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Quantifying Growth Control of Annual Bedding Plants with Ethephon Substrate Drenches

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Abstract. **Ethephon (2-chloroethylphosphonic acid) is a plant growth regulator widely used in horticultural and agronomic crop production to control stem elongation, increase lateral branching, and manipulate flowering. While substrate drench applications of ethephon can inhibit the growth of containerized annual bedding plants, research has been limited to fewer than 30 taxa despite the hundreds of species grown in floriculture production. Therefore, our objective was to evaluate and quantify the efficacy of ethephon substrate drenches on the growth of 20 taxa of containerized annual bedding plants. Plants were transplanted into 12-cm, 12.7-cm, or 16.5-cm containers filled with a soilless peat-based substrate. After 10 d, eight single-plant replicates received a substrate drench of 90-mL or 150-mL aliquots of solution, based on container size, containing 0, 25, 50, 75, 100, or 200 mg·L^{-1} ethephon. Plants were grown in a glass-glazed greenhouse for 3 to 6 weeks after drench before growth and morphological data, including plant height, plant diameter, shoot dry weight (SDW), and root dry weight (RDW) were determined. The magnitude of growth control varied among annual bedding plant taxa with increasing ethephon substrate drench concentrations. For most taxa, drenches of 25 to 100 mg·L^{-1} ethephon were determined to be effective at controlling plant height and plant diameter without negatively impacting visual ornamental plant quality. For example, when drenched with 100 mg·L^{-1} ethephon, interspecific geranium (*Pelargonium interspecific* 'Calliope® Large Dark Red') and zonal geranium [*Pelargonium zonale* (L.) L'Hér. 'Americana® Dark Red'] were 27% (8.0 cm) and 29% (8.1 cm) shorter, respectively, than untreated plants. We observed 1.5% (0.34 cm) and 18.1% (3.2 cm) smaller plant diameters for coleus [*Coleus scutellarioides* (L.) Benth. 'Main Street™ Ocean Drive'] and heliotropium (*Heliotropium arborescens* L. 'Scentropia™ Dark Blue'), respectively, as concentrations increased from 0 to 25 mg·L^{-1} ethephon. The SDW and RDW were also influenced by increasing ethephon substrate concentrations. For instance, SDW of New Guinea impatiens (*Impatiens hawkeri* R.W. Baker & Corner 'Magnum Fire') and calibrachoa [*Calibrachoa* ×*hybrida* (Llave and Lex.) M. Martens and L. Westra. 'Callie® Dark Red'] drenched with 25 mg·L^{-1} ethephon were 24% (2.1 g) and 33% (0.9 g) smaller, respectively, compared with untreated plants. The RDWs of lantana (*Lantana camara* L. 'Bandolista™ Red Chili') and portulaca (*Portulaca oleracea* L. 'Flame Red') were 62% (1.42 g) and 55% (0.8 g) less, respectively, as concentrations increased from 0 to 200 mg·L^{-1} ethephon. While responses varied across taxa, this research expands the scope of annual bedding plants and further demonstrates the effectiveness of ethephon applied as a substrate drench.**

Annual bedding plants are the largest sector of the floriculture market in the United States, with a total sales value of USD $2.5 billion (US Department of Agriculture, National Agricultural Statistics Service 2024). Many hundreds of species with thousands of cultivars of annual bedding plants are commercially available, with each varying in growth habits, cultural and environmental needs, and specified finished plant size for market and consumers (Ball Horticultural Co. 2025; Bisgrove 2004). Although finished plant size varies among species, plants often exhibit excessive stem elongation that, if left uncontrolled, can lead to reduced ornamental quality and shipping challenges for greenhouse growers. For most annual bedding plant species, there are no specific requirements for finished plant height; however, a general recommendation is 1.5-times to twice the container height (Sachs et al. 1976). As such, growers must adequately control stem elongation to produce high-quality and compact annual bedding plants. Growers can control plant growth and development by manipulating environmental conditions such as light (intensity, quality, and photoperiod) and temperature (+DIF, –DIF, or DROP) or changing cultural practices like plant spacing (density), water stress, or limiting plant mineral nutrition (Rich and Owen 2025). An alternative method of controlling plant growth in bedding plant production is applying plant growth regulators (PGRs).

A PGR is a natural or synthetic compound that manipulates plant growth by interfering with the plant hormonal status to enhance or control growth (Rademacher 2000, 2015). There are 11 PGR active ingredients specifically labeled for use on ornamental crops, mainly to restrict stem elongation; however, they can also be used to initiate rooting, promote stem elongation or lateral branching, and manipulate flowering (Rich and Owen 2025; Whipker 2025). In bedding plant production, PGRs are used to control stem elongation, thus producing a compact and uniform crop that meets the ornamental market needs and is less likely to experience damage during shipping (Currey et al. 2010; Whipker and Latimer 2021). Furthermore, PGRs can be applied using various methods, including foliar sprays, sprenches, substrate drenches, or preplant liner or bulb soaks (Krug 2004; Sajjad et al. 2017; Whipker and Latimer 2021). For each active ingredient, the application method can greatly impact the efficacy. For instance, paclobutrazol [(2R, 3R)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl)pentan-3-ol] has a greater degree of activity in root tissue when compared with that in the stem or leaf tissue, suggesting that a substrate drench would provide a greater level of growth control than a foliar application (Whipker 2025).

Among the PGR active ingredients used in annual bedding plant production, pyrimidine and triazole-classified growth restrictors are most widely used to control plant growth. These groups include ancymidol [cyclopropyl-(4-methoxyphenyl)-pyrimidin-5-ylmethanol], flurprimidol [2-methyl-1-pyrimidin-5-yl-1-[4-(trifluoromethoxy)phenyl]propan-1-ol], paclobutrazol, and uniconazole [(1E)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl)pent-1-en-3-ol] (Currey 2019; Owen 2024; Whipker and Latimer 2021). These active ingredients control stem elongation by inhibiting the biosynthesis of gibberellic acid, which is the primary hormone responsible for cell elongation and division, and are also known as gibberellin antagonists (Davies et al. 2017; Rademacher 2015). Ethephon (2-chloroethylphosphonic acid), while not a gibberellin antagonist, can provide growth control levels comparable to those associated with triazole PGRs in floriculture crops by breaking down inside plant cells to generate ethylene gas (Currey et al. 2016).

The inception of ethephon as a PGR for floriculture crop use occurred in the 1990s (Konjoian 1995). Foundational research explored the efficacy of ethephon foliar sprays and found the effects to be beneficial for controlling plant height, reducing apical dominance, and aborting undesired flowers of annual bedding plants (Konjoian 1995; Whipker 2014; Whipker and Latimer 2021). Styer (2002) suggested that ethephon had no root activity, suggesting that growth control was achieved through restricted root growth. However, research by Miller et al. (2012) demonstrated that ethephon substrate drenches significantly influenced time to flower, plant height, shoot dry weight (SDW), and root dry weight (RDW) of 11 cultivars of daffodil (*Narcissus* sp.) and 24 species of annual bedding plants. For instance, when drenched with 200 mg·L^{-1} ethephon, stem length of angelonia (*Angelonia angustifolia* Benth. 'Serena Lavander') was 53% less compared with that of untreated plants (Miller et al. 2012). It

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was hypothesized that growth control was the result of ethylene generated by ethephon in shoot tissue, not merely restrictions in root growth. Subsequent research by Miller et al. (2022) reinforced this hypothesis by reporting that ethephon accumulated in nontreated shoot tissues following substrate drench application, thus demonstrating that ethephon is xylem-mobile. Even though research has shown the efficacy of ethephon applied as substrate drench, at the time of publication, ethephon is only labeled for foliar spray applications, and literature regarding ethephon substrate drenches remains limited. Therefore, the objective of this research was to evaluate the efficacy of ethephon substrate drenches on growth control of 20 taxa of containerized annual bedding plants and determine optimal substrate drench concentrations.

Materials and Methods

Plant material. On 12 Sep 2023 (Expt. 1), unrooted shoot-tip cuttings of bacopa (*Bacopa cordata* L. 'Pink Sand'), coleus [*Coleus scutellarioides* (L.) Benth. 'Main Street™ Ocean Drive'], New Guinea impatiens (*Impatiens hawkeri* R.W. Baker & Corner 'Magnum Fire' and 'Magnum Red Flame'), petunia (*Petunia ×atkinsiana* D. Don. 'Durabloom™ Royal Pink'), and portulaca (*Portulaca oleracea* L. 'Flame Red') were received from a commercial cutting supplier (Dümmen Orange NA; Hilliard, OH, USA). On 13 Sep (Expt. 1), unrooted shoot-tip cuttings of lantana (*Lantana camara* L. 'Bandolista™ Red Chili') and mezoo (*Aptenia cordifolia* L. Bolus. 'Trailing Red') were received from a commercial cutting supplier (Syngenta Flowers LLC, Gilroy, CA, USA). On 19 Dec (Expt. 2), unrooted shoot-tip cuttings of calibrachoa [*Calibrachoa ×hybrida* (Llave and Lex.) M. Martens and L. Westra. 'Callie® Dark Red'], dahlia [*Dahlia ×hybrida* (Hort. ex. Andrews) Lindl. ex. Loudon. 'Grandalia™ Dark Red' and 'Dahlegria® Red'], fanflower (*Scaevola aemula* R. Br. 'Bombay® Dark Blue'), geranium species {[interspecific geranium (*Pelargonium interspecific* 'Calliope® Large Dark Red')], ivy geranium [*P. peltatum* (L.) L'Hér. ex Aiton. 'Cascade Dark Red'], and zonal geranium [*P. zonale* (L.) L'Hér. 'Americana® Dark Red']}, heliotropium (*Heliotropium arborescens* L. 'Scentropia™ Dark Blue'), lobelia (*Lobelia erinus* L. 'Techno® Large Blue Violet'), sweetpotato vine (*Ipomoea batatas* L. Lam 'Sidekick™ Lime'), and verbena (*Verbena ×hybrida* Jacq. Ex L. 'Lanai® Red' and 'Lanai® Upright Scarlet') were received from a commercial cutting supplier (Syngenta Flowers LLC).

Propagation, culture, and environment. Upon receipt, cuttings of each taxa were individually inserted into industry-standard 105-cell propagation trays (30-mL individual cell volume, 54 cm × 28 cm × 5 cm; Grower Select®; BFG Supply, Burton, OH, USA), while geraniums were individually inserted into industry-standard 72-cell propagation trays (33-mL individual cell volume, 54 cm × 28 cm × 5 cm; Grower Select®; BFG Supply). Propagation trays were filled with a premoistened propagation substrate formulated with 50:50 (v/v) commercial soilless substrate composed of (by volume) 75% Canadian sphagnum peatmoss, 25% perlite, dolomitic lime, a nutrient starter charge, a wetting agent (Sunshine Mix No. 1; Sun Gro Horticulture, Agawam, MA, USA) and 50% coarse perlite (Coarse Perlite; Sun Gro Horticulture). Propagation substrate physical properties were determined using three representative samples that were analyzed according to the North Carolina State University Porometer Procedure (Fonteno et al. 1995). Physical properties of the propagation substrate were (by volume) 14% (±1.2%) air space, 78% (±1.1%) total porosity, 64% (±0.3%) container capacity, and 0.09 g·cm^{-3} (±0.1 g·cm^{-3}) bulk density. Before cutting insertion, propagation trays were irrigated to container capacity and allowed to drain.

Table 1. Average photosynthetic daily light integrals (DLIs), calculated vapor pressure deficit (VPD), and canopy air temperature during propagation and toning of 20 annual bedding plant taxa. Expt. 1 included bacopa (*Bacopa cordata* L. 'Pink Sand'), coleus [*Coleus scutellarioides* (L.) Benth. 'Main Street™ Ocean Drive'], lantana (*Lantana camara* L. 'Bandolista™ Red Chili'), mezoo (*Aptenia cordifolia* L. Bolus. 'Trailing Red'), New Guinea impatiens (*Impatiens hawkeri* R.W. Baker & Corner 'Magnum Fire' and 'Magnum Red Flame')], petunia (*Petunia ×atkinsiana* D. Don. 'Durabloom™ Royal Pink'), and portulaca (*Portulaca oleracea* L. 'Flame Red'). Expt. 2 included calibrachoa [*Calibrachoa ×hybrida* (Llave and Lex.) M. Martens and L. Westra. 'Callie® Dark Red'], dahlia [*Dahlia ×hybrida* (Hort. ex. Andrews) Lindl. ex. Loudon. 'Grandalia™ Dark Red' and 'Dahlegria® Red'], fanflower (*Scaevola aemula* R. Br. 'Bombay® Dark Blue'), geranium species {[interspecific geranium (*Pelargonium interspecific* 'Calliope® Large Dark Red'), ivy geranium [*P. peltatum* (L.) L'Hér. ex Aiton. 'Cascade Dark Red'], and zonal geranium [*P. zonale* (L.) L'Hér. 'Americana® Dark Red']}, heliotropium (*Heliotropium arborescens* L. 'Scentropia™ Dark Blue'), lobelia (*Lobelia erinus* L. 'Techno® Large Blue Violet'), sweetpotato vine (*Ipomoea batatas* L. Lam 'Sidekick™ Lime'), and verbena (*Verbena ×hybrida* Jacq. Ex L. 'Lanai® Red' and 'Lanai® Upright Scarlet'). Unrooted cuttings were propagated and young plants were toned in a glass-glazed greenhouse for 21 d under ambient daylight supplemented with approximately 120 µmol·m^{-2}·s^{-1} from 1000-W light-emitting diode lamps from 0600 to 2200 HR (16-h photoperiod) to maintain a DLI of 10 or 14 mol·m^{-2}·d^{-1}. The canopy air temperature and root zone heating setpoints were 23 °C.

Annual bedding plants	DLI (mol·m^{-2}·d^{-1})	VPD (kPa)	Canopy air temp. (°C)
Expt. 1			
Bacopa Coleus New Guinea impatiens 'Magnum Fire' New Guinea impatiens 'Magnum Red Flame'	12.8 ± 0.8	1.8 ± 0.6	21.4 ± 0.9
Lantana Mezoo	13.6 ± 0.8	1.9 ± 0.8	22.4 ± 4.1
Petunia Portulaca	12.8 ± 0.8	1.8 ± 0.6	21.4 ± 0.9
Expt. 2			
Calibrachoa Dahlia 'Grandalia™ Dark Red' Dahlia 'Dahlegria® Red' Geranium, interspecific Geranium, ivy Geranium, zonal Fanflower Heliotropium Lobelia Sweetpotato vine Verbena 'Lanai® Red' Verbena 'Lanai® Upright Scarlet'	10.7 ± 1.6	1.7 ± 0.6	21.0 ± 0.7

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Table 2. Average photosynthetic daily light integrals (DLIs), relative humidity (RH), and canopy air temperature during finishing of 20 annual bedding plant taxa. Expt. 1 included bacopa (*Bacopa cordata* L. 'Pink Sand'), coleus [*Coleus scutellarioides* (L.) Benth. 'Main Street™ Ocean Drive'], lantana (*Lantana camara* L. 'Bandolista™ Red Chili'), mezoo (*Aptenia cordifolia* L. Bolus. 'Trailing Red'), New Guinea impatiens (*Impatiens hawkeri* R.W. Baker & Corner 'Magnum Fire' and 'Magnum Red Flame'), petunia (*Petunia ×atkinsiana* D. Don. 'Duraboom™ Royal Pink'), and portulaca (*Portulaca oleracea* L. 'Flame Red'). Expt. 2 included calibrachoa [*Calibrachoa ×hybrida* (Llave and Lex.) M. Martens and L. Westra. 'Callie® Dark Red'], dahlia [*Dahlia ×hybrida* (Hort. ex. Andrews) Lindl. ex. Loudon. 'Grandalia™ Dark Red' and 'Dahlegria® Red'], fanflower (*Scaevola aemula* R. Br. 'Bombay® Dark Blue'), geranium species {[interspecific geranium (*Pelargonium interspecific* 'Calliope® Large Dark Red')], ivy geranium [*P. peltatum* (L.) L'Hér. ex Aiton. 'Cascade Dark Red], and zonal geranium [*P. zonale* (L.) L'Hér. 'Americana® Dark Red']}, heliotropium (*Heliotropium arborescens* L. 'Scentropia™ Dark Blue'), lobelia (*Lobelia erinus* L. 'Techno® Large Blue Violet'), sweetpotato vine (*Ipomoea batatas* L. Lam 'Sidekick™ Lime'), and verbena (*Verbena ×hybrida* Jacq. Ex L. 'Lanai® Red' and 'Lanai® Upright Scarlet'). Plants were transplanted into 12.7-cm (946 mL) or 16.5-cm (1.9 L) containers filled with a peat-based substrate and grown in a glass-glazed greenhouse under ambient daylight supplemented with approximately 120 $\mu mol \cdot m^{-2} \cdot s^{-1}$ from 1000-W light-emitting diode lamps from 0600 to 2200 HR (16-h photoperiod) to maintain a DLI of 10 to 14 $mol \cdot m^{-2} \cdot d^{-1}$. The canopy air temperature setpoint was 20 °C.

Annual bedding plants	DLI ($mol \cdot m^{-2} \cdot d^{-1}$)	RH (%)	Canopy air temp (°C)
Expt. 1			
Bacopa Coleus	10.5 ± 2.6	36.2 ± 12.1	21.1 ± 1.2
New Guinea Impatiens 'Magnum Fire' New Guinea Impatiens 'Magnum Red Flame'	11.3 ± 1.8	37.5 ± 12.7	21.1 ± 1.2
Lantana	10.5 ± 2.6	36.2 ± 12.1	21.1 ± 1.2
Mezoo Petunia	11.5 ± 1.9	38.2 ± 12.7	21.1 ± 1.4
Portulaca	11.6 ± 2.2	41.2 ± 12.6	21.1 ± 1.3
Expt. 2			
Calibrachoa	9.7 ± 1.6	47.3 ± 12.6	20.8 ± 0.8
Dahlia 'Grandalia™ Dark Red'	15.5 ± 2.7	48.6 ± 11.7	21.2 ± 0.9
Dahlia 'Dahlegria® Red' Geranium, interspecific Geranium, ivy Geranium, zonal	14.9 ± 3.1	47.9 ± 12.3	21.5 ± 0.9
Fanflower	9.7 ± 1.6	47.2 ± 12.9	20.8 ± 0.8
Heliotropium	9.6 ± 1.5	45.8 ± 12.8	20.8 ± 0.8
Lobelia	9.8 ± 1.8	46.7 ± 12.5	20.9 ± 0.8
Sweetpotato vine	9.8 ± 1.8	46.7 ± 12.6	20.9 ± 0.8
Verbena 'Lanai® Red'	9.7 ± 1.6	47.3 ± 12.6	20.8 ± 0.8
Verbena 'Lanai® Upright Scarlet'	9.8 ± 1.8	46.7 ± 12.5	20.9 ± 0.8

Propagation trays of each taxa were placed in a propagation environment in a glass-glazed greenhouse (71.2 m^2; 9.75 m × 7.3 m; 5-m gutter height) at The Ohio State University Controlled Environment Agriculture Research Complex, Columbus, OH, USA (lat. 40°N, long. 83°W, 238 m above sea level), equipped with two exhaust fans, evaporative pad cooling, a vertical air flow fan, retractable shade and energy curtains, and perimeter heat provided from a hot water boiler; all of these were controlled by an environmental computer system (version 9.7; Priva B.V., De Lier, Netherlands). Vertical air flow speed was measured at 24 points across the greenhouse environment with a handheld hotwire anemometer (model A004; Kanomax Japan, Inc., Osaka, Japan), with an average of 0.07 $m \cdot s^{-1}$ (±0.02 $m \cdot s^{-1}$). Ambient carbon dioxide (CO_2) in the greenhouse environment was measured at 24 points across the greenhouse with a handheld CO_2 meter (model GM70; Vaisala, Helsinki, Finland), with an average of 472.9 $\mu mol \cdot mol^{-1}$ (±23.5 $\mu mol \cdot mol^{-1}$). No supplemental CO_2 was provided throughout any of the experiments conducted.

The propagation bench (6.0 m × 1.5 m) was elevated 0.86 m above the greenhouse floor and oriented with a latitudinal axis running east–west. The expanded metal bench was insulated with expanded polystyrene (EPS) boards faced with a reflective foil (1.2 m × 2.4 m × 2.3 cm; Polyshield®; Cellofoam, Whiteland, IN, USA) and covered with bench-top root zone heating mats (Redi-Heat™ Heavy-Duty Propagation Mats; Phytotronics Inc., Earth City, MO, USA). Each heating mat was controlled independently with a thermostat (RDT-4 Thermostat; Phytotronics Inc.) and set to maintain a root zone temperature of 23 °C. To prevent heat loss and moisture accumulation, the propagation bench was covered with a 4-mil black construction film (3 m × 30.5 m roll, Blue Hawk; Poly-America, Grand Prairie, TX, USA). A propagation tent (6.0 m × 1.5 m × 1.5 m) was constructed with 1.9-cm-diameter polyvinyl chloride pipe (Charlotte Piper and Foundry Co., Charlotte, NC, USA) and covered with fixed 4-mil clear construction film (3 m × 30.5 m roll, Blue Hawk; Poly-America) and a woven shadecloth providing approximately 56% shade (Solaro 5620 O-R-FR; Ludvig Svensson, Inc., Charlotte, NC, USA).

Beginning at the placement of cuttings under propagation conditions, mist consisting of clear tap water was controlled (Super Nova 12B mist controller; Phytotronics, Inc., Earth City, MO, USA) and applied for 6 s every 10 min beginning and ending 2 h before and after the photoperiod. After 1 d, mist was suspended from 0900 to 0930 HR to allow unrooted cutting surfaces to dry. A foliar rooting hormone solution containing deionized water and indole-3-butric acid (20% IBA) (Advocate®; Fine Americas, Walnut Creek, CA, USA) was applied and uniformly delivered 200 $mg \cdot L^{-1}$ IBA at 0.20 $L \cdot m^{-2}$ across propagation trays. Cuttings were allowed to dry and mist was resumed at 1030 HR.

Upon visible adventitious root formation (root length, ≥5 mm), cuttings of each taxa were removed from the propagation bench and transferred to an adjacent expanded metal bench for subsequent rooting. Upon transfer, cuttings were overhead-irrigated once daily with clear tap water supplemented with a water-soluble fertilizer [15 nitrogen (N)–2.2 phosphorous (P)–12.5 potassium (K)–4 calcium (Ca)–2 magnesium (Mg); 15–5–15 Ca-Mg Jack's Professional Pure Water XL; J.R. Peters Inc., Allentown, PA, USA] containing 3% ammoniacal-N and 12% nitrate-N delivered by an injector (Model D25RE2, 0.05–11 GPM Dosatron; Dosatron International, LLC, Clearwater, FL, USA). Young plants received the following ($mg \cdot L^{-1}$): 150 N, 21.5 P, 124.5 K, 40 Ca, 20 Mg, 0.15 boron (B), 0.13 sulfur (S), 0.08 copper (Cu), 0.75 iron (Fe), 0.38 manganese (Mn), 0.08 molybdenum (Mo), and 0.38 zinc (Zn). After 1 week of adventitious root development, young plants received a magnesium sulfate (J.R. Peters Inc.) drench providing 11.7 $mg \cdot L^{-1}$ Mg and 15.4 $mg \cdot L^{-1}$ S.

Supplemental and day-extension lighting was provided by 1000-W light-emitting diode (LED) lamps (Gavita CT1930e LED 120–277V; Gavita Horticultural Lighting, Amsterdam, Netherlands) from 0600 to 2200 HR (16-h photoperiod) that delivered a supplemental photosynthetic photon flux density of approximately 120 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at cutting height as measured with a quantum sensor (LI-250A light meter; LI-COR Biosciences, Lincoln, NE, USA). The LED lamps were controlled by an environmental computer system (version 9.7; Priva B.V.); they were turned off when the outdoor light intensity reached approximately 490 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and turned on when the outdoor light intensity decreased below the radiation limit. Dual-layer retractable woven shade curtains were deployed when the outdoor light intensity reached approximately 980 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and retracted when the outdoor light intensity fell below the radiation limit. The top retractable woven shade curtains (Luxous 1547 D FR; Ludvig Svensson Inc.) were deployed to 70%, and the bottom layer (Harmony 4647 FR; Ludvig Svensson Inc.) was deployed to 100%. Vertical retractable woven light spill curtains (Obscura 10070 R FR W; Ludvig Svensson Inc.) were deployed from 1700 to 0800 HR.

Full-spectrum quantum sensors (SQ-500; Apogee Instruments, Logan, UT, USA) measured photosynthetic photon flux density at plant canopy level. Canopy air temperature and relative humidity (RH) were measured

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Table 3. Regression equations (see Figs. 8 to 11) for plant height, plant diameter, shoot dry weight (SDW), and root dry weight (RDW) of 20 annual bedding plant taxa Expt. 1 included bacopa (*Bacopa cordata* L. 'Pink Sand'), coleus [*Coleus scutellarioides* (L.) Benth. 'Main Street™ Ocean Drive'], lantana (*Lantana camara* L. 'Bandolista™ Red Chili'), mezoo (*Aptenia cordifolia* L. Bolus. 'Trailing Red'), New Guinea impatiens (*Impatiens hawkeri* R.W. Baker & Corner 'Magnum Fire' and 'Magnum Red Flame'), petunia (*Petunia ×atkinsiana* D. Don. 'Duraboom™ Royal Pink'), and portulaca (*Portulaca oleracea* L. 'Flame Red'). Expt. 2 included calibrachoa [*Calibrachoa ×hybrida* (Llave and Lex.) M. Martens and L. Westra. 'Callie® Dark Red'], dahlia [*Dahlia ×hybrida* (Hort. ex. Andrews) Lindl. ex. Loudon. 'Grandalia™ Dark Red' and 'Dahlegria® Red'], fanflower (*Scaevola aemula* R. Br. 'Bombay® Dark Blue'), geranium species {[interspecific geranium (*Pelargonium interspecific* 'Calliope® Large Dark Red'), ivy geranium [*P. peltatum* (L.) L'Hér. ex Aiton. 'Cascade Dark Red'], and zonal geranium [*P. zonale* (L.) L'Hér. 'Americana® Dark Red']}, heliotropium (*Heliotropium arborescens* L. 'Scentropia™ Dark Blue'), lobelia (*Lobelia erinus* L. 'Techno® Large Blue Violet'), sweetpotato vine (*Ipomoea batatas* L. Lam 'Sidekick™ Lime'), and verbena (*Verbena ×hybrida* Jacq. Ex L. 'Lanai® Red' and 'Lanai® Upright Scarlet')].

Annual bedding plants	Figure	Plant ht (cm)	Figure	Plant diam (cm)	Figure	SDW (g)	Figure	RDW (g)
				Expt. 1				
Bacopa	8A	NS[i]	8E	$y = 27.562 - 0.003x - 2.377x^{2}$[ii]	8I	$y = 2.864 - 0.0004x$	8M	$y = 2.589 - 0.001x$
Coleus	8B	$y = 11.950 - 0.001x$	8F	$y = 22.908 - 0.010x + 0.000007x^2$	8J	$y = 2.9555 - 0.0004x$	8N	$y = 2.972 - 0.0014x$
New Guinea Impatiens 'Magnum Fire'	8C	$y = 12.671 - 0.008x + 0.000005x^2$	8G	$y = 24.435 - 0.015x + 0.00001x^2$	8K	$y = 7.949 - 0.005x + 0.000003x^2$	8O	$y = 7.479 - 0.008x + 0.000003x^2$
New Guinea Impatiens 'Magnum Red Flame'	8D	$y = 14.810 - 0.009x + 0.000005x^2$	8H	$y = 26.874 - 0.011x + 0.000006x^2$	8L	$y = 9.820 - 0.007x + 0.000004x^2$	8P	$y = 6.983 - 0.009x + 0.000005x^2$
Lantana	9A	$y = 11.354 - 0.002x$	9E	$y = 28.025 - 0.012x$	9I	$y = 4.508 - 0.003x + 0.000001x^2$	9M	$y = 2.072 - 0.002x + 0.000001x^2$
Mezoo	9B	NS	9F	$y = 32.547 - 0.022x + 0.00001x^2$	9J	$y = 6.843 - 0.007x + 0.000004x^2$	9N	$y = 3.413 - 0.001x$
Petunia	9C	NS	9G	NS	9K	NS	9O	$y = 4.076 - 0.004x + 0.000003x^2$
Portulaca	9D	$y = 7.323 + 0.018x - 0.00001x^2$	9H	$y = 36.254 - 0.031x + 0.00001x^2$	9L	$y = 3.754 - 0.001x$	9P	$y = 1.331 - 0.0007x$
				Expt. 2				
Calibrachoa	10A	NS	10G	$y = 23.740 - 0.160x + 0.0005x^2$	10M	$y = 2.432 - 0.021x + 0.00007x^2$	10S	$y = 0.992 - 0.011x + 0.00003x^2$
Dahlia 'Grandalia™ Dark Red'	10B	$y = 25.563 - 0.242x + 0.0008x^2$	10H	$y = 38.246 - 0.185x + 0.0006x^2$	10N	$y = 23.378 - 0.173x - 0.0005x^2$	10T	$y = 10.518 - 0.033x$
Dahlia 'Dahlegria® Red'	10C	$y = 29.705 - 0.077x + 0.0001x^2$	10I	$y = 51.707 - 0.151x + 0.0004x^2$	10O	$y = 35.053 - 0.146x + 0.0003x^2$	10U	$y = 36.156 - 0.310x + 0.001x^2$
Fanflower	10D	NS	10J	$y = 33.121 - 0.169x + 0.0004x^2$	10P	$y = 2.664 - 0.019x + 0.00006x^2$	10V	$y = 0.922 - 0.009x + 0.00003x^2$
Geranium, interspecific	10E	$y = 28.560 - 0.107x + 0.0003x^2$	10K	$y = 42.970 - 0.021x$	10Q	$y = 25.223 - 0.018x$	10W	$y = 4.242 - 0.026x + 0.00006x^2$
Geranium, ivy	10F	$y = 25.018 - 0.034x$	10L	$y = 37.757 - 0.156x + 0.0004x^2$	10R	$y = 12.325 - 0.016x$	10X	NS
Geranium, zonal	11A	$y = 27.769 - 0.117x + 0.0003x^2$	11G	NS	11M	$y = 21.525 - 0.024x$	11S	$y = 4.889 - 0.044x + 0.0001x^2$
Heliotropium	11B	$y = 11.908 - 0.045x + 0.0001x^2$	11H	$y = 17.367 - 0.053x + 0.0002x^2$	11N	NS	11T	$y = 3.301 - 0.021x + 0.00007x^2$
Lobelia	11C	$y = 15.662 - 0.011x$	11I	$y = 42.792 - 0.028x$	11O	$y = 2.243 - 0.001x$	11U	$y = 1.581 - 0.002x$
Sweetpotato vine	11D	$y = 9.961 - 0.016x$	11J	$y = 27.290 - 0.152x + 0.0004x^2$	11P	$y = 4.195 - 0.026x + 0.00006x^2$	11V	$y = 6.261 - 0.045x + 0.0001x^2$
Verbena 'Lanai Red'	11E	$y = 11.949 - 0.011x$	11K	$y = 42.342 - 0.213x + 0.0005x^2$	11Q	$y = 4.654 - 0.029x + 0.0001x^2$	11W	$y = 4.327 - 0.033x + 0.0001x^2$
Verbena 'Lanai® Upright Scarlet'	11F	$y = 11.596 - 0.022x$	11L	$y = 15.744 - 0.022x$	11R	$y = 3.693 - 0.004x$	11X	$y = 2.901 - 0.029x + 0.0001x^2$

[i] NS = nonsignificant.

[ii] Linear ($y = a + bx$) or quadratic ($y = a + bx + cx^2$) equations for each parameter.

using a precision thermistor (ST-110-SS; Apogee Instruments) and humidity probe (EE08-SS; Apogee Instruments), respectively, encased in a fan-aspirated solar radiation shield (TS-130-SS; Apogee Instruments). Measurements were recorded every 15 s, and the average for each sensor was logged every 15 min by a data logger (Model CR1000X; Campbell Scientific, Inc., Logan, UT, USA). Greenhouse air temperature and RH set points were 23 °C and 80%, respectively. Environmental data during propagation and toning phases for each taxa during Expts. 1 and 2 are reported in Table 1. The vapor pressure deficit was calculated from greenhouse air temperature and RH averages.

Plant culture and environment. In all experiments, 21-d-old young plants with similar heights, stem calipers, and node and leaf numbers were selected. On 3 Oct, bacopa, coleus, portulaca, New Guinea impatiens cultivars, and petunia were transplanted, with one plant per 12-cm-diameter container (970 mL individual volume; Landmark Plastics, Akron, OH, USA). After transplant, containers were individually placed into 15-count shuttle trays (30.5 cm × 51.4 cm; Shuttle Tray® Flower Trays, East Jordan Plastics, Inc., East Jordan, MI, USA) on 23-cm^2 centers. On 4 Oct, lantana and mezoo were transplanted and spaced as previously described. On 16 Jan 2024, calibrachoa, fanflower, heliotropium, lobelia, sweetpotato vine, and verbena cultivars were transplanted, with one plant per 12.7-cm-diameter container (946 mL individual volume; East Jordan Plastics, Inc.). Each dahlia cultivar and geranium species were transplanted, with one plant per 16.5-cm diameter container (1.9 L individual volume; Landmark Plastic Corp., Akron, OH, USA). All containers were filled with a premoistened commercial soilless substrate (Sunshine Mix No. 1; Sun Gro Horticulture). Substrate physical properties were determined using procedures previously described by Fonteno et al. (1995) and were (by volume) 15.2% (±1.1%) air space, 84.1% (±0.8%) total porosity, 68.9% (±1.3%) container capacity, and 5.3 g·cm^{-3} (±0.2 g·cm^{-3}) bulk density.

Upon transplant, plants were overhead-irrigated to container capacity with clear tap water. At each subsequent irrigation, plants were overhead-irrigated with clear tap water supplemented with a water-soluble fertilizer as previously described. At 14 d after transplant, plants were irrigated with magnesium sulfate (J.R. Peters Inc.) as previously described.

Except when indicated, the greenhouse environment, setpoints, and monitoring were the same as those described for propagation. Plants were grown on expanded metal benches (6.0 m × 1.5 m) elevated 0.86 m above the greenhouse floor and oriented with a latitudinal axis running east–west in a glass-glazed greenhouse. The LED lamps were controlled by an environmental computer system (version 9.7; Priva B.V.); they were turned off when the outdoor light intensity reached approximately 490 μmol·m^{-2}·s^{-1} and turned on

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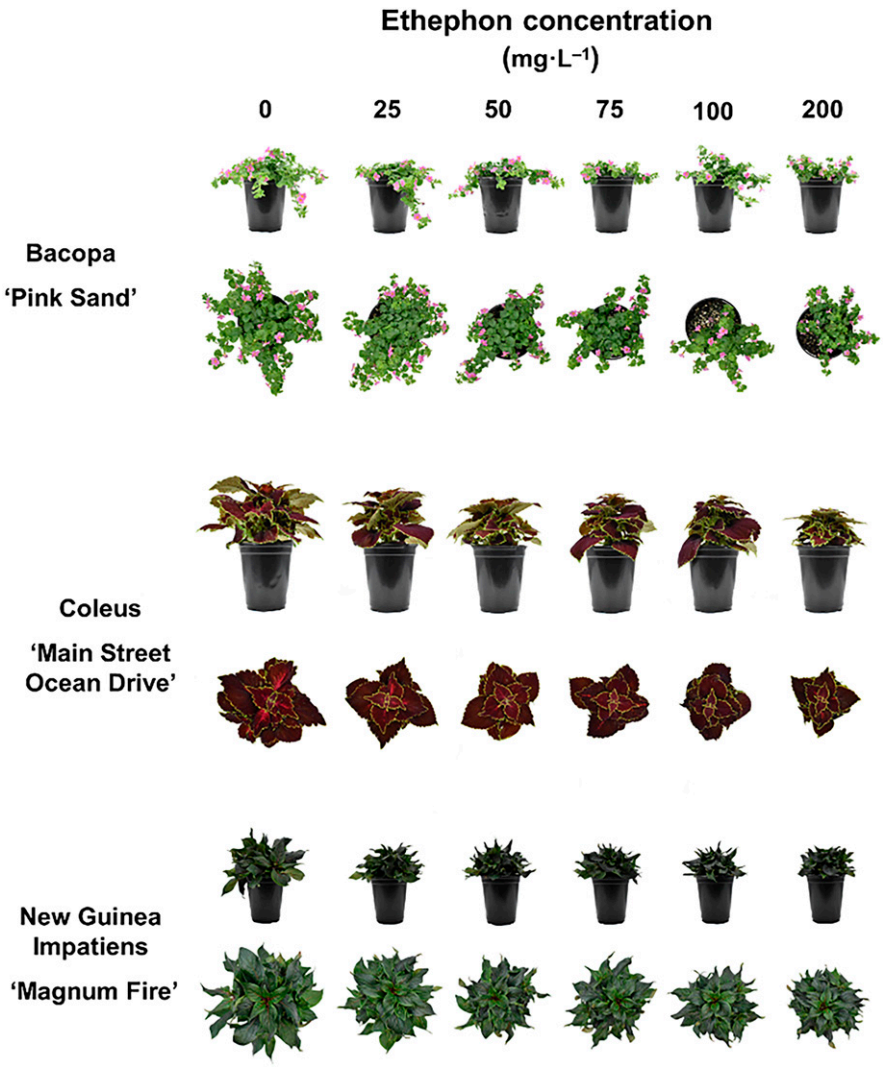

Fig. 1. Depictions of bacopa (*Bacopa cordata* L. 'Pink Sand'), coleus [*Coleus scutellarioides* (L.) Benth. 'Main Street™ Ocean Drive'], and New Guinea impatiens (*Impatiens hawkeri* R.W. Baker & Corner 'Magnum Fire') grown in 12-cm containers (946 mL) filled with a commercial soilless peat-based substrate and drenched with 90-mL aliquots of a solution containing 0, 25, 50, 75, 100, or 200 mg·L^{-1} ethephon at 10 d after transplant. Photographs were taken 3, 3, and 6 weeks after drench for bacopa, coleus, and 'Magnum Fire' New Guinea impatiens, respectively.

when the outdoor light intensity decreased below the radiation limit. Greenhouse air temperature and RH set points were 20 °C and 70%, respectively. Environmental data collected during plant culture for each taxa during Expts. 1 and 2 are reported in Table 2.

Ethephon substrate drenches. At 10 d after transplant, ethephon substrates drenches were applied from 0900 to 1330 HR. Eight single-plant replicates (individual plants) of each taxa were drenched with 90-mL or 150-mL aliquots of solution containing deionized water (0 mg·L^{-1}; control) or 25, 50, 75, 100, or 200 mg·L^{-1} ethephon (Collate® 2L; Fine Americas, Inc.) (90 mL: 0, 2.2, 4.4, 6.7, 8.9, and 17.7 mg a.i./pot; 150 mL: 0, 3.7, 7.4, 11.1, 14.8, and 29.6 mg a.i./pot).

Substrate pH management. At 7 d before the ethephon drench application and 2 d and 7 d after drench application, substrate solution was extracted 1 h after irrigation using the PourThru method (Cavins 2002). Substrate solution was analyzed to determine the pH and electrical conductivity (EC) using a handheld pH and EC meter (HI 9813-6; Hanna Instruments, Woonsocket, RI, USA). The average initial substrate pH before ethephon drench application was 5.8 ± 0.1. At 2 d after ethephon drench application, the substrate pH was determined to be 5.5 ± 0.1. However, at 7 d after drench application, the substrate pH returned to 5.8 ± 0.2 (data not shown). No low-substrate pH-induced nutrient disorder symptomologies were observed for any of the taxa grown during Expts. 1 and 2.

Growth and morphological data and calculations. Throughout each experiment, visual observations were recorded for phytotoxic effects. The experiments were ended, and the plants were harvested 3 weeks (bacopa, coleus, heliotropium, lobelia, and petunia), 4 weeks (calibrachoa, 'Grandalia™ Dark Red' dahlia, fanflower, mezoo, sweetpotato vine, and 'Lanai® Red' and 'Lanai® Upright Scarlet' verbena), 5 weeks ('Dahlegria® Red' dahlia, geranium species, lantana, and portulaca), or 6 weeks ('Magnum Fire' and 'Magnum Red Flame' New Guinea impatiens) after drench. At termination, plant height and plant diameter were determined. Plant height was determined by measuring from the substrate surface to the highest growing point of the plant. Plant diameter was determined by measuring the widest dimension and the axis perpendicular to the widest dimension and averaged. Plants with at least one open flower (reflexed petals with visible pollen) were recorded, and the percentage of plants flowering at termination was calculated for each taxa and ethephon drench concentration. After measurements were performed, shoots were excised at the substrate surface, and all possible substrate was removed from roots while minimally damaging the root system with gentle washing in tap water. Shoots and roots were individually bagged and dried separately in a forced-air convection oven (179 L Fisherbrand™ Isotemp™ General Purpose Heating and Drying Oven; Fisher Scientific, Pittsburgh, PA, USA) at 65 °C. After 1 week, shoots and roots were weighed using an analytical balance (ME204E; Mettler Toledo, Columbus, OH, USA) to determine SDW and RDW, respectively.

Experimental design and data analysis. The experiment was conducted using a completely randomized design with eight single-plant replicates per taxa for each ethephon concentration. For each taxa, the effects of the ethephon concentration were analyzed with the general linear model (PROC GLM) and an analysis of variance (ANOVA) using SAS (ver. 9.4; SAS Institute, Cary, NC, USA). For flowering percentage, plant height, plant diameter, SDW, and RDW, a regression analysis within taxa with the ethephon concentration as the independent variable was performed using the SAS regression procedure (PROC REG). Regression equations for plant height, plant diameter, SDW, and RDW for each taxa are listed in Table 3. For all analyses, $P \leq 0.05$ was used to determine significant effects.

Results

Ethephon drench concentrations significantly influenced plant height, plant diameter, SDW, and RDW of most species investigated (Figs. 1–11). In general, a dose-dependent relationship was observed, with higher ethephon drench concentrations resulting in shorter compact plants (Figs. 1–7). The magnitude of plant height control attained by increasing ethephon substrate drench concentrations varied among species [Figs. 8A–D (Expt. 1), 9A–D (Expt. 1), 10A–F (Expt. 2), and 11A–F (Expt. 2)]. For example, lantana (Fig. 9A) and heliotropium (Fig. 11B) were 16% (1.9 cm) and 20% (2.6 cm) shorter, respectively, whereas portulaca (Fig. 9D) was 70% (4.4 cm) taller when plants were drenched with 25 mg·L^{-1} ethephon when compared with untreated plants. Other species require higher ethephon drench concentrations to attain growth control. For instance, compared with untreated plants, substrate drenches containing up to 75 mg·L^{-1}

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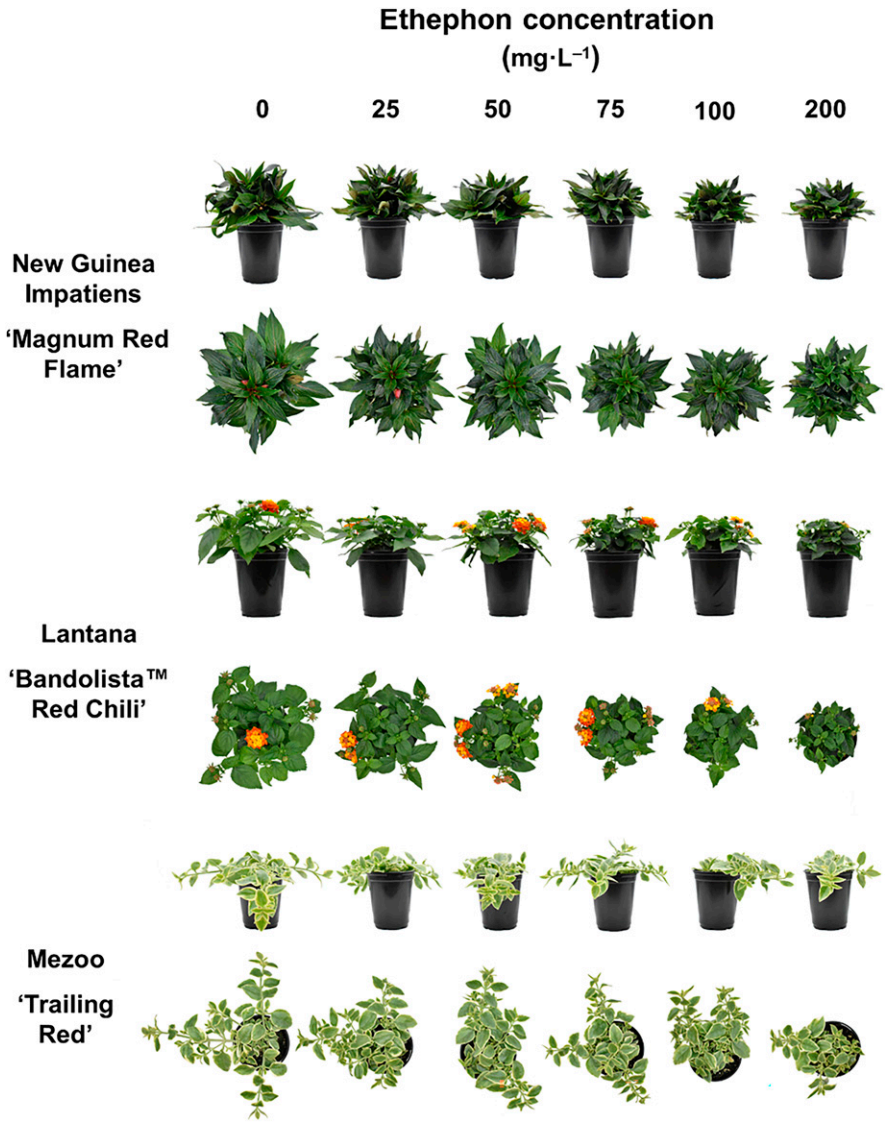

Fig. 2. Depictions of New Guinea impatiens (*Impatiens hawkeri* R.W. Baker & Corner 'Magnum Red Flame'), lantana (*Lantana camara* L. 'Bandolista™ Red Chili'), and mezoo (*Aptenia cordifolia* L. Bolus. 'Trailing Red') grown in 12-cm containers (946 mL) filled with a commercial soilless peat-based substrate and drenched with 90-mL aliquots of a solution containing 0, 25, 50, 75, 100, or 200 mg·L^{-1} ethephon at 10 d after transplant. Photographs were taken 6, 5, and 4 weeks after drench for 'Magnum Red Flame' New Guinea impatiens, lantana, and mezoo, respectively.

ethephon controlled plant height of 'Grandalia™ Dark Red' (Fig. 10B) and 'Dahlegria® Red' dahlia (Fig. 10C) by 50% (15.4 cm) and 17% (5.1 cm), respectively. Furthermore, sweetpotato vine (Fig. 11D) was 33% (3.2 cm) shorter than untreated plants as concentrations increased from 0 to 200 mg·L^{-1} ethephon. 'Lanai® Upright Scarlet' verbena (Fig. 11F) drenched with 50 to 200 mg·L^{-1} ethephon was 15% to 39% (1.8–4.6 cm) shorter than untreated plants. Plant heights of bacopa (Fig. 8A), coleus (Fig. 8B), mezoo (Fig. 9B), petunia (Fig. 9C), calibrachoa (Fig. 10A), and fanflower (Fig. 10D) were unaffected by ethephon drenches.

Plant diameter [Figs. 8E–H (Expt. 1), 9E–H (Expt. 1), 10G–L (Expt. 2), and 11G–L (Expt. 2)] of most species was significantly influenced by increasing ethephon drench concentrations. Coleus (Fig. 8F) and heliotropium (Fig. 11H) drenched with 25 mg·L^{-1} ethephon were 1.5% (0.3 cm) and 18.1% (3.2 cm) narrower, respectively, compared with untreated plants. Additional growth control was not observed at higher concentrations in these species. Some species such as bacopa and 'Magnum Fire' and 'Magnum Red Flame' New Guinea impatiens responded at higher concentrations of ethephon. For example, 'Magnum Fire' (Fig. 8G) and 'Magnum Red Flame' (Fig. 8H) New Guinea impatiens drenched with 50 mg·L^{-1} ethephon were 23% (5.9 cm) and 12% (3.4 cm) narrower, respectively, when compared with untreated plants. Furthermore, when compared with untreated plants, 'Grandalia™ Dark Red' (Fig. 10H) and 'Dahlegria® Red' dahlia (Fig. 10I) drenched with 25 to 75 mg·L^{-1} ethephon were 25% to 31% (9.8–12.4 cm) and 9% to 15% (4.5–7.9 cm) smaller, respectively. Lantana (Fig. 9E) drenched with 25 to 200 mg·L^{-1} ethephon was 14% to 47% (4.1–13.9 cm) smaller than untreated plants. Plant diameter of petunia (Fig. 9G) and interspecific geranium (Fig. 10K) were unaffected by all trialed concentrations of ethephon.

The SDWs [Figs. 8I–L (Expt. 1), 9I–L (Expt. 1), 10M–R (Expt. 2), and 11M–R (Expt. 2)] of most species were significantly less with increasing ethephon drench concentrations, but the magnitude of growth control varied among species. For example, those of 'Magnum Fire' New Guinea impatiens (Fig. 8K) and calibrachoa (Fig. 10M) drenched with 25 mg·L^{-1} ethephon were 24% (2.1 g) and 33% (0.9 g) smaller, respectively, compared with untreated plants. 'Magnum Red Flame' New Guinea impatiens (Fig. 8L) and 'Grandalia™ Dark Red' dahlia (Fig. 10N) drenched with 25 to 75 mg·L^{-1} ethephon were 14% to 30% (1.4–3.0 g) and 35% to 48% (8.9–12.2 g) smaller, respectively, than untreated plants. Lantana (Fig. 9I) drenched with 25 to 100 mg·L^{-1} ethephon was 24% to 37% (1.2–1.8 g) smaller than untreated plants. Furthermore, mezoo (Fig. 9J) and portulaca (Fig. 9L) treated with 25 to 200 mg·L^{-1} ethephon were 36% to 62% (2.8–4.8 g) and 22% to 40% (0.9–1.7 g) smaller, respectively, than untreated plants. The SDWs of coleus (Fig. 8J), petunia (Fig. 9K), interspecific geranium (Fig. 10Q), and lobelia (Fig. 11O) were unaffected at all trialed concentrations of ethephon. The maximum level of control observed in SDW is species-dependent and ranges from 25 to 100 mg·L^{-1} ethephon.

The RDW generally diminished with increasing substrate drench concentrations of ethephon, with the magnitude of reduction varying among species [Figs. 8M–P (Expt. 1), 9M–P (Expt. 1), 10S–X (Expt. 2), and 11S–X (Expt. 2)]. Coleus (Fig. 8N), petunia (Fig. 9O), and 'Lanai® Upright Scarlet' verbena (Fig. 11X) drenched with 25 mg·L^{-1} ethephon resulted in RDWs that were 45% (1.7 g), 35% (1.6 g), and 47% (1.5 g) lower, respectively, compared with untreated plants. When compared with untreated plants, zonal geranium (Fig. 11S) and 'Lanai® Red' verbena (Fig. 11W) drenched with 50 to 75 mg·L^{-1} ethephon yielded RDWs that were 37% to 54% (1.8–2.7 g) and 25% to 46% (1.1–1.9 g) smaller, respectively, than untreated plants. The RDWs of 'Magnum Fire' New Guinea impatiens (Fig. 8N) and portulaca (Fig. 9P) drenched with 75 to 100 mg·L^{-1} ethephon were 42% to 62% (3.5–5.2 g) and 31% to 45% (0.5–0.7 g) smaller, respectively, compared with untreated plants. The RDWs of some species were affected at higher concentrations of ethephon. For example, when treated with 100 to 200 mg·L^{-1} ethephon, the RDW of 'Grandalia™ Dark Red' dahlia (Fig. 10T) diminished by 31% to 63% (3.1–6.3 g) compared with untreated plants. The RDW of ivy geranium (Fig. 10X) was unaffected by all trialed ethephon concentrations.

The flowering response to increasing ethephon drench concentrations varied among the annual bedding plants investigated (Table 4). Flowering at termination of bacopa,

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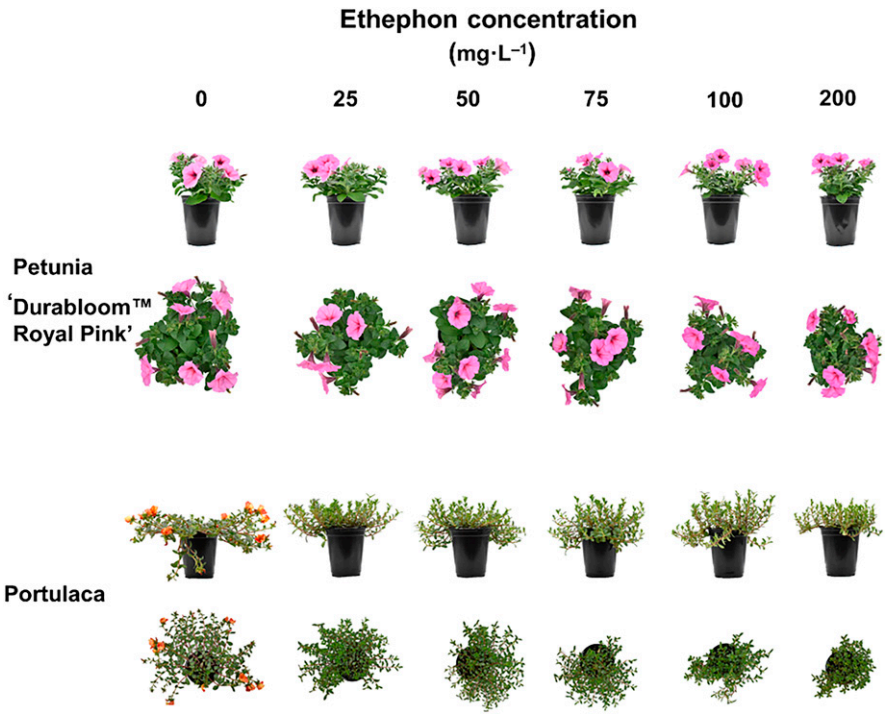

Fig. 3. Depictions of petunia (*Petunia ×atkinsiana* D. Don. 'Durabloom™ Royal Pink') and portulaca (*Portulaca oleracea* L. 'Flame Red') grown in 12-cm containers (946 mL) filled with a commercial soilless peat-based substrate and drenched with 90-mL aliquots of a solution containing 0, 25, 50, 75, 100, or 200 mg·L^{-1} ethephon at 10 d after transplant. Photographs were taken 3 and 5 weeks after drench for petunia and portulaca, respectively.

calibrachoa, 'Grandalia™ Dark Red' dahlia, heliotropium, lantana, lobelia, mezoo, 'Magnum Fire' and 'Magnum Red Flame' New Guinea impatiens, petunia, and zonal geranium was unaffected by all trialed concentrations of ethephon (Table 4). However, for fanflower, interspecific geranium, ivy geranium, portulaca, and 'Lanai® Red' and 'Lanai® Upright Scarlet' verbena, delayed flowering was observed as ethephon substrate drench concentrations increased. For example, the percentage of interspecific geranium and ivy geranium plants flowering at the time of termination were significantly less when plants were drenched with 100 mg·L^{-1} ethephon compared with untreated plants. Furthermore, portulaca drenched with any concertation of ethephon did not flower, while 100% of untreated plants were flowering at the time of termination.

Discussion

Our research demonstrated that ethephon substrate drenches can effectively control plant height of annual bedding plants, and the results are in agreement with those of previous studies (Aiken et al. 2015; Currey et al. 2016; Miller et al. 2012; Rich and Owen 2025). While our research expands the scope of annual species evaluated, it complements the work by Miller et al. (2012), who found a shorter stem length than that of untreated plants for 23 species of annual bedding plants when treated with ethephon drenches. For instance, when drenched with 200 mg·L^{-1} ethephon, the stem lengths of marguerite daisy [*Argyranthemum frutescens* (L.) Sch. Bip. 'Madeira Cherry Red'] and nemesia [*Nemesia fruticans* (Thunb.) Benth. 'Aromatica Royal'] were 19% (3.2 cm) and 32% (11.6 cm) shorter compared with untreated plants (Miller et al. 2012). Additionally, the authors found that Madagascar periwinkle [*Catharanthus roseus* (L.) G. Don. 'Cooler Grape'], plume cockscomb (*Celosia argentea* L. var. *plumosa* Voss. 'New Look'), and dianthus (*Dianthus chinensis* L. 'Super Parfait Raspberry') drenched with 200 mg·L^{-1} ethephon were 59% (7.3 cm), 70% (18.2 cm), and 35% (5.6 cm) shorter, respectively, than untreated plants. Furthermore, our research agrees with that of Rich and Owen (2025), who reported ethephon substrate drenches controlled plant height of 15 herbaceous perennial species. For example, Russian sage (*Salvia yangii* B.T. Drew) and blanket flower (*Gaillardia aristata* Pursh. 'SpinTop® Red Starburst') were 48% to 56% and 11% to 14% shorter, respectively, when drenched with 125 and 250 mg·L^{-1} ethephon than untreated plants. Overall, our research demonstrated 25 to 100 mg·L^{-1} ethephon can effectively control plant height of the majority of the annual bedding plant species trialed.

Plant diameter of most species trialed was significantly affected by increasing concentrations of ethephon. Our results agree with those of Barker et al. (2016), who reported a 38% reduction in the plant diameter of plumbago (*Plumbago auriculata* Lam. 'Imperial Dark Blue') when plants were drenched with 1000 mg·L^{-1} ethephon compared with untreated plants. Similarly, Currey et al. (2016) found that the plant diameter of 'Serena White' angelonia was 38% (10.2 cm) smaller as substrate drench concentrations increased from 0 to 100 mg·L^{-1} ethephon. Furthermore, Rich and Owen (2025) demonstrated that substate drenches of 125 to 500 mg·L^{-1} ethephon provided adequate growth control of plant diameter for many species of herbaceous perennials. For example, as substrate drench concentrations increased from 0 to 500 mg·L^{-1} ethephon, tender foxglove (*Digiplexis ×hybrida* 'Berry Canary') and 'SpinTop® Red Starburst' blanket flower were 16% (6.5 cm) and 21% (5.4 cm) narrower, respectively, than untreated plants (Rich and Owen 2025). We concluded that substrate drenches containing 25 to 100 mg·L^{-1} ethephon are effective at controlling the plant diameter of the majority of annual bedding plants reported herein. Plant diameters of petunia and interspecific geranium were unaffected by increasing concentrations of ethephon substrate drenches. This is surprising because petunia and geraniums are known to be sensitive to ethylene; therefore, further research is needed (Jones and Edelman 2013; 2014; Jones et al. 2001; Leatherwood and Mattson 2007).

Increasing ethephon drench concentrations reduced SDW of most of the species trialed. Our results support the findings by Miller et al. (2012), who found a reduction in SDWs of 16 annual bedding plant species. For example, 'Serena Lavendar' angelonia, 'Super Parfait Raspberry' dianthus, and African daisy [*Osteospermum ecklonis* (DC.) Norl. 'Zion Orange'] drenched with 200 mg·L^{-1} ethephon were 68% (2.6 g), 62% (2.3 g), and 54% (2.6 g) smaller, respectively, compared with untreated plants (Miller et al. 2012). Currey et al. (2016) also reported that 'Serena White' angelonia drenched 10 d after transplant with 100 mg·L^{-1} ethephon was 34% (1.7 g) smaller than untreated plants. Additionally, Rich and Owen (2025) determined drench concentrations of 250 to 500 mg·L^{-1} ethephon provided adequate growth control of 15 herbaceous perennials. For instance, lobed tickseed (*Coreopsis auriculata* L. 'Leading Lady Iron') and Russian sage drenched with 125 to 500 mg·L^{-1} ethephon were 24% to 39% (5.0–8.1 g) and 54% to 76% (4.5–6.3 g) smaller, respectively, compared with untreated plants. Our research results and those of these previous studies demonstrated that ethephon substrate drenches can effectively control SDW of annual bedding plants. Furthermore, our research concluded that substrate drenches of 25 to 100 mg·L^{-1} ethephon provided the greatest level of control of SDW for most species trialed.

The RDW of most annual bedding plant species trialed herein was influenced by increasing concentrations of ethephon. Our observations are supported by the findings of Miller et al. (2012), who reported that the RDWs of 'Zion Orange' African daisy, bacopa (*Sutera cordata* Roth. 'Abunda Giant White'), calibrachoa, diascia (*Diascia barberae* Hook. F. 'Wink Coral'), French marigold (*Tagetes patula* L. 'Crested Janie Deep Orange'), 'Madeira Cherry Red' marguerite daisy, 'Aromatica Royal' nemesia, and viola

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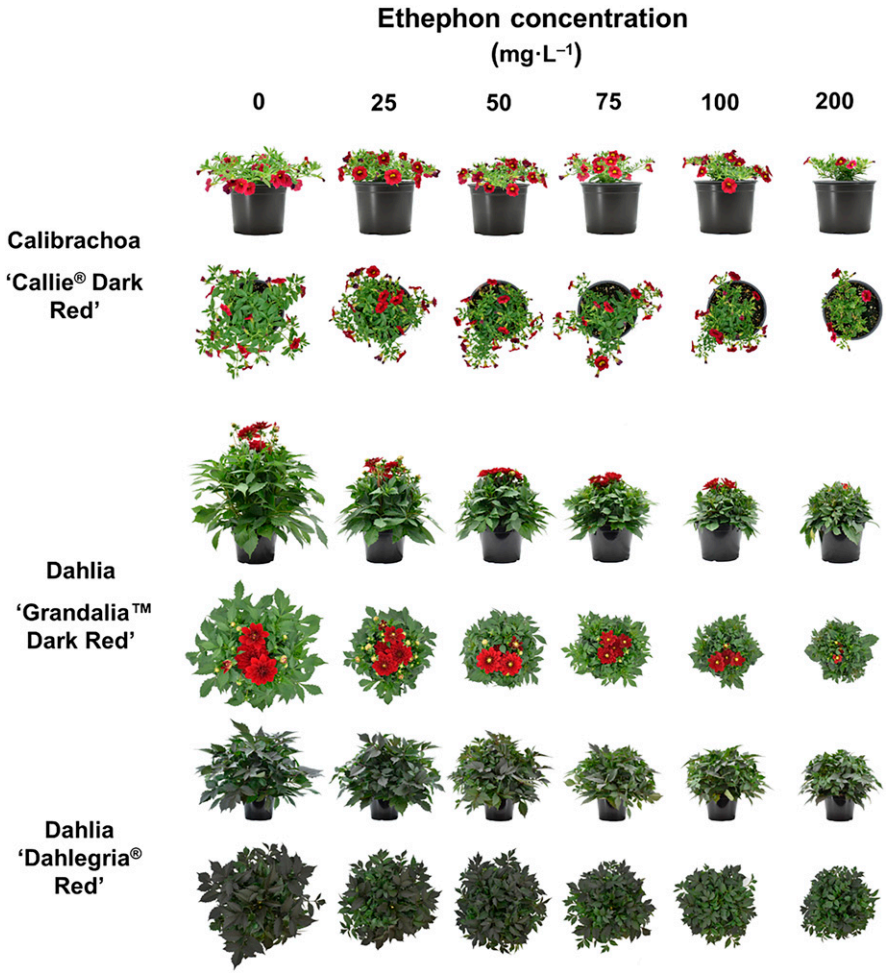

Fig. 4. Depictions of calibrachoa [*Calibrachoa* ×*hybrida* (Llave and Lex.) M. Martens and L. Westra. 'Callie® Dark Red'] and dahlia [*Dahlia* ×*hybrida* (Hort. ex. Andrews) Lindl. ex. Loudon. 'Grandalia™ Dark Red' and 'Dahlegria® Red'] grown in 12.7-cm (946 mL) or 16.5-cm (1.9 L) containers for calibrachoa and both dahlia cultivars, respectively, filled with a commercial soilless peat-based substrate and drenched with 90-mL or 150-mL aliquots of a solution, depending on pot size, containing 0, 25, 50, 75, 100, or 200 mg·L^{-1} ethephon at 10 d after transplant. Photographs were taken 4, 4, and 5 weeks after drench for calibrachoa, 'Grandalia™ Dark Red' dahlia, and 'Dahlegria® Red' dahlia, respectively.

(*Viola cornuta* L. 'Penny Lane Mixed') decreased with increasing ethephon drench concentrations. For instance, when treated with 200 mg·L^{-1} ethephon, 'Crested Janie Deep Orange' French marigold and 'Penny Lane Mixed' viola were 54% (0.3 g) and 78% (0.3 g) smaller, respectively, than untreated plants (Miller et al. 2012). Additionally, Rich and Owen (2025) reported increasing ethephon substrate drench concentrations suppressed root growth and, thus, RDW of 15 herbaceous perennial species. For instance, 'Spin-Top® Red Starburst' blanket flower drenched with 250 mg·L^{-1} ethephon was 42% (4.5 g) smaller than untreated plants (Rich and Owen 2025). Currey et al. (2016) also found that the RDWs of 'Serena White' angelonia and geranium (*Pelargonium* ×*hortorum* L.H. Bailey 'Pinto Premium Deep Red') drenched with 200 mg·L^{-1} ethephon were 54% (0.51 g) and 11% (0.09 g) smaller, respectively, than untreated plants. Similar to the results reported by Rich and Owen (2025), reductions in RDW were expected with ethephon substrate drenches because ethylene is known to impact root development. Khoury et al. (2024) reported that exogenous applications of ethylene gas or its precursor, aminocyclopropane-1-caboxylic acid, inhibit root elongation within 5 min of application and limited overall root branching as well as the development of root hairs in *Arabidopsis*. Therefore, it is speculated that ethephon substrate drenches impact the development and growth of the root system, leading to smaller RDW observed in the current trial and subsequently limiting plant growth and biomass accumulation in addition to the effects of ethephon translocated to the shoot inhibiting cell elongation (Rich and Owen 2025).

We found that several species were unaffected by ethephon substrate drenches. Plant heights of bacopa, calibrachoa, coleus, fanflower, mezoo, and petunia were unaffected by all trialed concentrations of ethephon trialed. The SDWs of coleus, interspecific geranium, lobelia, and petunia were unaffected by all trialed concentrations of ethephon. The lack of response to ethephon substrate drenches was not unexpected because Miller et al. (2012) reported that the plant heights of 'Zion Orange' African daisy, 'Wink Coral' diascia, petunia (*Petunia* ×*grandiflora* 'Dreams Burgundy'), and tomato (*Lycopersicon esculentum* L. 'Beefmaster') were unaffected when plants were drenched with 25 to 200 mg·L^{-1} ethephon. Miller et al. (2012) suggested that taxa, application timing, temperature, light, substrate composition, and other environmental factors can influence ethephon drench efficacy. We controlled the greenhouse environment (light and temperature) throughout the experiments, applied ethephon in the morning when plants were not stressed, and grew plants in peat-based substrates, similar to previous studies. As such, we speculated that the lack of response of the species reported herein to ethephon substrate drenches can be attributed to a lack of sensitivity to ethylene, which was also reported by Rich and Owen (2025). Moreover, Aiken et al. (2015) found that substrate pH impacts the efficacy of ethephon substrate drenches. We determined the substrate pH before and after ethephon drench application and, as expected, an initial drop in substrate pH was observed that may or may not have affected the ethephon efficacy and impact on plant growth. However, substrate pH increased over the course of the experiments and, because ethephon drenches influenced some aspect of plant growth and development in all 20 taxa trialed, we considered the lack of growth control to be a result of an unknown exogenous or endogenous factor (Rich and Owen 2025). Further research investigating other species and cultivars, lower and higher ethephon drench concentrations, and environmental or root zone factors is warranted.

A slight decrease in flowering was observed in five annual bedding plant species, but only at ≥50 mg·L^{-1} ethephon concentrations (Table 4). Because flowering percentages varied widely among species trialed in the current study, in-house grower trials should determine whether a significant decrease in flowering will occur and disrupt production schedules.

It must be noted that some phytotoxic effects were observed at concentrations of 50 to 200 mg·L^{-1} ethephon. For some species, leaf epinasty, lower leaf chlorosis, or necrosis of the leaf margins was observed (Table 5). For example, leaf epinasty was observed in 'Magnum Fire' and 'Magnum Red Flame' New Guinea impatiens when plants were drenched with 200 mg·L^{-1} ethephon. However, there was no reduction in visual ornamental appeal of these plants. Necrosis and deformation of the meristems manifested in sweetpotato vine drenched with 200 mg·L^{-1} ethephon. This was not unexpected because ethephon foliar sprays are commonly used to reduce apical dominance and increase lateral branching (Currey 2018). Because of these effects, it is recommended that annual bedding plant producers should perform in-house trials to ensure that the desired growth control effects are achieved, and that phytotoxic effects do not develop or cause damage to ornamental esthetic quality and value.

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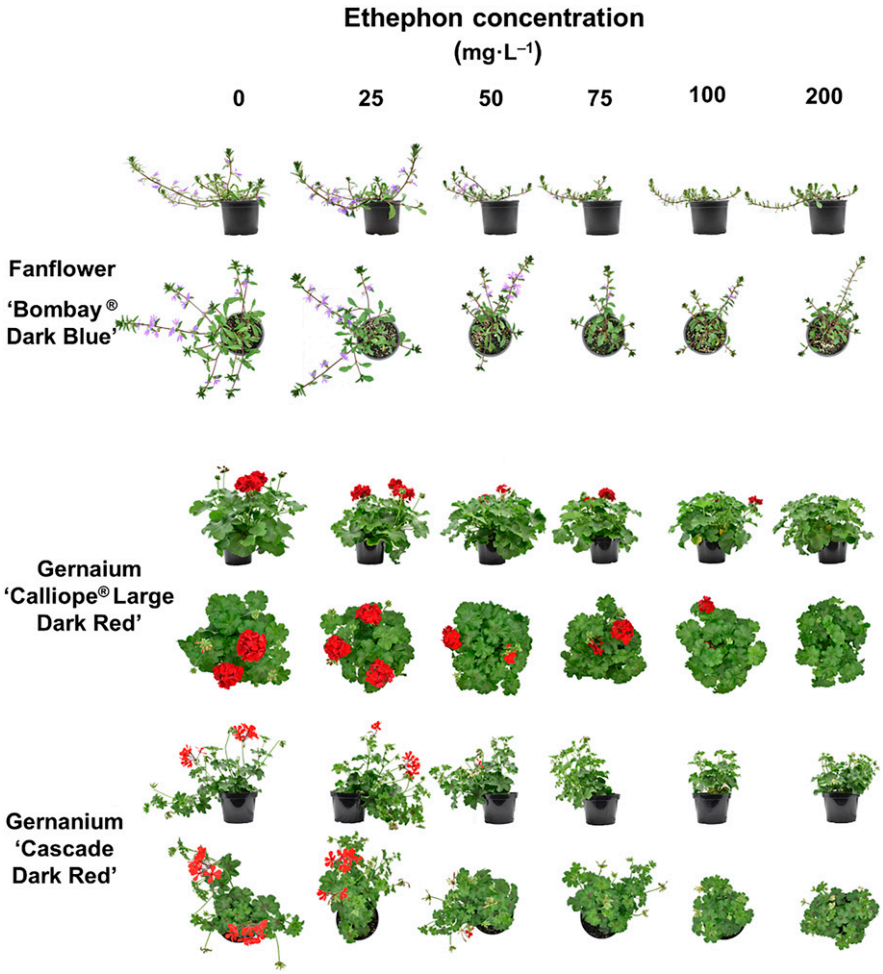

Fig. 5. Depictions of fanflower (*Scaevola aemula* R. Br. 'Bombay® Dark Blue'), interspecific geranium (*Pelargonium interspecific* 'Calliope® Large Dark Red'), and ivy geranium [*Pelargonium peltatum* (L.) L'Hér. ex Aiton. 'Cascade Dark Red'] grown in 12.7-cm (946 mL) (fanflower) or 16.5-cm (1.9 L) (interspecific and ivy geranium) containers filled with a commercial soilless peat-based substrate and drenched with 90-mL or 150-mL aliquots of a solution containing 0, 25, 50, 75, 100, or 200 mg·L^{-1} ethephon at 10 d after transplant. Photographs were taken 4, 5, and 5 weeks after drench for fanflower, interspecific geranium, and ivy geranium, respectively.

Conclusions

This research has expanded the use of ethephon in floriculture and found that substrate drenches are an effective and promising application method of controlling growth of annual bedding plants. Because some species were unresponsive to ethephon substrate drenches and others experienced extreme phytotoxic effects, further research defining the sensitivity of annual bedding plants to ethephon substrate drenches is warranted. Annual bedding plant producers should consider performing in-house trials to determine specific ethephon concentrations for species and cultivars not investigated herein or evaluate our suggestions based on their crop culture procedures, growing environment, and market demands; however, we suggest 25 to 100 mg·L^{-1} ethephon as an initial range for trials.

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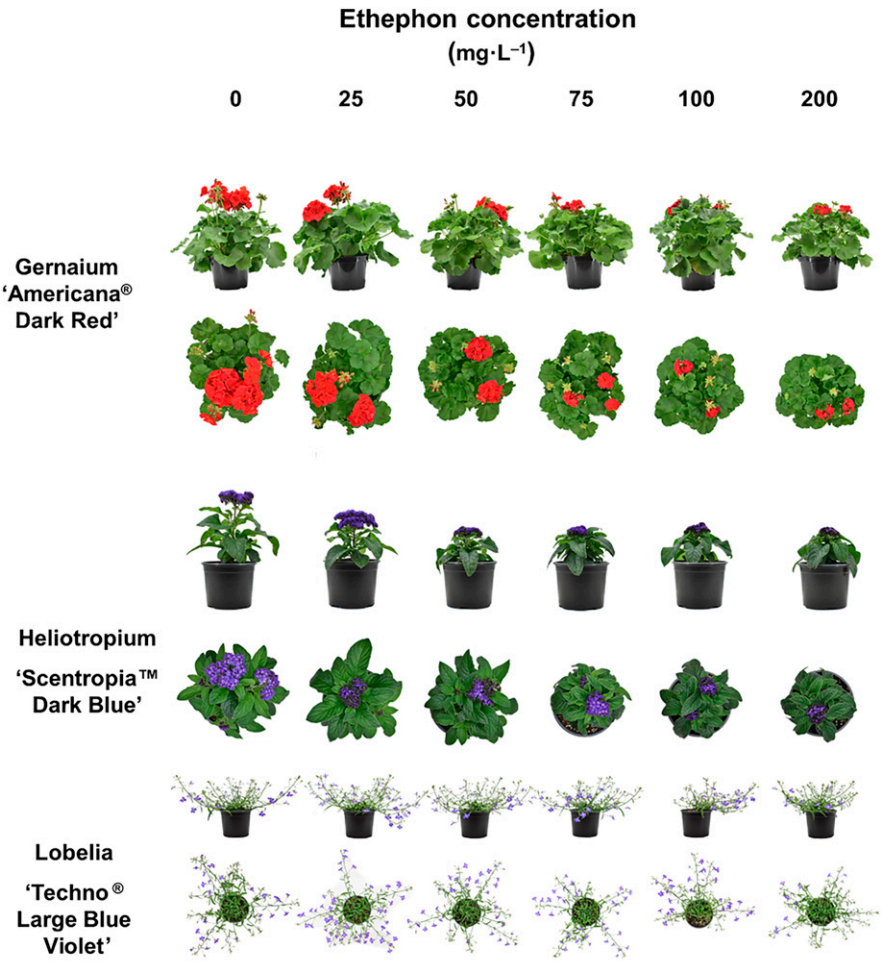

Fig. 6. Depictions of zonal geranium [*Pelargonium zonale* (L.) L'Hér. 'Americana® Dark Red'], heliotropium (*Heliotropium arborescens* L. 'Scentropia™ Dark Blue'), and lobelia (*Lobelia erinus* L. 'Techno® Large Blue Violet') grown in 12.7-cm (946 mL) or 16.5-cm (1.9 L) containers filled with a commercial soilless peat-based substrate and drenched with 90-mL (heliotropium and lobelia) or 150-mL (zonal geranium) aliquots of a solution containing 0, 25, 50, 75, 100, or 200 mg·L^{-1} ethephon at 10 d after transplant. Photographs were taken 5, 3, and 3 weeks after drench for zonal geranium, heliotropium, and lobelia, respectively.

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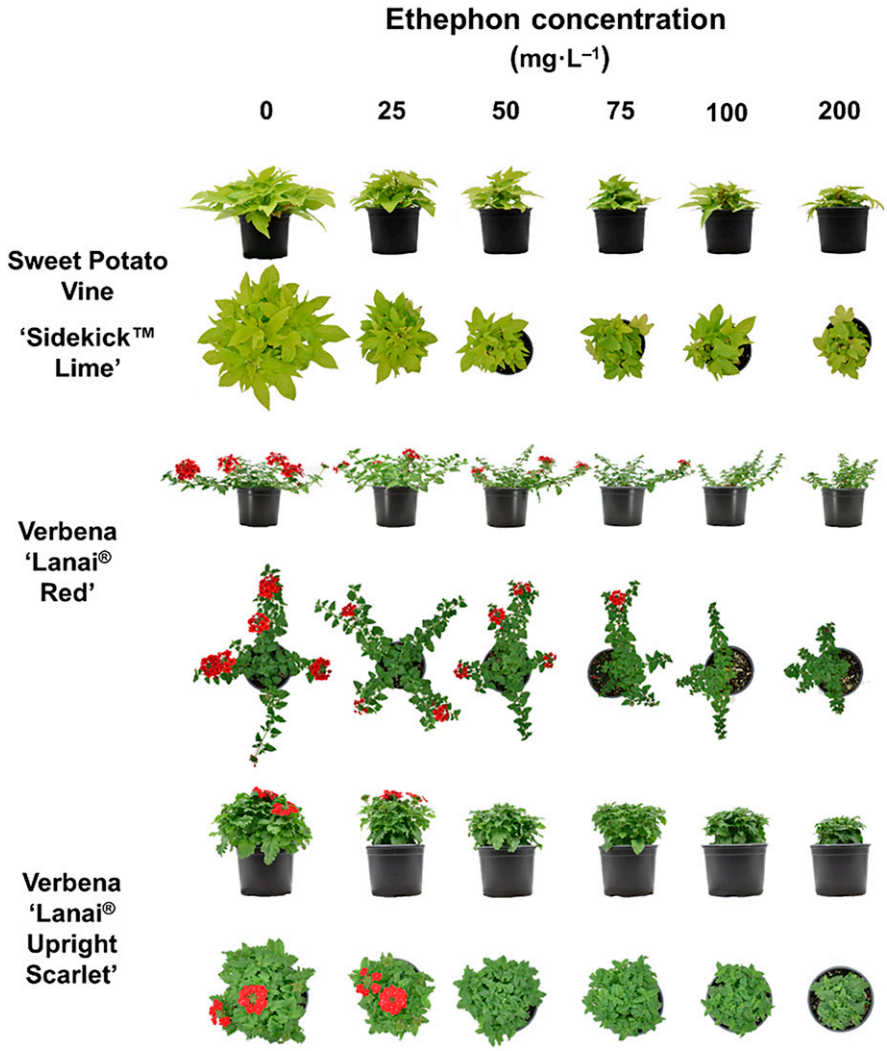

Fig. 7. Depictions of sweetpotato vine (*Ipomoea batatas* L. Lam 'Sidekick™ Lime'), and verbena (*Verbena* ×*hybrida* Jacq. Ex L. 'Lanai® Red' and 'Lanai® Upright Scarlet') grown in 12.7-cm containers (946 mL) filled with a commercial soilless peat-based substrate and drenched with 90-mL aliquots of a solution containing 0, 25, 50, 75, 100, or 200 mg·L^{-1} ethephon at 10 d after transplant. Photographs were taken 4 weeks after drench.

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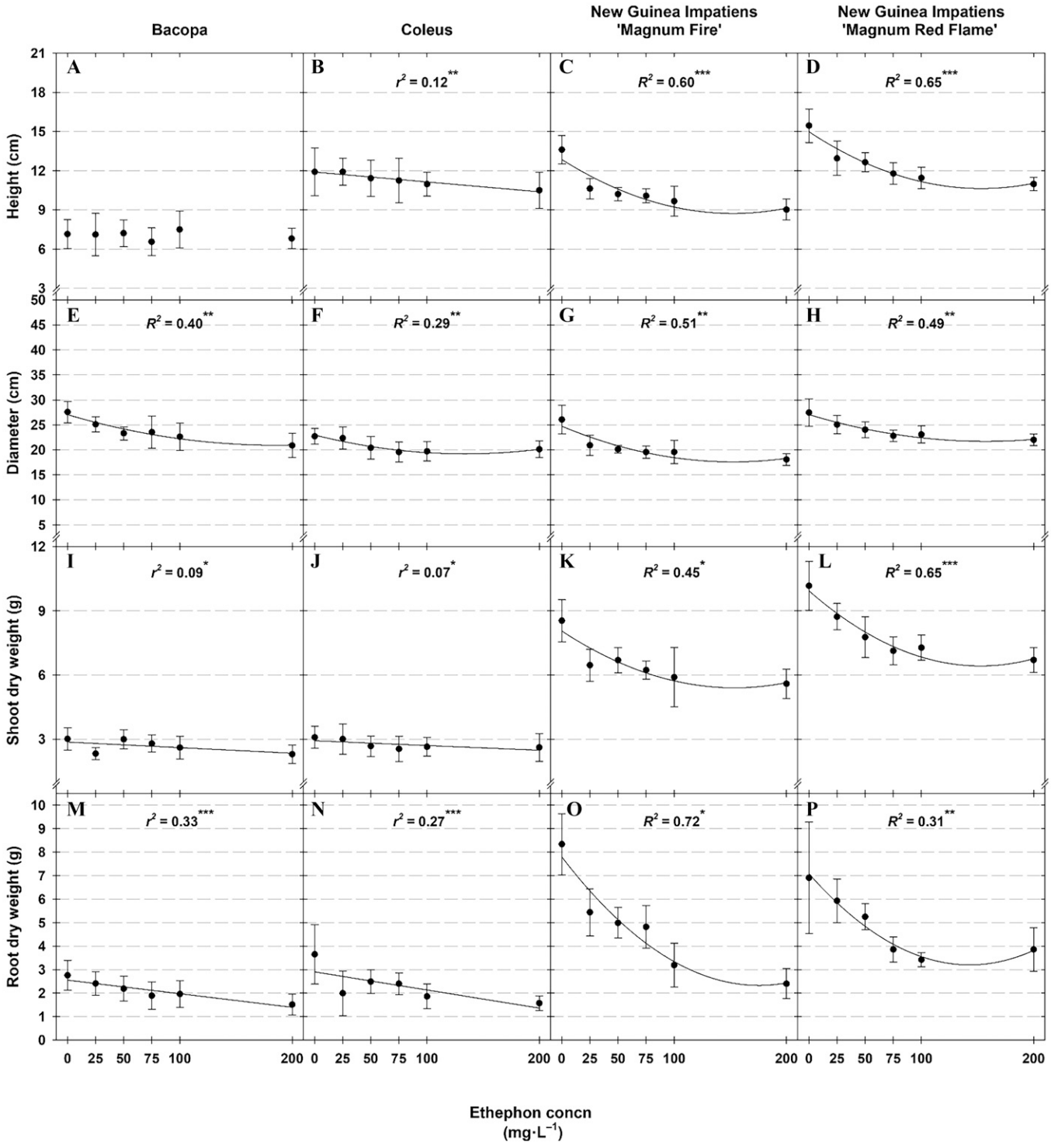

Fig. 8. Linear and quadratic regression for plant height (**A–D**), plant diameter (**E–H**), shoot dry weight (**I–L**), and root dry weight (**M–P**) of bacopa (*Bacopa cordata* L. 'Pink Sand'), coleus [*Coleus scutellarioides* (L.) Benth. 'Main StreetTM Ocean Drive'], and New Guinea impatiens (*Impatiens hawkeri* R.W. Baker & Corner 'Magnum Fire' and 'Magnum Red Flame') grown in 12-cm containers filled with soilless peat-based substrate. Plants were grown in a glass-glazed greenhouse under ambient daylight from 0600 to 2200 HR (16-h photoperiod) and received a supplemental photosynthetic photon flux density of approximately 120 μmol·m^{-2}·s^{-1} from 1000-W light-emitting diode lamps to maintain a daily light integral (DLI) of approximately 14 mol·m^{-2}·d^{-1}. Relative humidity and canopy air temperature setpoints were 60% and 20 °C, respectively. Plants were drenched with 90-mL aliquots of a solution containing 0, 25, 50, 75, 100, or 200 mg·L^{-1} ethephon at 10 d after transplant and grown for 3 to 8 weeks after drench. Each symbol represents a mean of eight individual plant samples (n = 8), and error bars represent ± standard error. For each model, corresponding r^2 (linear) or R^2 (quadratic) values and significance at $P \leq 0.05$ (*), 0.001 (**), or 0.0001 (***) are presented.

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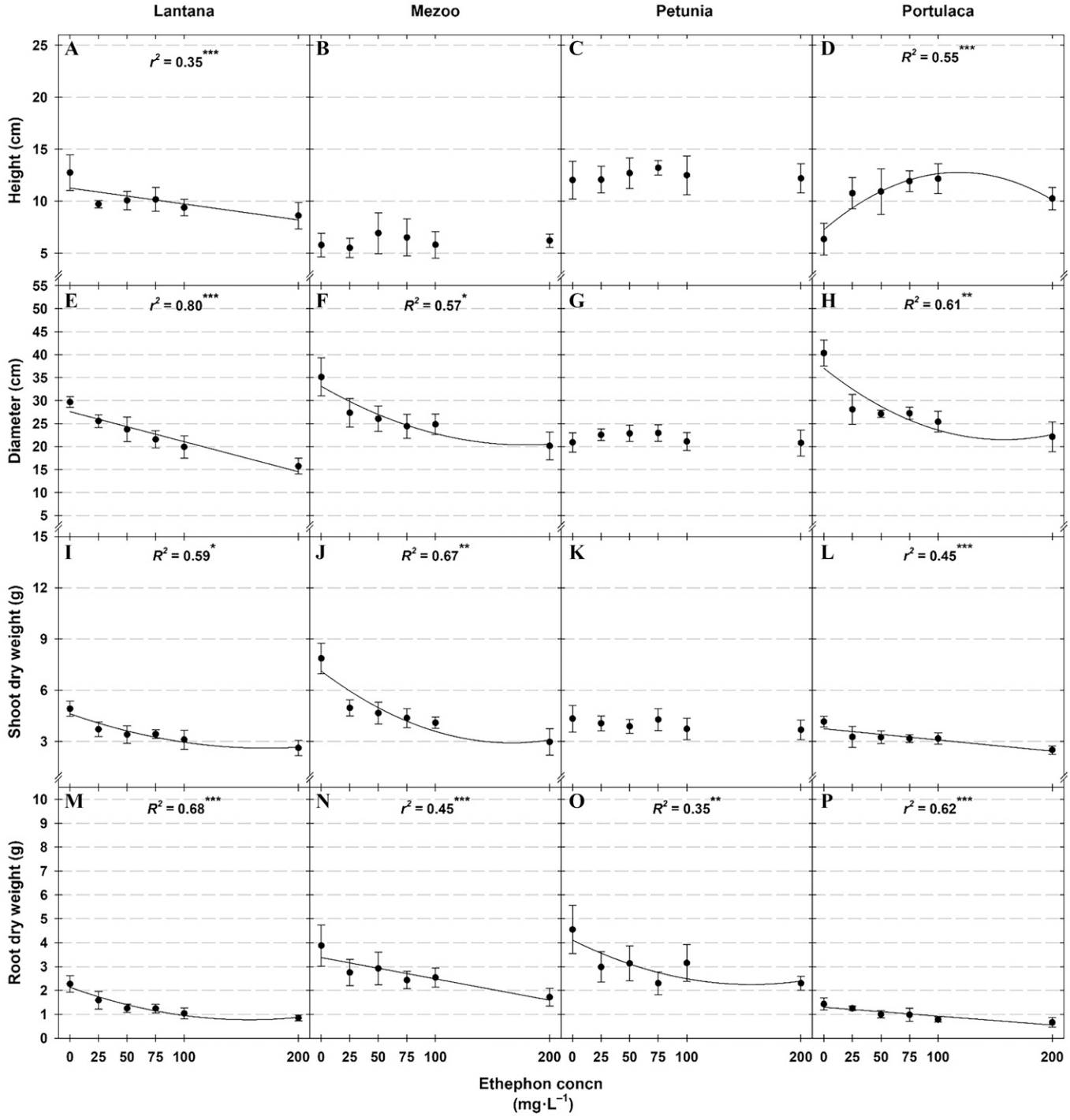

Fig. 9. Linear and quadratic regression for plant height (**A–D**), plant diameter (**E–H**), shoot dry weight (**I–L**), and root dry weight (**M–P**) of lantana (*Lantana camara* L. 'Bandolista^{TM} Red Chili'), mezoo (*Aptenia cordifolia* L. Bolus. 'Trailing Red'), petunia (*Petunia ×atkinsiana* D. Don. 'Durabloom^{TM} Royal Pink'), and portulaca (*Portulaca oleracea* L. 'Flame Red') grown in 12-cm containers filled with soilless peat-based substrate. Plants were grown in a glass-glazed greenhouse under ambient daylight from 0600 to 2200 HR (16-h photoperiod) and received a supplemental photosynthetic photon flux density of approximately 120 μmol·m^{-2}·s^{-1} from 1000-W light-emitting diode lamps to maintain a daily light integral (DLI) of approximately 14 mol·m^{-2}·d^{-1}. Relative humidity and canopy air temperature setpoints were 60% and 20 °C, respectively. Plants were drenched with 90-mL aliquots of a solution containing 0, 25, 50, 75, 100, or 200 mg·L^{-1} ethephon at 10 d after transplant and grown for 3 to 8 weeks after drench. Each symbol represents a mean of eight individual plant samples (n = 8), and error bars represent ± standard error. For each model, corresponding r^2 (linear) or R^2 (quadratic) values and significance at $P \leq 0.05$ (*), 0.001 (**), or 0.0001 (***) are presented.

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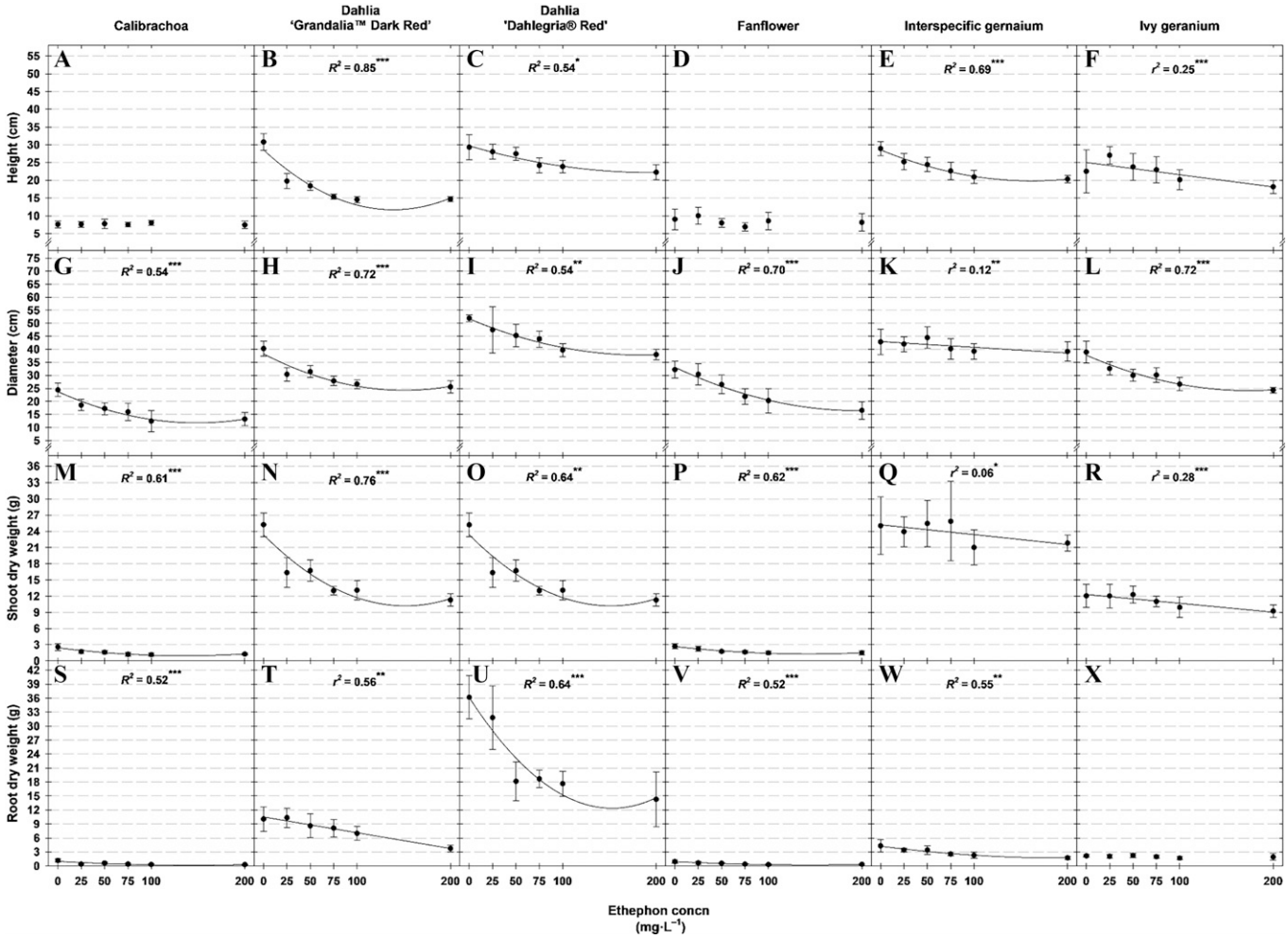

Fig. 10. Linear and quadratic regression for plant height (**A–F**), plant diameter (**G–L**), shoot dry weight (**M–R**), and root dry weight (**S–X**) of calibrachoa [*Calibrachoa* ×*hybrida* (Llave and Lex.) M. Martens and L. Westra. 'Callie® Dark Red'], dahlia [*Dahlia* ×*hybrida* (Hort. ex. Andrews) Lindl. ex. Loudon. 'Grandalia™ Dark Red' and 'Dahlegria® Red'], and fanflower (*Scaevola aemula* R. Br. 'Bombay® Dark Blue') grown in 12.7-cm containers filled with soilless peat-based substrate and geranium species [*Pelargonium interspecific* 'Calliope® Large Dark Red' and *P. peltatum* (L.) L'Hér. ex Aiton. 'Cascade Dark Red'] grown in 16.5-cm containers filled with soilless peat-based substrate. Plants were grown in a glass-glazed greenhouse under ambient daylight from 0600 to 2200 HR (16-h photoperiod) and received a supplemental photosynthetic photon flux density of approximately 120 $\mu mol \cdot m^{-2} \cdot s^{-1}$ from 1000-W light-emitting diode lamps to maintain a daily light integral of approximately 14 $mol \cdot m^{-2} \cdot d^{-1}$. Relative humidity and canopy air temperature setpoints were 60% and 20 °C, respectively. Plants were drenched with 90-mL or 150-mL aliquots of a solution for 12.7-cm and 16.5-cm containers, respectively, containing 0, 25, 50, 75, 100, or 200 $mg \cdot L^{-1}$ ethephon at 10 d after transplant and grown for 3 to 8 weeks after drench. Each symbol represents a mean of eight individual plant samples (n = 8), and error bars represent ± standard error. For each model, corresponding r^2 (linear) or R^2 (quadratic) values and significance at $P \leq 0.05$ (*), 0.001 (**), or 0.0001 (***) are presented.

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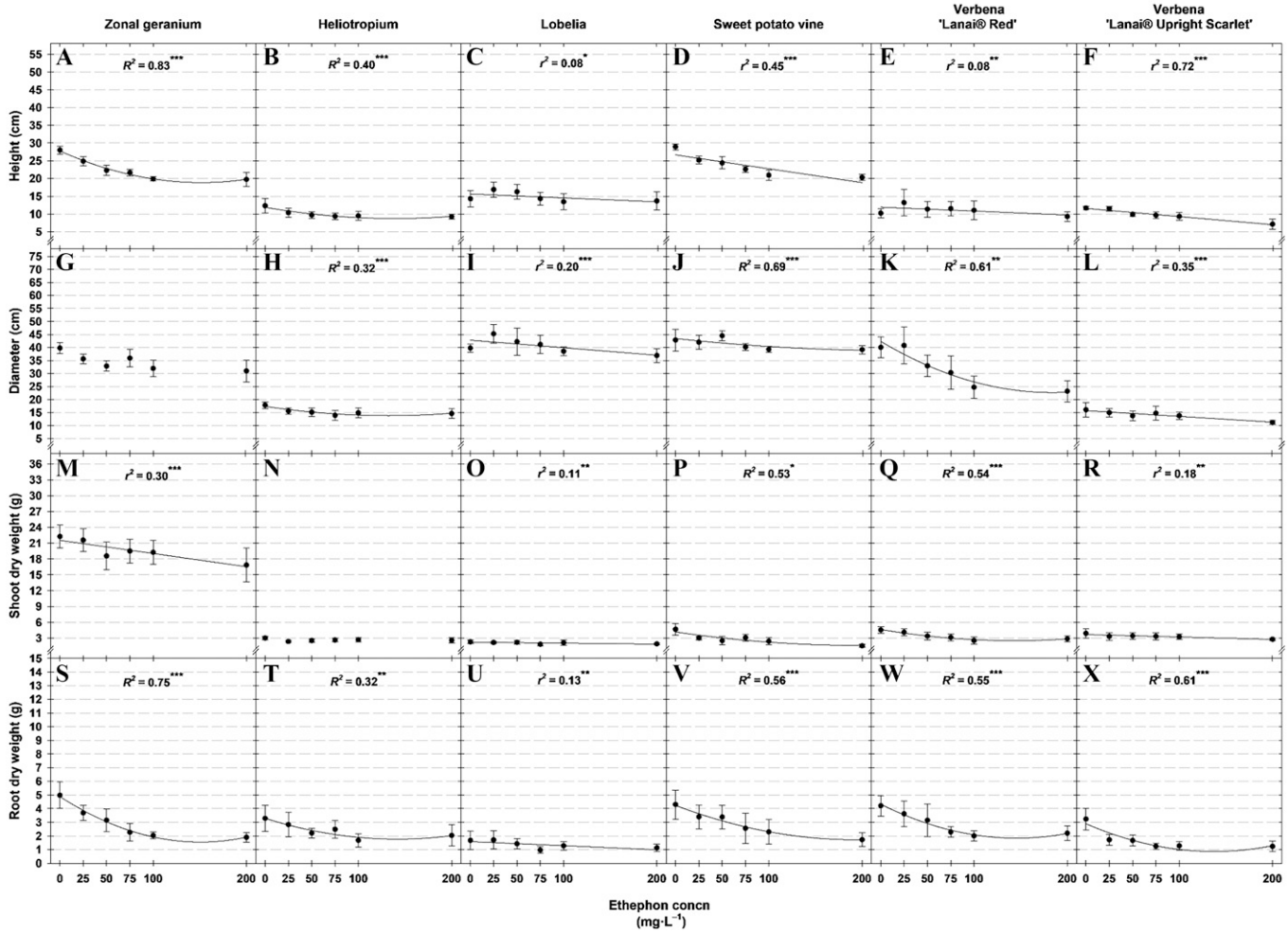

Fig. 11. Linear and quadratic regression for plant height (**A–F**), plant diameter (**G–L**), shoot dry weight (**M–R**), and root dry weight (**S–X**) of zonal geranium (*Pelargonium zonale* 'Americana® Dark Red') grown in 16.5-cm containers filled with soilless peat-based substrate, heliotropium (*Heliotropium arborescens* L. 'Scentropia™ Dark Blue'), lobelia (*Lobelia erinus* L. 'Techno® Large Blue Violet'), sweetpotato vine (*Ipomoea batatas* L. Lam 'Sidekick™ Lime'), and verbena (*Verbena* ×*hybrida* Jacq. Ex L. 'Lanai® Red' and 'Lanai® Upright Scarlet') grown in 12.7-cm containers filled with soilless peat-based substrate. Plants were grown in a glass-glazed greenhouse under ambient daylight from 0600 to 2200 HR (16-h photoperiod) and received a supplemental photosynthetic photon flux density of approximately 120 μmol·m^{-2}·s^{-1} from 1000-W light-emitting diode lamps to maintain a daily light integral of approximately 14 mol·m^{-2}·d^{-1}. Relative humidity and canopy air temperature setpoints were 60% and 20 °C, respectively. Plants were drenched with 90-mL or 150-mL aliquots of a solution for 12.7-cm and 16.5-cm containers, respectively, containing 0, 25, 50, 75, 100, or 200 mg·L^{-1} ethephon at 10 d after transplant and grown for 3 to 8 weeks after drench. Each symbol represents a mean of eight individual plant samples (n = 8), and error bars represent ± standard error. For each model, corresponding r^2 (linear) or R^2 (quadratic) values and significance at $P \leq 0.05$ (*), 0.001 (**), or 0.0001 (***) are presented.

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Table 4. Flowering percentages of 20 annual bedding plant taxa. Expt. 1 included bacopa (*Bacopa cordata* L. 'Pink Sand'), coleus [*Coleus scutellarioides* (L.) Benth. 'Main Street™ Ocean Drive'], lantana (*Lantana camara* L. 'Bandolista™ Red Chili'), mezoo (*Aptenia cordifolia* L. Bolus. 'Trailing Red'), New Guinea impatiens (*Impatiens hawkeri* R.W. Baker & Corner 'Magnum Fire' and 'Magnum Red Flame'), petunia (*Petunia ×atkinsiana* D. Don. 'Durabloom™ Royal Pink'), and portulaca (*Portulaca oleracea* L. 'Flame Red'). Expt. 2 included calibrachoa [*Calibrachoa ×hybrida* (Llave and Lex.) M. Martens and L. Westra. 'Callie® Dark Red'], dahlia [*Dahlia ×hybrida* (Hort. ex. Andrews) Lindl. ex. Loudon. 'Grandalia™ Dark Red' and 'Dahlegria® Red'], fanflower (*Scaevola aemula* R. Br. 'Bombay® Dark Blue'), geranium species {[interspecific geranium (*Pelargonium interspecific* 'Calliope® Large Dark Red'), ivy geranium [*P. peltatum* (L.) L'Hér. ex Aiton. 'Cascade Dark Red'], and zonal geranium [*P. zonale* (L.) L'Hér. 'Americana® Dark Red']}, heliotropium (*Heliotropium arborescens* L. 'Scentropia™ Dark Blue'), lobelia (*Lobelia erinus* L. 'Techno® Large Blue Violet'), sweetpotato vine (*Ipomoea batatas* L. Lam 'Sidekick™ Lime'), and verbena (*Verbena ×hybrida* Jacq. Ex L. 'Lanai® Red' and 'Lanai® Upright Scarlet')} drenched with 0, 25, 50, 75, 100, or 200 mg·L^{-1} ethephon at 10 d after transplant and grown for 3 to 6 weeks after drench. Percentages were determined at termination. Plants were transplanted into 12-cm (970 mL), 12.7-cm (946 mL), or 16.5-cm (1.9 L) containers filled with a peat-based substrate and grown in a glass-glazed greenhouse under ambient daylight supplemented with approximately 120 µmol·m^{-2}·s^{-1} from 1000-W light-emitting diode lamps from 0600 to 2200 HR (16-h photoperiod) to maintain a daily light integral of 10 to 14 mol·m^{-2}·d^{-1}. The canopy air temperature setpoint was 20 °C.

	Ethephon concn (mg·L^{-1})							
Annual bedding plants	0	25	50	75	100	200	Significance[i]	Regression (R^2)[ii]
Expt. 1								
Bacopa	100	100	100	100	100	100	NS[iii]	NS
Coleus	—[iv]	—	—	—	—	—	—	—
New Guinea Impatiens 'Magnum Fire'	0	0	0	0	0	0	NS	NS
New Guinea Impatiens 'Magnum Red Flame'	0	0	0	0	0	0	NS	NS
Lantana	63	38	50	88	63	50	NS	NS
Mezoo	0	0	0	0	0	0	NS	NS
Petunia	100	100	100	100	100	100	NS	NS
Portulaca	100	0	0	0	0	0	L*** Q***	0.66
Expt. 2								
Calibrachoa	100	100	100	100	100	100	NS	NS
Dahlia 'Grandalia™ Dark Red'	100	100	100	100	100	100	NS	NS
Dahlia 'Dahlegria® Red'	0	0	0	0	0	0	NS	NS
Geranium, interspecific	100	100	100	100	50	0	L*** Q***	0.70
Geranium, ivy	100	100	75	50	13	0	L*** Q***	0.58
Geranium, zonal	100	100	100	100	100	100	NS	NS
Fanflower	100	100	100	100	100	25	L*** Q***	0.70
Lobelia	100	100	100	100	100	100	NS	NS
Heliotropium	100	100	100	100	100	100	NS	NS
Sweetpotato vine	—	—	—	—	—	—	—	—
Verbena 'Lanai® Red'	88	100	88	100	88	25	L*** Q***	0.42
Verbena 'Lanai® Upright Scarlet'	100	100	38	13	0	0	L*** Q***	0.70

[i] Linear (L) or quadratic (Q) response to the ethephon substrate drench concentration. Significance at $P \leq 0.01$ (**) or 0.001 (***) or nonsignificant (NS).
[ii] Corresponding R^2 (quadratic) are presented for each species.
[iii] NS = nonsignificant.
[iv] No data recorded.

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Table 5. Suggested ethephon substrate drench concentrations for 20 annual bedding plant taxa. Plants were transplanted into 12-cm (970 mL), 12.7-cm (946 mL), or 16.5-cm (1.9 L) containers filled with a peat-based substrate and grown in a glass-glazed greenhouse under ambient daylight supplemented with approximately 120 $\mu mol \cdot m^{-2} \cdot s^{-1}$ from 1000-W light-emitting diode lamps from 0600 to 2200 HR (16-h photoperiod) to maintain a daily light integral (DLI) of 10 to 14 $mol \cdot m^{-2} \cdot d^{-1}$. The canopy air temperature setpoint was 20 °C.

Botanical name	Common name	Cultivar	Ethephon drench concentrations ($mg \cdot L^{-1}$)	Effects
Aptenia cordifolia	Mezoo	'Trailing Red'	25 to 100	Controlled plant diameter
Bacopa cordata	Bacopa	'Pink Sand'	≥200	Controlled plant height and diameter; no delay in flowering was observed, but lower leaf chlorosis was observed at concentrations >100 $mg \cdot L^{-1}$ ethephon
Calibrachoa ×hybrida	Calibrachoa	'Callie® Dark Red'	25 to 75	Controlled plant diameter; no significant delay in flowering was observed
Coleus scutellarioides	Coleus	'Main Street™ Ocean Drive'	75 to 200	Controlled plant diameter
Dahlia ×hybrida	Dahlia	'Grandalia™ Dark Red'	25 to 75	Controlled plant height and plant diameter; no significant delay in flowering was observed
Dahlia ×hybrida	Dahlia	'Dahlegria® Red'	75 to 200	Controlled plant height and diameter
Heliotropium arborescens	Heliotropium	'Scentropia™ Dark Blue'	25 to 75	Controlled plant height and diameter; no delay in flowering was observed at any concentration of ethephon
Impatiens hawkeri	New Guinea Impatiens	'Magnum Fire'	25 to 100	Controlled plant height and diameter; leaf epinasty was observed in plants drenched with 50 $mg \cdot L^{-1}$ ethephon
Impatiens hawkeri	New Guinea Impatiens	'Magnum Red Flame'	25 to 75	Controlled plant height and diameter; leaf epinasty was observed in plants drenched with 50 $mg \cdot L^{-1}$ ethephon
Ipomoea batatas	Sweetpotato vine	'Sidekick™ Lime'	25 to 50	Controlled plant height and diameter; meristem death was observed at substrate drenches of ≥75 $mg \cdot L^{-1}$ ethephon
Lantana camara	Lantana	'Bandolista™ Red Chili'	25 to 75	Controlled plant height and diameter; delay in flowering was observed in plants drenched with 200 $mg \cdot L^{-1}$ ethephon
Lobelia erinus	Lobelia	'Techno® Large Blue Violet'	25 to 75	Controlled plant height and diameter
Pelargonium interspecific	Geranium, interspecific	'Calliope® Large Dark Red'	25 to 100	Controlled plant height; a delay in flowering was seen at 200 $mg \cdot L^{-1}$ ethephon
Pelargonium peltatum	Geranium, ivy	'Cascade Dark Red'	50 to 100	Controlled plant height and diameter; a delay in flowering was seen at ≥75 $mg \cdot L^{-1}$ ethephon
Pelargonium zonale	Geranium, zonal	'Americana® Dark Red'	50 to 200	Controlled plant height and diameter; no delay in flowering was seen at any ethephon concentration
Petunia ×atkinsiana	Petunia	'Durabloom™ Royal Pink'	≥200	Provided no growth control; no delay in flowering or growth control was observed at any ethephon substrate drench concentrations trialed
Portulaca oleracea	Portulaca	'Flame Red'		Controlled plant diameter; a delay in flowering was seen at all concentrations of ethephon trialed
Scaevola aemula	Fanflower	'Bombay® Dark Blue'	50 to 100	Controlled plant diameter; a delay in flowering was observed in plants treated with 200 $mg \cdot L^{-1}$ ethephon
Verbena ×hybrida	Verbena	'Lanai® Red'	25 to 75	Controlled plant height and diameter; a delay in flowering was observed in plants drenched with ≥100 $mg \cdot L^{-1}$ ethephon
Verbena ×hybrida	Verbena	'Lanai® Upright Scarlet'	25 to 75	Controlled plant height and diameter; a delay in flowering was observed in plants drenched with ≥50 $mg \cdot L^{-1}$ ethephon

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