
Significance	LNSQNS	L***Q**	L**Q**	L***Q***	L**Q***
			Nemesia		
0	36.1	5.37	5.20	0.17	0.03
25	37.5	4.52	4.38	0.14	0.03
50	30.2	3.49	3.37	0.12	0.04
100	26.9	3.31	3.21	0.10	0.03
200	24.5	3.30	3.23	0.07	0.03
Significance	L***Q***	L*Q**	L*Q**	L***Q***	LNSQNS
			Osteospermum		
0	22.7	7.16	6.39	0.78	0.12
25	22.1	6.59	5.85	0.75	0.13
50	19.5	5.21	4.70	0.52	0.11
100	20.6	4.87	4.41	0.45	0.10
200	19.1	5.12	4.60	0.52	0.12
Significance	L*Q*	L**Q***	L**Q***	L*Q**	LNSQNS
			Sutera		
0	40.0	10.72	10.20	0.51	0.05
25	43.1	9.38	8.90	0.48	0.05
50	37.8	9.54	9.03	0.51	0.06
100	33.7	6.56	6.25	0.31	0.05
200	34.3	6.41	6.12	0.29	0.05
Significance	L***Q***	L***Q***	L***Q***	L***Q***	LNSQNS
			Verbena		
0	28.2	7.00	6.74	0.26	0.04
25	29.8	6.47	6.15	0.32	0.05
50	23.1	5.31	5.07	0.24	0.05
100	19.3	4.04	3.79	0.25	0.06
200	24.9	4.38	4.17	0.21	0.05
Significance	LNSQ*	L**Q**	L**Q**	LNSQNS	LNSQ*

R:S ratio = root to shoot ratio; Significance of linear (L) or quadratic (Q) regression: NS, *, **, *** denotes nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Expt. 4: Bedding plants at Michigan State University. Ethephon drenches had no effect on flowering time of *Antirrhinum*, *Impatiens*, or *Osteospermum* but increasingly delayed flowering in *Lycopersicon* and *Petunia* as concentration increased from 0 to 200 mg·L^{-1} (Table 4). In *Lycopersicon*, the 100 and especially 200-mg·L^{-1} drench treatments caused stem epinasty and promoted adventitious rooting along stems (data not collected). Plant height at flowering decreased as the ethephon concentration increased in *Antirrhinum* (up to 12%) and *Impatiens* (up to 22%), but there was no consistent effect on the other three crops. Ethephon had contrasting effects on flower or inflorescence number at first flowering, showing a quadratic response with *Antirrhinum*, a decreasing response (up to 60%

Table 4. Days to flower and plant characteristics at flowering of five bedding plant crops grown at Michigan State University treated 10 d after transplant with a 60-mL ethephon drench per container at 0, 50, 100, and 200 mg·L^{-1}.[z]

Ethephon concn (mg·L^{-1})	Days to flower	Ht at flower (cm)	Number of branches	Number of flowers of inflorescences	Root rating
			Antirrhinum		
0	28.2	13.3	13.8	43.7	1.70
50	28.4	13.1	14.3	54.3	1.90
100	29.6	12.3	14.0	39.3	2.30
200	29.7	11.7	13.8	33.5	1.80
Significance	LNSQNS	L**Q*	LNSQNS	L*Q*	LNSQ*
			Impatiens		
0	33.5	6.57	4.20	60.0	3.40
50	31.1	5.24	4.10	42.4	2.60
100	33.2	5.34	4.20	33.8	2.30
200	34.0	5.14	4.00	24.2	1.90
Significance	LNSQNS	L**Q**	LNSQNS	L***Q***	L***Q***
			Lycopersicon		
0	37.4	64.1	11.3	9.20	4.60
50	38.1	52.8	10.6	12.2	4.60
100	44.4	56.6	12.6	15.1	4.90
200	55.8	58.8	11.3	17.4	2.60
Significance	L***Q***	LNSQ**	LNSQNS	L***Q***	L***Q***
			Osteospermum		
0	51.1	22.2	37.1	13.7	1.90
50	51.6	23.2	35.7	16.4	2.70
100	54.2	21.4	36.6	19.6	1.40
200	52.8	21.0	35.7	19.9	1.70
Significance	LNSQNS	LNSQNS	LNSQNS	L***Q***	LNSQNS
			Petunia		
0	28.1	8.69	10.7	7.10	1.70
50	29.1	7.80	11.7	8.90	2.70
100	36.4	8.94	11.9	16.5	2.40
200	42.3	9.67	11.0	20.3	2.10
Significance	L***Q***	LNSQNS	LNSQNS	L***Q***	LNSQ*

[z]The subjective root rating was performed at flowering and ranged from 5 (large, well developed) to 1 (small, poorly developed). Significance of linear (L) or quadratic (Q) regression: NS, *, **, *** denotes nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

fewer flowers) in *Impatiens*, and an increasing response in *Lycopersicon*, *Osteospermum*, and *Petunia* (up to 90%, 45%, and 186% more flowers, respectively). The root quality ratings at first flowering were variable and there were no consistent trends among the five crops studied.

Expt. 5: Ethylene release from substrates of varying pH. Within ≈120 h, maximal ethylene release in the container was measured with ethephon and KOH and final ethylene concentrations were close to the theoretical concentration of ≈1045 µL·L^{-1} (Fig. 1). Essentially no ethylene (less than 1 µL·L^{-1}) was released from ethephon in the absence of KOH or substrate. Ethylene release from peatmoss was dramatically increased by incorporating dolomitic lime (Table 5). When no lime was added to the substrate, very little ethylene accumulated (less than 20 µL·L^{-1}), although this concentration was significantly greater than the container with only ethephon. As lime addition increased to 9.5 kg·L^{-1}, ethylene release and accumulation in the headspace increased.

Discussion

Ethephon drenches inhibited stem growth in nearly all of the bedding plants studied, although the magnitude varied among species and locations. For example, a 60- to 70-mL drench per 10-cm container of 100 mg·L^{-1} ethephon solution reduced plant height at flowering by greater than 30% in *Angelonia* (at Cornell), *Catharanthus*, *Celosia*, *Dianthus*, and *Verbena* but by only 10% to 15% in *Angelonia* (at Purdue), *Lobelia*, *Lycopersicon*, and *Tagetes* (Fig. 2). Generally, the height suppression was greatest in the study at Cornell, which could be attributed to the earlier

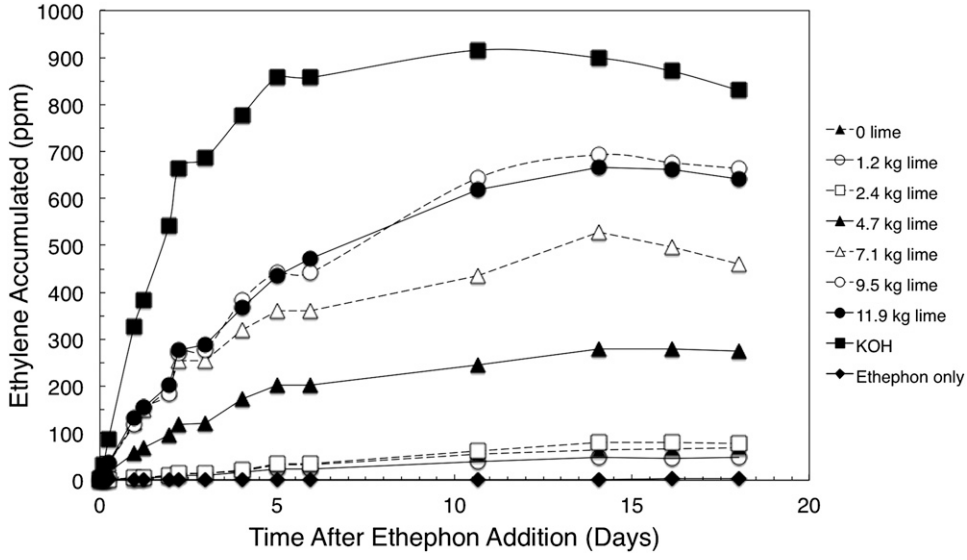

Fig. 1. Effect of lime addition to peatmoss on ethylene evolution after ethephon application. Substrates were prepared by mixing 0 to 11.9 kg dolomitic lime to 1 m^3 of sphagnum peatmoss, moistened slightly, sealed, then held at room temperature in darkness for 3 weeks. A volume of substrate equivalent to that held in a 10-cm pot was placed in a 0.88-L glass jar, moistened with tap water, then 60 mL of solution containing 100 mg·L^{-1} ethephon was added to each jar. Jars were sealed and 1-mL samples withdrawn at varying intervals for ethylene analysis by gas chromatography. Additional controls (without peat) consisted of 60 mL of 100 mg·L^{-1} ethephon with or without 2 pellets of KOH added. Points are means of three to five replicates.

application (2 d after transplant) compared with the other locations (10 d after transplant). For most crops, stem length decreased linearly or quadratically with increasing ethephon application. Exceptions were *Lobelia* at Cornell, *Diascia* at Purdue, and *Osteospermum* and *Petunia* at Michigan State University, which showed no significant trends. It is likely the response to a given ethephon drench will depend on many variables, perhaps including species and cultivar, drench timing, temperature, light, substrate components, and other factors. To our knowledge, this is the first published report on the effects of an ethephon drench on bedding plants and thus, comparisons with other studies are not possible.

Flowering time of bedding plants was quantified at Cornell and Michigan State University and an ethephon drench delayed flowering in 10 of the 16 crops, especially at concentrations 100 mg·L^{-1} or greater. For example, a 200-mg·L^{-1} ethephon drench delayed flowering of *Petunia* by 81% at Cornell and by 51% at Michigan State University. Ethephon drenches had no effect on flowering time of *Antirrhinum* at either location and *Dianthus*, *Impatiens*, or *Osteospermum* only at Michigan State University. Ethephon drenches inhibited SDM in all crops in which it was quantified at Cornell and Purdue. The RDM was also suppressed in most of these crops, resulting in somewhat inconsistent R:S ratios. Ethephon had a contrasting effect on flower number at Michigan State University. Increasing ethephon concentration dramatically decreased flower numbers in *Impatiens* but increased flowers in *Lycopersicon*, *Osteospermum*, and *Petunia*.

The present experiments show potential for the use of ethephon as a substrate drench on *Narcissus*. Unlike the bedding plant studies, we did not evaluate root growth of *Narcissus*, because nearly all root growth occurred during cooling before ethephon was applied. Thus, in *Narcissus*, the growth reductions are not the result of restricted root growth and are more likely a direct result of the ethylene released from ethephon. In the *Narcissus* forcing industry, ethephon sprays are the most common method of height control, but they are not always effective (Moe, 1980; Miller, personal observation) and this has prompted more recent research into using bulb dips and substrate drenches containing flurprimidol, paclobutrazol, and uniconazole for height control (Krug, et al., 2005, 2006a, 2006b; Miller, 2011). The present results demonstrate that excellent height control of *Narcissus* using ethephon substrate drenches may be achieved. This suggests that variability in *Narcissus* response to ethephon sprays may be the result of spray application technique such as the volume of solution applied per container or area. Perhaps much of the height-suppressing effect of ethephon sprays on *Narcissus* is actually the result of a substrate drench effect and greater efficacy is seen when greater spray volumes are used.

Table 5. pH of sphagnum peat amended with dolomitic lime.[z]

Lime (kg·m^{-3})	pH
0	3.86
1.2	4.58
2.4	5.10
4.7	6.52
7.1	6.87
9.5	7.13
11.9	7.27

[z]Means of five replications.

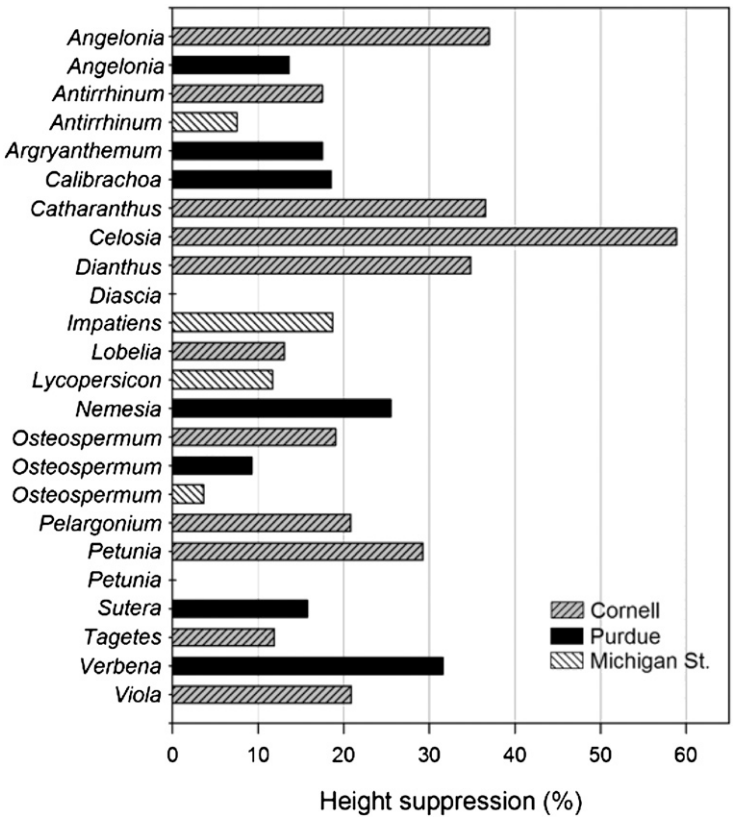

Fig. 2. The effect of a drench containing 100 mg·L^{-1} ethephon on percentage height reduction in bedding plants grown in 10-cm containers at three universities. The drench volume per pot and time of application (days after transplant) were 70 mL and 2 d at Cornell and 60 mL and 10 d at Purdue and Michigan State University (MSU). Ethephon had no effect on plant height of *Diascia* at Purdue or *Petunia* at MSU.

Although our results demonstrate that ethephon applied to substrate can be an effective growth retardant, the exact mechanism by which this occurs is unknown. Ethephon drenches reduced RDM, root ratings, or R:S ratios in several bedding plants in this study (Tables 2 to 4). However, similar ethephon concentrations reduced plant height when applied to both fully rooted *Narcissus* plants (Table 1) or newly transplanted bedding plants (Tables 2 to 4). Therefore, reduced root growth or development cannot be the primary mechanism by which inhibited stem growth occurred in *Narcissus*. One mechanism may be that ethylene released in substrate diffuses toward the shoot over a prolonged period of time, where it suppresses cell elongation. This hypothesis is supported by data from Expt. 5 showing long-term release of ethylene from substrates of varying pH (Fig. 1) and by the fact *Narcissus* leaves elongate as a result of cell divisions in the intercalary meristem with further elongation occurring within ≈40 mm of the leaf base (Denne, 1960). In most forcing situations, these zones would be under the substrate surface and exposed to substrate borne ethylene or direct contact with ethephon. Alternatively, some of the applied ethephon may be translocated in the plant, as has been demonstrated (Edgerton and Hatch, 1972; Martin et al., 1972). Such translocated ethephon could then release ethylene in subapical elongation regions, leading to inhibited stem growth. It is unknown, however, if ethephon can be absorbed into intact roots of the plants investigated or the overall extent of translocation (if any). Clearly, additional work is needed to elucidate the mode(s) of action of substrate-applied ethephon. The effect of liming on ethylene release suggests a possible experimental approach whereby rate of ethylene generation may be modified by substrate pH.

Despite the potential benefits of ethephon drenches in terms of regulation of stem extension, our findings demonstrate several unwanted side effects for many of the bedding plant crops. The reduction in root and shoot development was most dramatic when drenches were applied 2 d after transplant as opposed to 10 d after transplant. It was also noted that morphology of *Lycopersicon* plants was significantly affected by ethephon drenches. Treated plants exhibited severely bent stems and adventitious rooting on stems (Runkle,

personal observation), similar to the characteristic ''triple response'' to ethylene (Reid, 1987). A delay in flowering due to ethephon drenches was found in many bedding plant crops, although species varied in their sensitivity (Tables 2 and 4) and this finding was not unexpected. Although some flowers are insensitive to ethylene, flowering may be promoted by ethylene such as in bromeliads (Dolan, 1997). However, exogenous applications of ethylene are well known to affect various aspects of flower development including flower bud abortion, delay in floral initiation, senescence of mature flower buds, wilting of petals, or failure of the bud to open (Reid, 1987).

One of the drawbacks of ethephon drenches in bedding plant production is a delay in flowering. However, consideration must also be given to the potential effect of ethephon drenches on postharvest flower life and senescence when drenches are made late in crop production. Ethephon drenches of 100 or 200 $mg \cdot L^{-1}$ applied to mature seed *Impatiens* resulted in a 2- to 3-fold increase in flower senescence 5 d after drench as compared with untreated plants (Mattson, unpublished data). Although flower and bud abscission was not observed when ethylene-sensitive *Impatiens* plants were placed next to ethephon-drenched plants (Runkle, personal observation), it could be envisioned that when several thousand plants are drenched in a poorly ventilated greenhouse that nearby sensitive crops may be affected. More work is needed to assess any effect of ethephon drenches on neighboring crops, because ethylene in the air could accumulate to damaging levels for other crops.

Conclusions

This work demonstrates potential for ethephon application as a substrate drench for height control on a range of containerized floriculture crops. However, additional studies are necessary before ethephon drenches are adopted by the commercial industry. For example, we found that drench effects varied based on the specific crop and application rate and timing. More work is needed to determine any potential interactions with greenhouse environmental conditions and/or cultural practices. Further studies may help identify the mechanism of action for ethephon substrate drenches on stem extension. Finally, it should be noted that currently available ethephon products are not labeled for drench application.

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